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# Trade Liberalisation, Transboundary Pollution and Market Size

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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 are relevant variables for empirical studies on trade and pollution.

*Keywords*: Market size, Emission tax, Trade liberalisation
*JEL classification*: D21, F12, F15



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# 1 Introduction

An extensive literature explores the mechanisms through which trade can affect the environment. A topical concern is that trade liberalisation allows firms to locate production in countries with lower emission standards.[1] While there is considerable theoretical support and an intuitive appeal for pollution havens, they have 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 using sector level data often find evidence of pollution havens in some sectors but not in others.[2]

The present paper suggests a new set of theoretical reasons why it may be hard to empirically identify pollution havens. The analysis juxtaposes relative market size and asymmetric emission tax levels in determining the patterns of production and pollution. We use a two-country monopolistic competition trade model with transboundary emissions generated from the production of manufactured goods and 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, as in the first part of the paper where taxes are exogenous. To focus on effects related to the monopolistically competitive framework, we assume that countries are identical except for their size and the emission tax they set. 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).[3] At the same time, asymmetric emission taxes imply a pollution haven. Trade liberalisation affects the interaction between the HME and asymmetric emission taxes and the outcome of trade liberalisation on global emissions will therefore depend on this interaction.

We first analyse the model in a setting with exogenous taxes, and show how the HME dominates when the size difference between markets is large, when abatement is easy, and when the degree of differentiation between goods is high. When the HME dominates, trade liberalisation will lead firms to concentrate in the larger market. This decreases global emissions if the larger market has a higher emission tax. In contrast, when markets are relatively similar in size, the HME is weak. Hence trade liberalisation will lead firms to concentrate in the

[1] It is possible to distinguish between the pollution haven effect, meaning that firms move their operation or location abroad in response to an increase in environmental taxes, and the pollution haven hypothesis where trade liberalisation induces firms to relocate to the low tax country, see Copeland and Taylor (2004).

[2] See e.g.Eskeland and Harrison (2003),Javorcik and Wei (2004),Ederington et al. (2005),Cole and Elliott (2005),Levinson and Taylor (2008), Kellenberg (2009), and Wagner and Timmins (2009)Cole et al. (2010).

[3] The is a considerable empircal literature that documents the home market effect. See e.g. Head and Ries (2001), and Head et al. (2002).

country with lower emission taxes leading to higher global emissions. We thereafter assume that the emission taxes are set endogenously, and numerically simulate a Nash game between the governments. It is illustrated how the HME will tend to dominate in this setting. The larger country, which has the advantage of the HME, will be able to set a higher Nash emission tax than its smaller trade partner, yet still maintain its manufacturing base. Trade liberalisation therefore leads firms to concentrate in the larger high-tax economy. However, tax competition between the two countries is intensified by trade liberalisation, and this leads to lower taxes in both countries. Global emissions therefore increase sharply in trade liberalisation, even as firms move to the high-tax economy, and welfare in both countries deteriorate for deeper levels of trade liberalisation. We then simulate cooperatively set emission taxes and find that the larger country sets slightly lower taxes than the smaller country, and trade liberalisation therefore leads firms to relocate into the low-tax country. However, in this case emission taxes are relatively constant (an may even increase) as trade is liberalised. Global emissions are therefore roughly constant and much lower than in the Nash case. The welfare effects of trade liberalisation are also much more benign in the case of cooperation. Thus, despite the potentially helpful role played by the HME in mitigating pollution havens, the simulations maintain the case for international cooperation on emission taxes.[4]

Our theoretical findings suggest a reason why pollution havens can be difficult to identify empirically; namely, that the effect of asymmetric emission taxes is dominated by the large market advantage in the high-tax economy. The analysis suggests that relative market size, ease of abatement and product differentiation could be important variables in empirical studies examining trade liberalisation and transboundary pollution.

Our analytical results suggest that under monopolistic competition and intra-industry trade, liberalisation between similar countries (of similar size) may increase global emissions while trade liberalisation between dissimilar countries can decrease global emissions if the larger country has 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 liberalisation 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 matters. If the rich country has a larger market, then the HME may induce firms to stay despite higher emission taxes and trade liberalisation 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 (see e.g. Copeland and Taylor (2003), Copeland and Taylor (2004) and Antweiler et al. (2001). The importance of scale economies and imperfect competition for trade and

[4]The simulation results with endogenous taxes are closely related to the large literature on enivironmental tax competition started by Markusen (1975). This literature uses a different theoretical framework from ours but the conclusions are similar. See in particular Cremer and Gahvarib (2004). See also the surveys by Cremer et al. (1996), Wilson (1999), and Haufler (2001).

emissions has generally been analysed in an oligopolistic strategic setting (see e.g. Markusen et al. (1993), Markusen et al. (1995), and Rauscher (1997)).

A relatively smaller literature analyses trade and the environment in models with differentiated products and 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 liberalisation can therefore not be analysed. Benarroch and Weder (2006) analyse a model of monopolistic competition with vertically linked industries. Trade liberalisation induces the final good industry to use a higher share of imported intermediates, which implies that the "clean" country increases its imports of dirty intermediates and the "dirty" country increases its imports of clean intermediates. Trade, as a consequence, makes the dirty country cleaner and the clean country dirtier.

Pfluger (2001) analyses local emissions using a monopolistic competition framework with internationally mobile capital à la Martin and Rogers (1995). The effect of trade liberalisation is analysed when countries are symmetric in size but have different emission taxes. Trade liberalisation will benefit the country with lower emission taxes as capital moves there. Thereafter an endogenous Nash emission tax rate is derived when countries are identical and there is free trade. It is shown that this equilibrium tax may be higher or lower than the efficient one depending on parameters such as the emission share in production. The present paper instead analyses trade liberalisation when countries are different in size. We show how this size difference gives rise to a home market effect that can compensate for a higher emission tax when trade is liberalised. However, because of the asymmetric country size, our set-up does not allow for an analytically derived Nash tax rate, and we instead simulate this case. Another paper that uses the framework by Martin and Rogers (1995) is Ishikawa and Okubo (2008). They study the different impacts of environmental taxes and quotas for the location of firms as trade is liberalised.

Finally, 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 liberalisation 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, and moreover they do not consider endogenous emission taxes whereas we do.

## 2 The Model

This paper builds a two-country monopolistic competition trade model with emissions and abatement costs. The focus of the discussion is how tax rate differentials interact with market size. Tax rates are initially set exogenously. Thereafter we allow for endogenous emission taxes.

## 2.1 Basics

There are two countries, home and foreign, denoted by $(j, m) \in (h, f)$, and two sectors denoted by $A$ and $M$. Each country has a single primary factor of production, labour denoted with $L$, used in the A-sector and the M-sector. The A-sector is a Walrasian, homogenous-goods sector, which is traded costlessly. The M-sector is characterised by increasing returns, monopolistic competition and iceberg trade costs. M-sector firms face constant marginal production costs and fixed costs, and 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 country have two-tier utility functions with the upper tier determining the consumer's division of expenditure among sectors and the second tier dictating the consumer's preferences over the various differentiated varieties within the M-sector with a constant elasticity of substitution (CES).

All individuals in country $j$ have the utility function

$$U_j = C_{Mj}^{\beta} C_{Aj}^{1-\beta} + l(G_j) - g(E_w), \tag{1}$$

where $C_{Aj}$ is consumption of the homogeneous good, $C_{Mj}$ is consumption of a CES-aggregate of differentiated good, and $\beta \in (0, 1)$. The function $l(G_j)$ captures the private benefits of public expenditures, $G_j$, and the function $g(E_w)$ captures climate damages. $g(E_w)$ is a function of global emissions generated by the M-sectors in the home and foreign countries, $E_w \equiv E_h + E_f$. Differentiated goods from the manufacturing sector enter the utility function through the index $C_{Mj}$, defined by

$$C_{Mj} = \left[ \int_0^{N_j} c_{i,j}^{(\sigma-1)/\sigma} di \right]^{\sigma/(\sigma-1)}, \tag{2}$$

where $N_j$ is the mass of varieties in the differentiated goods sector in country $j$, $c_{i,j}$ is the amount of variety $i$ consumed in the sector and $\sigma > 1$ is the elasticity of substitution between varieties.

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 $Y_j = L_j$. Each consumer spends an overall share $\beta$ of his income on manufactures, and the demand for a variety $i$ is therefore

$$x_{i,j} = \frac{p_{i,j}^{-\sigma}}{P_j^{1-\sigma}} \beta L_j, \tag{4}$$

where $p_{i,j}$ is the consumer price of variety $i$, $L_j$ is income, and

$$P_j \equiv \left( \int_0^{N_j} p_i^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$$

is the price index of manufacturing goods.

Let us also account for the fact that manufacturing activity entails pollution in terms of emissions.[5] We follow Copeland and Taylor (1994) and assume that each firm $i$ produces two outputs: a manufactured good ($x_{i,j}$) and emissions ($e_{i,j}$). Governments in both countries use emission taxes (production taxes), and the tax revenues are used to produce a public good $G_j$. A firm can reduce emissions by diverting a fraction $\theta_{i,j}$ of the primary factor, labour, away from the production of $x_{i,j}$. Firms pay a fixed cost, and thereafter joint production is given by

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

$$e_{i,j} = \varphi_i(\theta_{i,j}) \frac{l_{i,j}}{a}, \tag{6}$$

where $l_{i,j}$ is labour used in the variable cost term by firm $i$, $a$ is the labour input coefficient, and $0 \leq \theta_{i,j} \leq 1$. Emission intensity $(e_{i,j}/x_{i,j})$ is determined by the abatement function

$$\varphi_{i,j} = (1 - \theta_{i,j})^{1/\alpha} \tag{7}$$

which is characterised by $\varphi_{i,j}(0) = 1$, $\varphi_{i,j}(1) = 0$, $\varphi'_{i,j}(.) < 0$, and $0 < \alpha < 1$. $\frac{1}{\alpha}$ is a measure of the effectiveness of the abatement technology. All firms in country $j$ are symmetric in equilibrium, and we therefore drop subscript $i$ from now on. Using (6) and (7) to substitute for $\theta_j$ in (5) yields

$$x_j = e_j^{\alpha} \left( \frac{l_j}{a} \right)^{1-\alpha} \tag{8}$$

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

$$\Psi_j = F + \kappa (wa)^{1-\alpha} t_j^{\alpha} x_j = F + \kappa t_j^{\alpha} x_j \tag{9}$$

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

$$p_{jm} = \frac{\sigma}{\sigma - 1} \tau_{jm} \kappa t_j^{\alpha}, \tag{10}$$

in country $m$. Shipping the manufactured good involves a frictional trade cost of the "iceberg" form: for one unit of a good from country $j$ to arrive in country $m$, $\tau_{j,m} > 1$ units must be shipped. It is assumed that trade costs are equal in both directions, $\tau_{jm} = \tau_{mj}$, and that $\tau_{jj} = 1$, which allows us to drop the country subscript from trade cost, hence $\tau$.

Local emissions in country $j$ are given by

$$E_j = e_j n_j. \tag{11}$$

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

## 2.2 Equilibrium

Firm profits are given by

$$\pi_h = \frac{\beta L_w}{\sigma}\gamma\kappa^{1-\sigma}\left(\frac{s}{\Delta_h}+\phi\frac{1-s}{\Delta_f}\right)t_h^{\alpha(1-\sigma)} - F \quad (12)$$

$$\pi_f = \frac{\beta L_w}{\sigma}\gamma\kappa^{1-\sigma}\left(\phi\frac{s}{\Delta_h}+\frac{1-s}{\Delta_f}\right)t_f^{\alpha(1-\sigma)} - F \quad (13)$$

where $\gamma \equiv \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}$ and $\phi \equiv \tau^{1-\sigma}$ is the freeness of trade that varies between autarky ($\phi = 0$) and free trade ($\phi = 1$). $s \equiv \frac{L_h}{L_w}$ and $1 - s \equiv \frac{L_f}{L_w}$ are the income and expenditure shares in home and foreign, respectively, and $L_w = L_h + L_f$. Finally,

$$\Delta_h \equiv n_h p_h^{1-\sigma} + n_f\phi p_f^{1-\sigma} \quad (14)$$

$$\Delta_f \equiv n_h\phi p_h^{1-\sigma} + n_f p_f^{1-\sigma}. \quad (15)$$

Assuming free entry ensures that the equilibrium firm profits are zero, i.e. $\pi_j = 0$. 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 $j$

$$x_j^* = \frac{F(\sigma-1)}{\kappa t_j^{\alpha}}. \quad (16)$$

Substitute (10), (14), and (15) into to equations (12) and (13), at zero profit, to obtain the equilibrium values for $n_j$

$$n_h = \frac{\beta L_w\left\{\left((1-s)\phi^2+s\right)T^{\alpha(\sigma-1)}-\phi\right\}}{\sigma F\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)}-\phi\right\}} \quad (17)$$

$$n_f = \frac{\beta L_w T^{\alpha(\sigma-1)}\left\{1-\left(1-\phi^2\right)s-\phi T^{\alpha(\sigma-1)}\right\}}{\sigma F\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)}-\phi\right\}} \quad (18)$$

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

$$n^w = n_h + n_f = \frac{\beta L_w}{\sigma F}, \quad (19)$$

which is 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 liberalisation 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 $\phi$

$$s_n \equiv \frac{n_h}{n_f+n_h} = \frac{(1-s)\phi^2+s-\phi}{(1-\phi)^2}. \quad (20)$$

Differentiating (20) with respect to $s$ yields

$$\frac{ds_n}{ds} = \frac{1+\phi}{1-\phi} > 1. \tag{21}$$

As the relative size of the home country increases, the share of firms locating in home increases *more* than proportionately; this is the HME. Furthermore, as seen from (21), the steepness of $\frac{ds_n}{ds}$ increases in $\phi$. Trade liberalisation magnifies the HME.[6]

## 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:

$$e_j = \frac{\partial C_j}{\partial t_j} = \alpha\kappa t_j^{\alpha-1} x_j, \tag{22}$$

which yields the emission intensity

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

Substituting the firm's equilibrium output from (16) gives firm-level emissions:

$$e_j = \frac{\alpha F(\sigma-1)}{t_j}. \tag{24}$$

A higher emission tax and a more efficient abatement technology (lower $\alpha$) decreases firms' emissions and emission intensity.[7] Total emissions from each country and world emissions are given by

$$E_h = n_h e_h = \frac{\alpha(\sigma-1)\beta L_w}{\sigma t_h} \frac{\left\{\left((1-s)\,\phi^2 + s\right) T^{\alpha(\sigma-1)} - \phi\right\}}{\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)} - \phi\right\}}, \tag{25}$$

$$E_f = n_f e_f = \frac{\alpha(\sigma-1)\beta L_w}{\sigma t_f} \frac{T^{\alpha(\sigma-1)}\left\{1-\left(1-\phi^2\right) s - \phi T^{\alpha(\sigma-1)}\right\}}{\left\{1-\phi T^{\alpha(\sigma-1)}\right\}\left\{T^{\alpha(\sigma-1)} - \phi\right\}}, \tag{26}$$

and

$$E_w = \frac{\alpha(\sigma-1)\beta L_w}{\sigma t_h} \frac{\left((1-s)\,\phi^2 + s - \phi T^{-\alpha(\sigma-1)}\right)}{\left(1+\phi^2 - \phi\left(T^{\alpha(\sigma-1)} + T^{-\alpha(\sigma-1)}\right)\right)} \tag{27}$$

[6] All firms concentrate in the larger (home) country when trade liberalisation reaches $\phi^* = \frac{1-s}{s}$, as seen from (20). The locational advantage of the larger market continues to increase as trade is liberalised beyond $\phi^*$, but eventually this effect reverses and there is no locational advantage left at free trade. The relative attractiveness of the larger market (the HME) is therefore *hump-shaped* in the level of trade costs. However, the eventual weakening of the HME is not sufficiently pronounced to produce a relocation back to the small market in this case with symmetric taxes.

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

## 3 The effect of trade liberalisation on emissions

The analysis juxtaposes the impact of a varying market size and emission taxes. The size difference gives rise to an HME, while the difference in emissions taxes leads to a pollution haven. Before examining the interplay of these forces, we characterise these mechanisms separately.

### 3.1 Symmetric taxes

Constrain emission taxes to be symmetric in the home and foreign country, $t_h = t_f = t$ to isolate the HME. This means that trade liberalisation will lead to a relocation of firms to the larger market. At the same time, note that equation (24) suggests that firm emissions are unaffected by $\phi$. It follows from this that emissions will increase in the large market and decrease in the small one, as trade is liberalised. More precisely, the shift of production to the larger market entails a proportionate shift of emissions. Substituting $t_h = t_f = t$ into equations (25) and (26) yields

$$\left.\frac{E_h}{E_f}\right|_{t_j=t} = \frac{\{s\,(\phi+1)-\phi\}}{\{1-(1+\phi)\,s\}}, \tag{28}$$

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

Global emissions under symmetric taxes are therefore the sum of equations (25) and (26) evaluated at $t_j = t$, or

$$E_w|_{t_j=t} = \frac{\alpha(\sigma-1)\beta L_w}{\sigma t}. \tag{29}$$

This suggests that when taxes are symmetric, global emissions: decrease in the emission tax rate; decrease in abatement efficiency $1/\alpha$; and increases in $\sigma$. However, note that global emissions are independent of trade openness $\phi$.

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

Proof: Differentiating the expression (28) with respect to $\phi$ gives $\frac{\partial E_h/E_f}{\partial\phi} = \frac{2s-1}{((\phi+1)s-1)^2}$. Hence $\frac{\partial E_h/E_f}{\partial\phi} > 0$ for $s > \frac{1}{2}$ and $\frac{\partial E_h/E_f}{\partial\phi} < 0$ for $s < \frac{1}{2}$. Also (29) shows that global emissions are unaffected by $\phi$.■

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

### 3.2 Symmetric markets

Next we constrain market sizes to be identical in home and foreign ($s = \frac{1}{2}$), while we allow emission taxes to vary. The identical market sizes isolates effects related to emission tax asymmetry 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 (17) and (18) yields the relative mass of firms in the home and foreign country

$$\left.\frac{n_h}{n_f}\right|_{s=\frac{1}{2}} = \frac{\left(1+\phi^2\right) T^{\alpha(\sigma-1)} - 2\phi}{1+\phi^2 - 2\phi T^{\alpha(\sigma-1)}}. \tag{30}$$

Note first that when $T = 1$, i.e. a totally symmetric economy, the expression reduces to $\frac{n_h}{n_f} = 1$. Rearranging equation (30) identifies the range of relative taxes, $T$, for which there are firms active in both countries:

$$\frac{2\phi}{1+\phi^2} < T^{\alpha(\sigma-1)} < \frac{1+\phi^2}{2\phi}. \tag{31}$$

Firms are active in both countries for any $T > 0$ in autarky ($\phi = 0$), but the range shrinks as trade is liberalised. 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 (30) with respect to $T$ yields the change in the location of production for a change in the relative tax rate

$$\left.\frac{\partial\left(\frac{n_h}{n_f}\right)}{\partial T}\right|_{s=\frac{1}{2}} = \frac{\alpha\left(\sigma-1\right) T^{\alpha(\sigma-1)-1}\left(1-\phi^2\right)^2}{\left(2\phi T^{\alpha(\sigma-1)} - 1 - \phi^2\right)^2} > 0. \tag{32}$$

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 the pollution haven effect (PHE): firms flee countries that raise their environmental standards.

The effect of trade liberalisation on the location of production is obtained by differentiating (30) with respect to $\phi$ :

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

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

Proposition 2 *Trade liberalisation always leads to a relocation of firms to the low-tax country when markets are symmetric.*

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

We now turn to analysing how the relocation of firms affects emissions. To characterise the change in global emissions with trade liberalisation, we differentiate $E^w$ with respect to $\phi$ and evaluate the expression at $s = \frac{1}{2}$. Some simplification yields

$$\left.\frac{\partial E^w}{\partial \phi}\right|_{s=\frac{1}{2}} = \frac{\alpha(\sigma-1)\beta L_w}{2\sigma t_h t_f} \frac{T^{\alpha(\sigma-1)}\left(1-\phi^2\right)\left(T^{2\alpha(\sigma-1)}-1\right)\left(t_f - t_h\right)}{\left(\phi T^{\alpha(\sigma-1)} - 1\right)^2 \left(T^{\alpha(\sigma-1)} - \phi\right)^2} > 0. \tag{34}$$

Proposition 3 *Trade liberalization always leads to higher global emissions if environmental taxes differ between countries and markets are symmetric.*

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

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 neo-classical analysis (see Copeland and Taylor (2004)).

### 3.3 Asymmetric taxes and markets

Can the HME dominate the PHH to the point where global emissions decrease as trade is liberalised? To examine this issue, we turn now to the case where both market size and taxes differ between the two countries: both $s$ and $T$ are unconstrained. The effect of trade liberalisation on the location of firms is found by differentiating (30) with respect to $\phi$

$$\frac{\partial \frac{n_h}{n_f}}{\partial \phi} = \frac{T^{2\alpha(\sigma-1)}\left(s-(1-s)\phi^2\right)+2\phi(1-2s)T^{\alpha(\sigma-1)}+s\left(1+\phi^2\right)-1}{T^{\alpha(\sigma-1)}\left(1-s+\phi^2 s-\phi T^{\alpha(\sigma-1)}\right)^2}. \tag{35}$$

The sign of this expression will depend on the relative emission tax, $T$, the relative market size $s$, and the level of trade openness $\phi$. Substituting $s=1$, gives

$$\left.\frac{\partial \frac{n_h}{n_f}}{\partial \phi}\right|_{s=1} = \frac{\left(T^{\alpha(\sigma-1)}-\phi\right)^2}{T^{\alpha(\sigma-1)}\left(\phi^2-\phi T^{\alpha(\sigma-1)}\right)^2} > 0, \tag{36}$$

which means that the HME will always dominate the PHH for a large enough difference in market size. The location of firms, in turn, determine the global level of emissions. The change in global emissions from a change in trade openness is given by

$$\frac{\partial E^w}{\partial \phi} = \alpha(\sigma-1)\beta L_w T^{\alpha(\sigma-1)}(T-1)\frac{s\left(T^{\alpha(\sigma-1)}-\phi\right)^2-(1-s)\left(T^{\alpha(\sigma-1)}\phi-1\right)^2}{\sigma t_f(1-\phi T^{\alpha(\sigma-1)})^2(T^{\alpha(\sigma-1)}-\phi)^2}. \tag{37}$$

Several cases are possible. 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 4 *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 $s>\frac{1}{2}$. The numerator in (37) is therefore positive, which implies that $\frac{\partial E^w}{\partial \phi}>0$.■

However, an interesting case is where the effect of trade liberalization on global emissions is ambiguous. This is the case 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, 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 the asymmetry of the emission taxes; trade liberalization will decrease global emissions when the HME dominates. 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 (37) 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 global emissions (from (25) and (26)) and (17) for two sets of parameter values, when the large home country has higher emission taxes,[8] that is, when the HME and the tax asymmetry counteract each other.

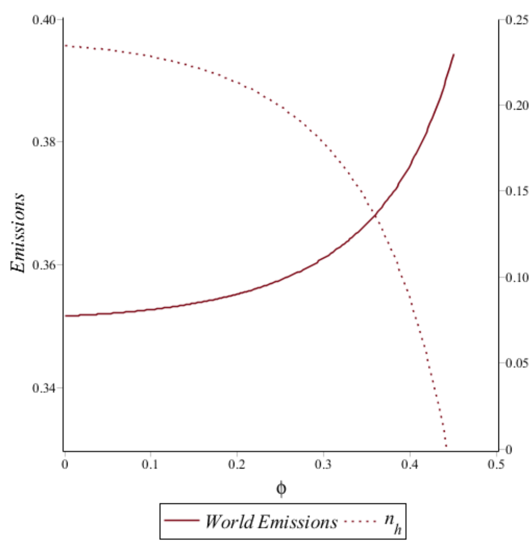


Figure 1: Trade liberalisation increases global emissions.

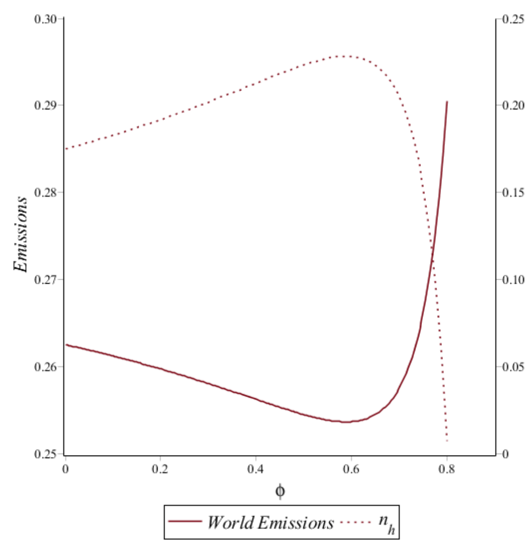


Figure 2: A U-shaped relationship between trade liberalisation and global emissions

The HME is always dominated by the PHH in Figure 1, leading to a monotone increase in global emissions, as trade is liberalised. Firms continuously move to the lower tax country as trade is liberalised and this increases global emissions. Remember that, from (19), the global mass of firms is constant and that firm-level emissions are independent of $\phi$ (from 24). A movement of firms from the high-tax home country to the low-tax foreign country is therefore 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 liberalised, starting from autarky, global emissions are reduced as firms are drawn to the larger high-tax

[8] 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 $\sigma = 2, \mu = 0.5, \alpha = 0.7, t_h = 0.35, t_f = 0.3, s = 0.7, F = 0.5$.

country. However, as trade is further liberalised, the pattern is reversed and global emissions then increase as we approach free trade. This effect follows from the well established property of these models: the location advantage of the larger market is hump-shaped in trade costs and is strongest for intermediate trade costs.[9] 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 advantage of the large market is U-shaped in $\phi$. 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.[10]

# 4 Endogenous emission taxes: Simulations

Our analysis has so far shown that market size considerations can dominate the effect of asymmetric emission taxes. Trade liberalization between a high-tax large economy and a low-tax small economy does not necessarily lead to the relocation of firms to the low-tax economy. However, a pertinent question is whether this holds when taxes are set endogenously. We therefore introduce endogenous taxes, and maintain the assumption that tax revenues are used to produce a public good. The combination of asymmetric markets and endogenous taxes can not be handled analytically, and we therefore proceed by numerical simulation. We start with the case where taxes are set in a Nash game between the two governments, and then proceed to examine the case where emission taxes are set cooperatively.

## 4.1 Nash taxes

The government in each country chooses a domestic emission tax to maximise the utility of domestic residents, taking the tax rate of the other country as given. The government's problem is

$$\max_{t_j} U_j$$

where

$$U_j = C_{Mj}^{\beta} C_{Aj}^{1-\beta} + \rho G_j^{\delta} - \varepsilon E_w^{\eta}. \tag{38}$$

$\varepsilon$ and $\eta$ are parameters determining the importance of the disutility related to global emissions, and $\rho$ and $\delta$ determine the importance of the utility associated with the public good, $G_j$.

[9] See e.g. Baldwin et.al. (2003), ch2.

[10] Note that the hump-shaped pattern of the HME is not visible in the location of firms when taxes are symmetric. See footnote 6.

Figure 3 shows the outcome of a typical simulation when the size difference between the countries is relatively large, which implies a strong HME (parameter values are: $s = 0.6, \sigma = 3, F = 1, \alpha = 0.1, \eta = 1.5, \beta = 0.4, \delta = 1, \rho = 0.1, \varepsilon = 0.1,\ L_w = 100$). The larger home country sets a higher emission tax, but firms are drawn to this market as trade is liberalised because of the HME. This movement of firms decreases emissions from the low-tax foreign country and increase emissions from the high-tax home country, the opposite of what the PHH would predict. However, global emissions here increase as trade is liberalised, even if the HME outweighs the asymmetry of the emission taxes, as shown in Figure 3a. The reason for this is that trade liberalisation increases the intensity of the tax competition between the Home and Foreign governments, creating a race to the bottom as illustrated in Figure 3c. The welfare effects are shown in Figure 3d. Welfare is considerably higher in the larger country, a usual result for this type of model as a larger mass of domestic firms implies a lower price index. Both countries initially gain from trade liberalisation. The small country gains despite loosing industry to the large economy because of lower prices on imported varieties. However, welfare begins to fall as trade liberalisation proceeds further. Higher emissions resulting from lower Nash taxes decrease welfare in both countries for deep levels of trade liberalisation.

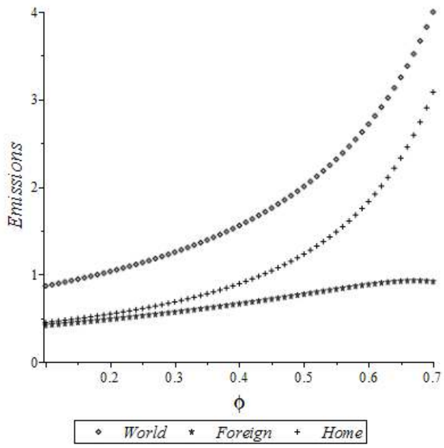


Figure 3a: Nash emission levels

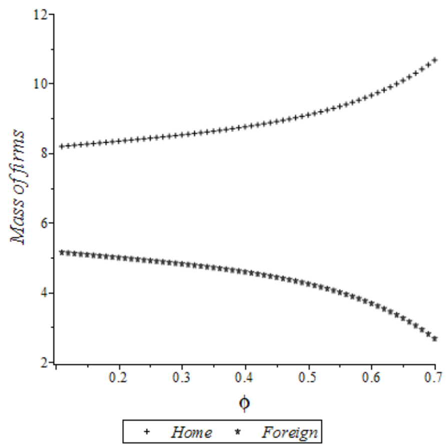


Figure 3b: Nash firm location

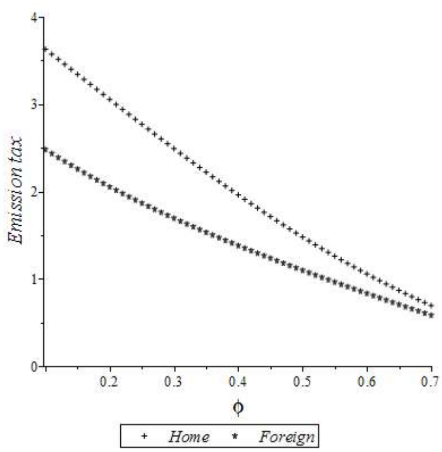


Figure 3c: Nash emission taxes

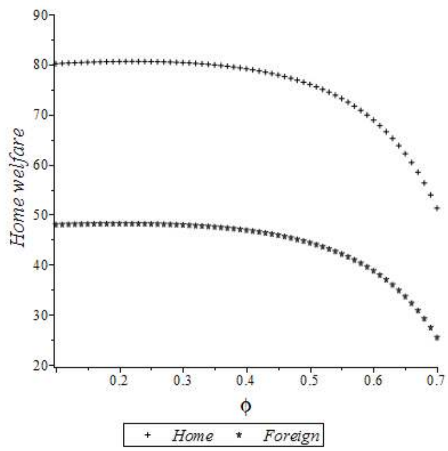


Figure 3d: Nash welfare levels

What if the HME is weak? This case is obtained by having a smaller size difference between the countries ($s = 0.52$). Figure 4 shows the results of such a simulation (parameter values are: $s = 0.52, \sigma = 3, F = 1, \alpha = 0.1, \eta = 1.5, \beta = 0.4, \delta = 1, \rho = 0.1, \varepsilon = 0.1,\ L_w = 100$). In this case, emission taxes are nearly the same although the larger country sets a slightly higher emission tax. The smaller tax difference means there is much less movement of firms between the countries. Nonetheless, trade liberalisation results in a movement of firms into the slightly larger high-tax country, away from the smaller low-tax country. Thus, again, a pollution haven does not materialise.[11] Moreover, Nash taxes fall as trade is liberalised, the result of tax competition, and as a result trade liberalisation again leads to higher emissions in both countries. Welfare displays a similar pattern as above although welfare levels are more equal between the countries as they are more equal in size.

[11] We have in fact not found any parameter values for which firms move from the large high tax country to the small low tax economy, when trade is liberalised.

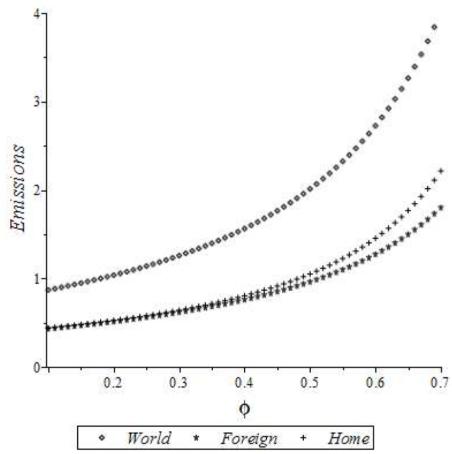


Figure 4a: Nash emission levels

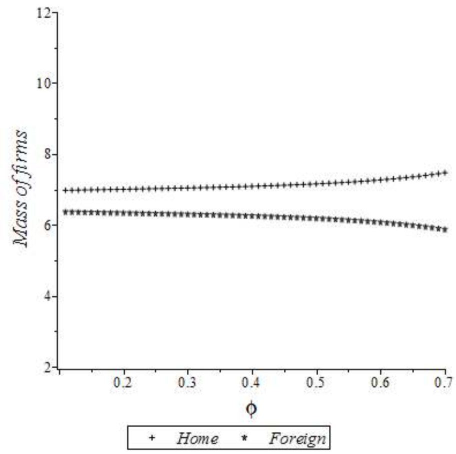


Figure 4b: Nash firm location

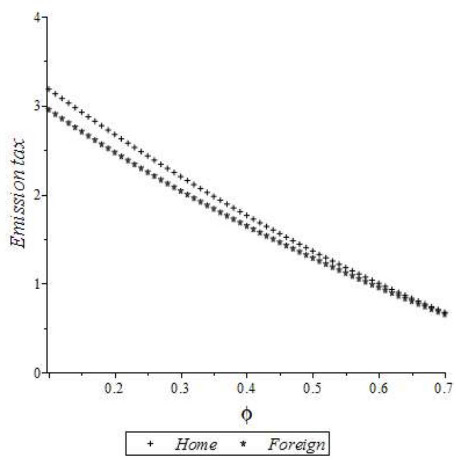


Figure 4c: Nash emission taxes

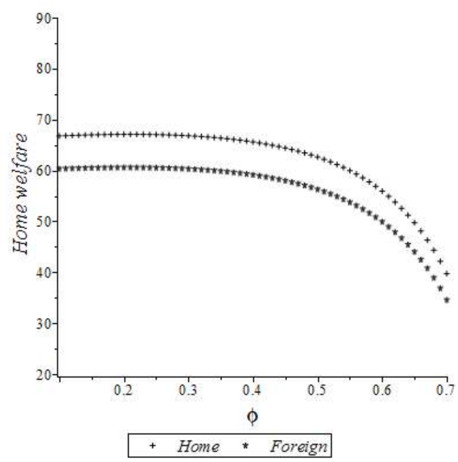


Figure 4d: Nash welfare levels

Our simulations show that the HME will outweigh the PHH in this type of model when taxes are set endogenously in a Nash game. The simulations also show that, even for a setting with nearly symmetric emission taxes (that neutralise the PHH), global emissions will increase as trade is liberalised. The reason for this is that trade liberalisation induces a "race to the bottom" on emission taxes. We next turn to a case where taxes are set cooperatively.

### 4.2 Cooperative taxes

It is here assumed that side payments are possible so that taxes are cooperatively set to maximise the sum of the welfare of the individuals in both countries. The global regulator's problem is therefore

$$\max_{t_h, t_f} \quad s \cdot U_h + (1-s) \cdot U_f .$$

Figure 5 shows the effect of trade liberalisation when the size difference between countries is relatively large (parameter values are: $s = 0.6, \sigma = 3, F = 1, \alpha = 0.1, \eta = 1.5, \beta = 0.4, \delta =$

$1, \rho = 0.1, \varepsilon = 0.1,\ L_w = 100)$.

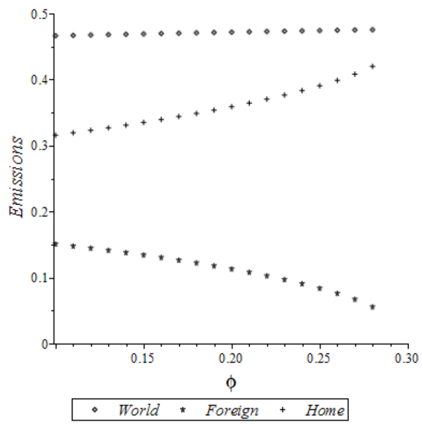


Figure 5a: Cooperative emission levels

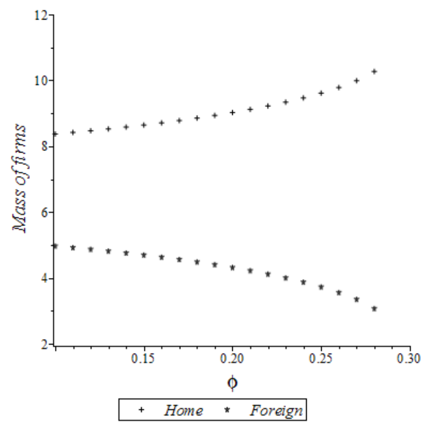


Figure 5b: Cooperative firm location

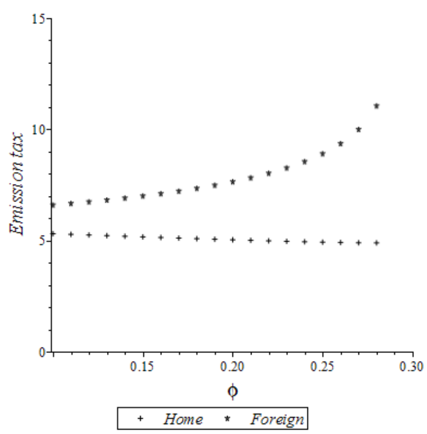


Figure 5c: Cooperative emission tax

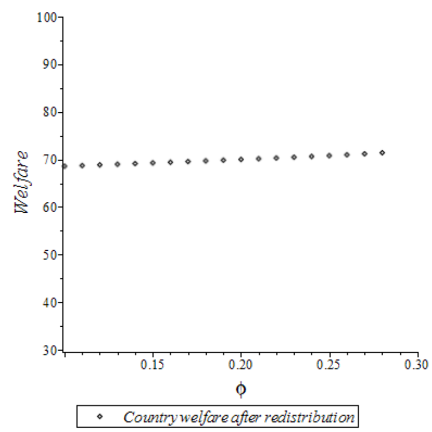


Figure 5d: Cooperative welfare levels in each country after redistribution

The outcome is improved markedly over the case with Nash taxes. Firms move to the larger country, but now the larger country is also the low-tax country: firms relocate production as per the PHH. It is optimal to set a lower tax in the larger country to support increased production there. This is because concentrating firms in the larger country yields an efficiency gain from the savings in transportation costs. Welfare after redistribution increase monotonically for both countries as trade is liberalised. Moreover, welfare for both countries is higher than under the Nash setting (Figure 3d). The relocation of firms create relatively strong welfare gains, which allow emission taxes to increase with trade liberalisation. Global emissions are almost constant in trade liberalisation, and are much lower than in the Nash cases.

Simulation results for the case with relatively equally sized countries (weak HME) yields essentially the same results. Emission taxes are almost the same but fall slightly when trade is liberalised as the gains from relocation are small. The development of global emissions is almost identical to the case with a strong HME, and welfare increase monotonically in both countries. In sum, the simulations demonstrate that there is still a strong need for international cooperation on environmental taxes, despite the potentially helpful role played by the HME in mitigating pollution havens.

## 5 Concluding remarks

This paper uses a monopolistic competitive framework to study the impact of trade liberalization on local and global emissions. We focus on effects stemming from tax differences and differences in market size and exclude comparative advantage effects derived from differences in factor intensities; our model only has one factor of production. We start by deriving analytical results with exogenous taxes, and thereafter turn to simulations with endogenous taxes.

With exogenously set emission taxes we examine the effect of market size 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 HME induces firms to locate to the larger market which, in turn, implies higher emissions in the larger market and lower emissions in the smaller 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 as firms relocate to the low tax economy.

We then analyse the case with both the asymmetric market size and asymmetric taxes, 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 liberalised, 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.

We then allow for endogenous emission taxes. We start by numerically simulating a Nash game between the governments. We show that the PHH is always dominated by the HME in this case. The larger economy has the upper hand and will set a higher emission tax but not so high that is loses industry. Industry therefore always relocate to the larger high-tax economy as trade is liberalised. This would seem to imply lower emissions. However, trade liberalization will intensify tax competition between the countries leading to lower emission taxes in both countries. Global emission therefore increase despite the fact that firms move to the high-tax economy. Welfare tend to be hump-shaped in openness: trade liberalisation initially increases welfare, but decreases welfare for deep liberalisation.

We thereafter simulate a case where taxes are set cooperatively. The larger country has a lower cooperatively set tax than the smaller country. Firms therefore relocate to the larger low-tax economy as trade is liberalised. However, the difference in tax rates is relatively small and, in contrast to the non-cooperative taxes, taxes may actually increase as trade is liberalised. Consequently, this case yields roughly constant emissions as trade is liberalised and a level of global emissions that is much lower compared to the Nash case. Also welfare (after redistribution) increases monotonically as trade is liberalised. These simulations demonstrate that there is still an strong need for international cooperation on environmental taxes, despite the potentially helpful role played by the HME in mitigating pollution havens.

Our results also have implications for empirical studies seeking to identify pollution havens. In particular, they suggest that relative market size, trade costs, ease of abatement, and the degree of product differentiation may need to be considered in the design of the estimated equation. It is not uncommon that a large country liberalises trade with a smaller market with a laxer environmental standard. The fact that some studies fail to identify a pollution haven could be due to the fact that the larger market is large enough to attract firms in spite of it's stricter environmental standards, e.g. in the case of U.S. and Mexico. Our results also suggest that trade liberalisation with a large economy with low environmental standards, such as China, may be particularly troublesome for global emissions.

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