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**貿易自由化と越境汚染—市場規模と汚染排出税**

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### 【要旨】

本論文は貿易自由化がどのように越境汚染に影響するのか理論的に検証した。特に市場規模、自国市場効果がどう関係しているのか分析した。排出税を市場の規模に応じて、どのように税を課せば、企業の汚染規制回避行動を抑制でき、世界全体の排出削減につながるかを検証した。政府間でも排出税・環境政策をめぐり、租税競争や政策協調があるが、どうすれば排出削減できるのかを理論分析した。

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# Trade Liberalization, Transboundary Pollution and Market Size\*

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## Abstract

This paper uses a monopolistic competitive framework to study the impact of trade liberalization on local and global emissions. We focus on the interplay of asymmetric emission taxes and the home market effect and show how a large-market advantage can counterbalance a high emission tax, so that trade liberalization leads firms to move to the large high-tax economy. Global emissions decrease when trade is liberalized in this case. We then simulate the model with endogenous taxes. The larger country, which has the advantage of the home market effect, will be able to set a higher Nash emission tax than its smaller trade partner, yet still maintain its manufacturing base. As a result, a pollution haven will typically not arise in this case as trade is liberalized. However, global emission increases as a result of international tax competition, which underscores that the importance of international cooperation increases as trade becomes freer.

## 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. 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.<sup>1</sup>

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

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<sup>1</sup>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), Wagner and Timmins (2009) and Cole et al. (2010).

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 we have greenhouse gas emissions in mind.<sup>2</sup> We assume that countries are identical except for their size and the emission tax they set to focus on effects related to the monopolistically competitive framework. 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).<sup>3</sup> At the same time, asymmetric emission taxes imply a pollution haven. Trade liberalization affects the interaction between the HME and asymmetric emission taxes and the outcome of trade liberalization on global emissions will therefore depend on this interaction.

We first analyze 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 liberalization will lead firms to concentrate in the larger market. This decreases global emissions if the larger market has a higher emission tax. In contrast, the HME is weak when markets are relatively similar in size and trade liberalization will lead firms to concentrate in the country with lower emission taxes leading to higher global emissions.

Then, we study a setting where emission taxes are set endogenously, and numerically simulate a Nash game between two governments. A government uses its market size advantage to set a higher Nash emission tax than its smaller trade partner, and yet maintain its manufacturing base. Trade liberalization therefore leads firms to concentrate in the larger high-tax economy. However, tax competition between the two countries is intensified by trade liberalization, and this leads to lower taxes in both countries. Global emissions therefore increase in trade liberalization, even as firms move to the high-tax economy, and welfare in both countries deteriorate for deeper levels of trade liberalization. We also simulate a Nash bargaining solution, which generates lower emissions and more benign welfare effects. 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.<sup>4</sup> Moreover, the gains from cooperation increase in the level of trade liberalization.

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<sup>2</sup> Absent welfare considerations, the analysis applies equally to local pollutants, as in the first part of the paper where taxes are exogenous.

<sup>3</sup> There is a considerable empirical literature that documents the home market effect. See e.g. Head and Ries (2001), and Head et al. (2002).

<sup>4</sup> The simulation results with endogenous taxes are closely related to the large literature on environmental 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 Gahvari (2004). See also the surveys by Cremer et al. (1996), Wilson (1999) and Haufler (2001).

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.<sup>5</sup> Naturally, there are other explanations for the difficulty to identify pollution havens (for surveys of this literature, see Brunnermeier and Levinson (2004) and Copeland and Taylor (2004)). These explanations are generally related to some form of comparative advantage, that is, cases where the country or region has a comparative advantage strong enough to outweigh the costs associated with higher environmental standards. The dominating factor for firm location also varies by sector. In some sectors, the standard comparative advantage may be the dominating force for location, e.g. in sectors that are very dependent on raw materials (paper, pulp, mining et c.) or in sectors with extreme factor intensities (textiles, apparel etc.). Other sectors may be more sensitive to market potential. In the next section, we employ data on FDI inflows to US states from Keller and Levinson (2002) to illustrate the effects of market size on firm location. This is an example where differences in factor prices are much lower than they would be when comparing countries, and market size should therefore be relatively important. This is confirmed by our empirical example: the sensitivity of inward FDI to US states to abatement costs is highly dependent on the market size of the individual US states.

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 is also of importance: trade liberalization between similar countries (of similar size) may increase global emissions while trade liberalization between dissimilar countries can decrease global emissions if the larger country has a more stringent environmental regulation. 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 analyzes 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 emissions has generally been analyzed in an oligopolistic strategic setting (see e.g. Markusen et al. (1993), Markusen et al. (1995) and Rauscher (1997)).

A relatively smaller literature analyzes trade and the environment in models with differentiated products and monopolistic competition. Gürtzgen and Rauscher (2000) examine trans-boundary 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 con-

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<sup>5</sup>Many empirical studies on pollution havens do include measures of market size in various ways. See e.g. Kellenberg (2008), Manderson and Kneller (2012), Rezza (2013) and Tang (2015).

trast to this paper, their model does not feature trade costs and the effects of trade liberalization can therefore not be analyzed. Benaroch and Weder (2006) analyze a model of monopolistic competition with vertically linked industries. Trade liberalization 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. As a consequence, trade makes the dirty country cleaner and the clean country dirtier.

Pfluger (2001) analyzes local emissions using a monopolistic competition framework with internationally mobile capital à la Martin and Rogers (1995). The effect of trade liberalization is analyzed when countries are symmetric in size but have different emission taxes. Trade liberalization will benefit the country with lower emission taxes as capital moves to that country. 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 analyzes trade liberalization 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 liberalized. However, because of the asymmetric country size, our set-up does not allow for an analytically derived Nash tax rate, and we do instead simulate this case. Another paper that uses the framework by Martin and Rogers (1995) is Ishikawa and Okubo (2016). They study the different impacts of environmental taxes and quotas for the location of firms as trade is liberalized.

Finally, Zeng and Zhao (2009) use a trade and geography model with capital, land and labor 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, and moreover they do not consider endogenous emission taxes whereas we do.

Before proceeding to our model, we present an empirical example that highlights the potential importance of market size for pollution havens. We do not here test hypotheses derived from our model but present this purely as a motivational example.

## 2 An empirical example

We employ data from Keller and Levinson (2002). They investigate how inward FDI inflows to US states are affected by differences in manufacturers' relative pollution abatement cost (RAC). Thus, we provide a limited description of the data. The same data has been used by Millimet and Roy (2016) who use an identification strategy with instruments based on higher moments of the data to identify the pollution haven effect.

An advantage of studying the effect of RAC on FDI at the state level is that the role of market size should be relatively important since differences in comparative advantages across US states are somewhat muted relative to e.g. different countries. The data covers the 48 contiguous US states over an 18-year period from 1977 to 1994. 1987 is omitted due to missing observations. The data also includes a number of control variables at the state level: market proximity, population, unemployment rate, unionization rate, wages, road mileage, land prices, energy prices, and tax effort which measures the extent to which a state utilizes its tax base. These controls pick up many of the standard sources of comparative advantage such as low wages, cheap land, good infrastructure, etc.

Keller and Levinson's estimating equation is in logs and employs state and time fixed effects:

$$\ln(FDI_{st}) = \beta \ln(RAC_{st}) + \gamma \ln(X_{st}) + \delta_t + d_s + \varepsilon_{st}, \quad (1)$$

where:  $FDI_{st}$  is the inward FDI flow, measured as changes in gross property, plant and equipment belonging to foreign-owned manufacturers, to state  $s$  in year  $t$ ;  $RAC_{st}$  is an index of relative state environmental stringency estimated by Keller and Levinson for each state, each year, from industry abatement costs;  $X_{st}$  is a vector of controls;  $\delta_t$  is time fixed effects; and  $d_s$  is sector fixed effects.

Keller and Levinson report results for the entire manufacturing sector and on the chemicals sector, which is a representative pollution intensive sector. In Table 1 column (1), we replicated their results for the Chemical sector. The same picture emerges for the manufacturing sector and therefore, we refrain from presenting them here. Our point estimates are identical to those of Keller and Levinson, but we have larger standard errors, since we cluster errors at the state level. Column (1) shows a negative and (weakly) significant effect of state level environmental stringency (RAC).

To illustrate the role played by market size, we first split the sample into two groups: one comprising large states and the other comprising small states. The ranking of state size is based on gross state product (GSP) in 1977.<sup>6</sup> These results are recorded in columns (2) and (3). The result is quite striking with a strong significant negative coefficient for the smaller states and a positive insignificant coefficient for the larger states. That is, the negative effect of RAC on FDI is not visible for the larger states. The same picture emerges if we instead interact  $\ln(RAC_{st})$  with a dummy that is equal to one for the largest 24 states in the sample, as shown in column (4). Finally, in column (5), we interact  $\ln(RAC_{st})$  with state size quartile dummies. The results show how the effect of abatement costs on FDI change from negative to positive with state size.

Splitting the sample into big and small states also indicates the importance of market size in determining the impact of other sources of comparative advantage included as control variables. Comparing the estimated coefficients in columns (2) and (3) shows that the negative effect of

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<sup>6</sup>The results are the same if we use population.

Table 1: The role of market size in determining the effect of RAC on FDI flows for US states over the period 1977-1994, replicating the results of Keller & Levinson (2002)

	(1) Replicate	(2) Small States	(3) Big States	(4) Big-Small Indicator	(5) Size Quartiles
ln(RAC)	-0.198 (0.113)*	-0.260 (0.124)**	0.322 (0.271)	-0.321 (0.119)***	-0.397 (0.134)***
Big x ln(RAC)				0.632 (0.316)*	
Q2 x ln(RAC)					0.137 (0.238)
Q3 x ln(RAC)					0.652 (0.499)
Q4 x ln(RAC)					0.766 (0.387)*
ln(production wages)	-1.131 (1.462)	-3.269 (1.515)**	2.826 (2.151)	-1.090 (1.453)	-1.096 (1.452)
ln(land prices)	-0.422 (0.286)	-0.317 (0.442)	-0.301 (0.357)	-0.391 (0.277)	-0.367 (0.283)
ln(energy price)	-0.000 (0.469)	0.392 (0.747)	-0.334 (0.540)	-0.058 (0.465)	-0.063 (0.464)
ln(road mileage)	-0.768 (0.967)	-0.337 (1.033)	-2.808 (2.868)	-0.738 (0.969)	-0.728 (0.963)
ln(market proximity)	1.601 (0.768)**	1.997 (1.338)	0.646 (0.818)	1.365 (0.770)*	1.324 (0.751)*
ln(population)	-0.673 (1.089)	-0.873 (1.445)	-0.895 (1.772)	-0.408 (0.995)	-0.366 (1.014)
ln(tax effort)	-0.114 (0.525)	-0.355 (0.764)	0.855 (0.628)	0.040 (0.518)	0.032 (0.506)
unemployment	0.036 (0.022)*	0.047 (0.040)	-0.026 (0.028)	0.021 (0.021)	0.020 (0.022)
unionization	-0.113 (0.027)***	-0.131 (0.051)**	-0.064 (0.031)*	-0.105 (0.025)***	-0.104 (0.026)***
Observations	563	232	331	563	563
$R^2$	0.965	0.961	0.950	0.965	0.966

Dependent variable: Chemical sector FDI property plant and equipment (PPE).

All regressions include state and year fixed effects.

Standard errors in parentheses. Errors are clustered by state. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 2: The role of market size in determining the effect of RAC on FDI flows for US states over the period 1977-1994, replicating the Lewbel (2012) IV method applied by Millimet & Roy (2015).

	(1) All States	(2) Small States	(3) Big States	(4) Big-Small Indicator	(5) Size Quartiles
ln(RAC)	-0.555 (0.246)**	-0.240 (0.104)**	0.127 (0.239)	-0.499 (0.273)*	-0.267 (0.091)***
Big x ln(RAC)				0.198 (0.551)	
Q2 x ln(RAC)					0.291 (0.179)
Q3 x ln(RAC)					0.454 (0.452)
Q4 x ln(RAC)					0.056 (0.262)
ln(production wages)	-0.932 (1.409)	-3.356 (1.287)***	1.846 (1.851)	-0.954 (1.340)	-1.325 (1.075)
ln(land prices)	-0.352 (0.258)	-0.451 (0.295)	-0.378 (0.303)	-0.363 (0.258)	-0.543 (0.190)***
ln(energy prices)	0.037 (0.426)	0.539 (0.618)	-0.534 (0.477)	0.001 (0.441)	-0.187 (0.406)
ln(road mileage)	-0.997 (0.921)	-0.353 (0.831)	-1.191 (2.470)	-0.897 (0.962)	-0.036 (0.501)
ln(market proximity)	1.529 (0.605)**	1.957 (1.033)*	0.372 (0.629)	1.487 (0.604)**	1.529 (0.551)***
ln(population)	-0.726 (0.867)	-0.972 (1.234)	0.846 (1.215)	-0.659 (0.846)	0.591 (0.679)
ln(tax effort)	-0.236 (0.503)	-0.516 (0.583)	0.631 (0.533)	-0.155 (0.507)	-0.078 (0.341)
unemployment	0.042 (0.018)**	0.041 (0.035)	-0.018 (0.025)	0.036 (0.025)	0.023 (0.020)
unionization	-0.107 (0.022)***	-0.131 (0.042)***	-0.070 (0.028)**	-0.107 (0.022)***	-0.090 (0.022)***
Observations	562	231	331	562	562
$R^2$	0.754	0.278	0.068	0.759	0.135

Dependent variable: Chemical sector FDI property plant and equipment (PPE).

All regressions include state and year fixed effects.

Standard errors in parentheses. Errors are clustered by state. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

wages disappears for large states, and that the negative effect of unionization is halved. The large market effect dominates these sources of comparative advantage.

Endogeneity of the state level environmental stringency (RAC) is a concern.<sup>7</sup> We therefore, in Table 2, replicate the Lewbel (2012) IV method by Millimet and Roy (2016).<sup>8</sup> The IV regression results are very similar to those in Table 1. Inward FDI flows continue to be significantly negatively related to environmental stringency for small states, but not for large ones.

### 3 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. The tax rates are initially set exogenously. Thereafter, we allow for endogenous emission taxes.

#### 3.1 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, labor denoted by  $L$ , used in the A-sector and the M-sector. The A-sector is a Walrasian, homogenous-goods sector, which is costlessly traded. The M-sector is characterized 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. Governments in both countries levy a tax on pollution, which is redistributed in a lump-sum fashion to consumers. 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

$$U_j = C_{Mj}^\beta C_{Aj}^{1-\beta} - g(E_w), \quad (2)$$

where  $C_{Aj}$  is consumption of the homogeneous good,  $C_{Mj}$  is consumption of a CES-aggregate of differentiated good,  $\beta \in (0, 1)$ , 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

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<sup>7</sup>We have also replicated Keller and Levinson (2002) results for the dynamic version of the empirical model using the Arrelano Bond GMM estimator. This method uses up about half the obsevations and the results are very similar, but with lower significance levels.

<sup>8</sup>As Millimet and Roy (2016), we use conditional second order moments of land prices, market proximity and road mileage as instruments for RAC in a GMM IV regression.

through the index  $C_{Mj}$ , defined by

$$C_{Mj} = \left[ \int_0^{n^w} c_{i,j}^{(\sigma-1)/\sigma} di \right]^{\sigma/(\sigma-1)}, \quad (3)$$

where  $n^w$  is the global mass of varieties in the differentiated goods sector,  $c_{i,j}$  is the amount of variety  $i$  consumed by an individual in country  $j$ , 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 labor. This good is freely traded and since it is chosen as the numeraire

$$p_A = w = 1; \quad (4)$$

$w$  being the nominal wage of workers in all countries. Income in country  $j$  consists of wage incomes plus the redistributed emission taxes:

$$Y_j = L_j + t_j E_j, \quad (5)$$

where  $t_j$  is the emission tax and  $E_j$  represents local emissions in country  $j$ .

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

$$x_{i,j} = \frac{p_{i,j}^{-\sigma}}{P_j^{1-\sigma}} \beta Y_j, \quad (6)$$

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

$$P_j \equiv \left( \int_0^{n^w} p_i^{1-\sigma} di \right)^{\frac{1}{1-\sigma}} \quad (7)$$

is the price index of manufacturing goods.

Let us also account for the fact that manufacturing activity entails pollution in terms of emissions.<sup>9</sup> 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 levy emission taxes (production taxes). A firm can reduce the emissions by diverting a fraction  $\theta_{i,j}$  of the primary factor, labor, away from the production of  $x_{i,j}$ . Firms pay a fixed cost, and thereafter joint production is given by

$$x_{i,j} = (1 - \theta_{i,j}) \frac{l_{i,j}}{a}, \quad (8)$$

$$e_{i,j} = \varphi_i(\theta_{i,j}) \frac{l_{i,j}}{a}, \quad (9)$$

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<sup>9</sup>We abstract from emissions related to the consumption of goods and only focus on supply-side emissions.

where  $l_{i,j}$  is labor used in the variable cost term by firm  $i$ ,  $a$  is the labor input coefficient, and  $0 \leq \theta_{i,j} \leq 1$ . Firm-level emissions, given  $\theta_{i,j}$ , are determined by the abatement function

$$\varphi_{i,j} = (1 - \theta_{i,j})^{1/\alpha}, \quad (10)$$

which is characterized by  $\varphi_{i,j}(0) = 1$ ,  $\varphi_{i,j}(1) = 0$ ,  $\varphi'_{i,j}(\cdot) < 0$ , 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 (9) and (10) to substitute for  $\theta_j$  in (8) yields

$$x_j = e_j^\alpha \left( \frac{l_j}{a} \right)^{1-\alpha} \quad (11)$$

from which we derive the variable cost function. Substituting out  $\theta_j$  with the fixed cost being sunk, and choosing units of labor so that  $a = 1$ , we obtain the following cost function:

$$\Psi_j = F + \kappa(wa)^{1-\alpha} t_j^\alpha x_j = F + \kappa t_j^\alpha x_j \quad (12)$$

where  $\kappa \equiv \alpha^{-\alpha}(1 - \alpha)^{(1-\alpha)}$ , and  $F$  is a fixed production cost.

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

$$e_j = \frac{\partial \Psi_j}{\partial t_j} = \alpha \kappa t_j^{\alpha-1} x_j, \quad (13)$$

which yields the emission intensity

$$\frac{e_j}{x_j} = \frac{\alpha \kappa}{t_j^{1-\alpha}}. \quad (14)$$

Profit maximization by a manufacturing firm in country  $j$  leads to the consumer price

$$p_{jm} = \frac{\sigma}{\sigma - 1} \tau_{jm} \kappa t_j^\alpha, \quad (15)$$

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  $\tau$ .

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  $j$

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

Substituting the firm's equilibrium output from (16) into (14) gives firm-level emissions:

$$e_j = \frac{\alpha F(\sigma - 1)}{t_j}. \quad (17)$$

A higher emission tax and a more efficient abatement technology (lower  $\alpha$ ) decrease firms' emissions and emission intensity.

### 3.2 Equilibrium

Using (6) and (7), firm profits,  $\frac{p_j x_j}{\sigma}$ , can be written as

$$\pi_h = \frac{\beta}{\sigma} \left( \frac{L_h + e_h n_h t_h}{n_h t_h^{\alpha(1-\sigma)} + n_f \phi t_f^{\alpha(1-\sigma)}} + \phi \frac{L_f + e_f n_f t_f}{n_h \phi t_h^{\alpha(1-\sigma)} + n_f t_f^{\alpha(1-\sigma)}} \right) t_h^{\alpha(1-\sigma)} - F \quad (18)$$

$$\pi_f = \frac{\beta}{\sigma} \left( \phi \frac{L_h + e_h n_h t_h}{n_h t_h^{\alpha(1-\sigma)} + n_f \phi t_f^{\alpha(1-\sigma)}} + \frac{L_f + e_f n_f t_f}{n_h \phi t_h^{\alpha(1-\sigma)} + n_f t_f^{\alpha(1-\sigma)}} \right) t_f^{\alpha(1-\sigma)} - F \quad (19)$$

where  $\phi \equiv \tau^{1-\sigma}$  is the freeness of trade that varies between autarky ( $\phi = 0$ ) and free trade ( $\phi = 1$ ).

Substitute (17) into equations (18) and (19) at zero profit to obtain the global number of firms, which is constant: a customary result of Dixit-Stiglitz models

$$n^w = n_h + n_f = \frac{\beta L_w}{F(\sigma - \beta \alpha(\sigma - 1))}. \quad (20)$$

The equilibrium values for  $n_j$  are

$$n_h = \frac{\beta \alpha(\sigma - 1) s_L (1 - \phi^2) + \phi^2 \sigma (s_L - 1) + T^{-\alpha(\sigma-1)} \phi \sigma - s_L \sigma}{\beta \alpha(\sigma - 1) (1 - \phi^2) - \phi^2 \sigma + T^{-\alpha(\sigma-1)} \phi \sigma + T^{\alpha(\sigma-1)} \phi \sigma - \sigma} n^w \quad (21)$$

$$n_f = \frac{\beta \alpha(\sigma - 1) (1 - s_L) (1 - \phi^2) - \phi^2 \sigma s_L + T^{\alpha(\sigma-1)} \phi \sigma - (1 - s_L) \sigma}{\beta \alpha(\sigma - 1) (1 - \phi^2) - \phi^2 \sigma + T^{-\alpha(\sigma-1)} \phi \sigma + T^{\alpha(\sigma-1)} \phi \sigma - \sigma} n^w \quad (22)$$

where:  $s_L \equiv \frac{L_h}{L_w}$  and  $1 - s_L \equiv \frac{L_f}{L_w}$ ;  $L_w = L_h + L_f$ ; and  $T \equiv \frac{t_f}{t_h}$ .

The model displays what Helpman and Krugman (1985) call a 'home market effect' (HME). That is, firms do disproportionately locate to the larger market. The reason for this is that firms save on transportation costs by locating production closer to centers 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  $s_L$  and  $\phi$

$$s_n \equiv \frac{n_h}{n_f + n_h} = \frac{s_L \beta \alpha(\sigma - 1) (1 + \phi) + \sigma ((1 - s_L) \phi - s_L)}{\beta \alpha(\sigma - 1) (1 + \phi) - \sigma (1 - \phi)}. \quad (23)$$

Differentiating (23) with respect to  $s_L$  yields

$$\frac{ds_n}{ds_L} = \frac{\sigma (1 + \phi) - (1 + \phi) \beta \alpha(\sigma - 1)}{\sigma (1 - \phi) - (1 + \phi) \beta \alpha(\sigma - 1)} > 1. \quad (24)$$

As the relative size of the home country increases, the share of firms locating in the home

country increases more than proportionately; this is the HME. Furthermore, as seen from (24), the steepness of  $\frac{ds_n}{ds_L}$  increases in  $\phi$ . Trade liberalization magnifies the HME.<sup>10</sup>

### 3.3 Emissions

Local emissions in each country are from (17), (21), and (22) given by

$$E_h = \frac{L_w}{\left(\frac{\sigma}{\beta\alpha(\sigma-1)} - 1\right) t_h} \frac{\left\{ \begin{array}{l} \beta\alpha(\sigma-1)s_L(1-\phi^2) + \\ \sigma\phi^2(s_L-1) + \sigma\phi T^{-\alpha(\sigma-1)} - s_L\sigma \end{array} \right\}}{\left(\beta\alpha(\sigma-1)(1-\phi^2) - \sigma\phi^2 + \sigma\phi T^{-\alpha(\sigma-1)} + \sigma\phi T^{\alpha(\sigma-1)} - \sigma\right)}, \quad (25)$$

$$E_f = \frac{L_w}{\left(\frac{\sigma}{\beta\alpha(\sigma-1)} - 1\right) t_f} \frac{\left\{ \begin{array}{l} \beta\alpha(\sigma-1)(1-s_L)(1-\phi^2) \\ -s_L\sigma\phi^2 + \sigma\phi T^{\alpha(\sigma-1)} - (1-s_L)\sigma \end{array} \right\}}{\left(\beta\alpha(\sigma-1)(1-\phi^2) - \sigma\phi^2 + \sigma\phi T^{-\alpha(\sigma-1)} + \sigma\phi T^{\alpha(\sigma-1)} - \sigma\right)}, \quad (26)$$

and world emissions are given by

$$E_w = \frac{L_w}{\left(\frac{\sigma}{\beta\alpha(\sigma-1)} - 1\right) t_h t_f} \frac{\left\{ \begin{array}{l} \sigma\phi(t_f T^{-\alpha(\sigma-1)} + t_h T^{\alpha(\sigma-1)}) - (t_f(1-s_L) + s_L t_h)\sigma\phi^2 \\ -(t_h(1-s_L) + s_L t_f)(\sigma - \beta\alpha(\sigma - \phi^2)) \end{array} \right\}}{\left(\beta\alpha(\sigma-1)(1-\phi^2) + \sigma(\phi(T^{-\alpha(\sigma-1)} - \phi + T^{\alpha(\sigma-1)}) - 1)\right)}. \quad (27)$$

Clearly, a proportional increase in  $t_h$  and  $t_f$ , which keeps  $T$  constant, leads to lower emissions.

## 4 The effect of trade liberalization on emissions

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

### 4.1 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 liberalization will lead to a relocation of firms to the larger market. At the same time, note that equation (17) 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 market, 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 (25) and (26)

<sup>10</sup> All firms concentrate in the larger (home) country when trade liberalization reaches  $\phi^* = \frac{1-s}{s}$ , as seen from (23). The locational advantage of the larger market continues to increase as trade is liberalized 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.

yields

$$\frac{E_h}{E_f} \Big|_{t_j=t} = \frac{s_L (1 + \phi) (\sigma - \beta\alpha (\sigma - 1)) - \sigma\phi}{s_L (1 + \phi) \left( \frac{s_L - 1}{s_L} \beta\alpha (\sigma - 1) - \sigma \right) + \sigma}. \quad (28)$$

Differentiation w.r.t.  $\phi$  gives

$$\frac{\partial}{\partial \phi} \left( \frac{E_h}{E_f} \right)_{t_j=t} = \frac{2\sigma (\sigma - \beta\alpha (\sigma - 1)) (s_L - \frac{1}{2})}{[\beta\alpha (\sigma - 1) (s_L - 1) (1 + \phi) + (1 - (1 + \phi) s_L) \sigma]^2}, \quad (29)$$

which is always positive for  $s_L > \frac{1}{2}$ : trade liberalization leads to higher emissions in the larger country. (29) also shows that no relocation takes place if countries are exactly equal in size ( $s_L = 0.5$ ), in which case each country generates half of the global emissions irrespective of  $\phi$ .

Global emissions under symmetric taxes are illustrated by equation (27) evaluated at  $t_j = t$ , or

$$E_w|_{t_j=t} = \frac{L_w}{\left( \frac{\sigma}{\beta\alpha(\sigma-1)} - 1 \right) t}. \quad (30)$$

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

**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: The proposition follows directly from (29) and (30). ■

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  $\phi$ .

## 4.2 Symmetric markets

Next we constrain market sizes to be identical in home and foreign ( $s_L = \frac{1}{2}$ ), but allow the emission taxes to vary. The identical market sizes isolate effects related to emission tax asymmetry.

The relative mass of firms in the two markets now depends on the relative tax rates and the level of trade costs. Combining equations (21) and (22) yields the relative number of firms in the home and foreign country

$$\frac{n_h}{n_f} \Big|_{s_L=\frac{1}{2}} = \frac{\sigma (1 + \phi^2) - \beta\alpha (\sigma - 1) (1 - \phi^2) - 2\sigma\phi T^{-\alpha(\sigma-1)}}{\sigma (1 + \phi^2) - \beta\alpha (\sigma - 1) (1 - \phi^2) - 2\sigma\phi T^{\alpha(\sigma-1)}}. \quad (31)$$

Rearranging equation (31) identifies the range of relative taxes,  $T \equiv \frac{t_f}{t_h}$ , for which there are firms active in both countries:

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

In a totally symmetric economy,  $T = 1$  and (31) reduces to  $\frac{n_h}{n_f} = 1$ . A higher foreign tax implies a higher  $T$ , and from (31) this leads to a higher  $\frac{n_h}{n_f}$ . 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 liberalization on the location of firms is given by

$$\left. \frac{\partial \left( \frac{n_h}{n_f} \right)}{\partial \phi} \right|_{s_L=\frac{1}{2}} = 2 \frac{(\sigma - \beta\alpha(\sigma-1) - \phi^2(\beta\alpha(\sigma-1) + \sigma)) (T^{\alpha(\sigma-1)} - T^{-\alpha(\sigma-1)})}{(\sigma(1+\phi^2) - 2T^{\alpha(\sigma-1)}\phi) - \beta\alpha(\sigma-1)(1-\phi^2)^2}, \quad (33)$$

and we can now formulate the following propositions:

**PROPOSITION 2** *Trade liberalization always leads to a relocation of firms to the low-tax country when markets are symmetric iff  $\phi < \sqrt{\frac{\sigma-\beta\alpha(\sigma-1)}{\sigma+\beta\alpha(\sigma-1)}}$ .*

Proof: Let  $t_h < t_f$ . Then,  $(T^{\alpha(\sigma-1)} - T^{-\alpha(\sigma-1)}) > 0$ . The sign of the differential in (33) now depends on the term  $(\sigma - \beta\alpha(\sigma-1) - \phi^2(\beta\alpha(\sigma-1) + \sigma))$ , which is positive iff  $\phi < \sqrt{\frac{\sigma-\beta\alpha(\sigma-1)}{\sigma+\beta\alpha(\sigma-1)}}$ . ■

The effect of trade liberalization on global emissions follows directly:

**PROPOSITION 3** *Trade liberalization leads to higher global emissions when the countries have different environmental tax rates and the markets are symmetric iff  $\phi < \sqrt{\frac{\sigma-\beta\alpha(\sigma-1)}{\sigma+\beta\alpha(\sigma-1)}}$ .*

Proof. This follows directly from Proposition 2 together with the fact that from (20), the global number of firms is constant and from (17), firm level emissions decrease in the emission tax rate. ■

Thus, starting from autarky, trade liberalization always leads more firms to locate in the low-tax country. This effect is labeled the pollution haven hypothesis (PHH). Trade liberalization in this case 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)).

What if trade costs are so low that  $\phi > \sqrt{\frac{\sigma-\beta\alpha(\sigma-1)}{\sigma+\beta\alpha(\sigma-1)}}$ ? Further trade liberalization would then lead firms to relocate to the high tax economy. However, there is an upper bound on  $\phi$  for there to be firms active in both countries, identified by condition (32). Between these two

conditions on  $\phi$ , there can exist a parameter space for which deeper trade liberalization leads to effects opposite of the PHH.<sup>11</sup>

### 4.3 Asymmetric taxes and markets

We now turn to the case where both market size and taxes differ between the two countries: both  $s$  and  $T$  are unconstrained. Clearly, when the large economy has low taxes, the PHH and the HME tend to work in the same direction, and trade liberalization should therefore lead to higher global emissions. The perhaps more interesting case to investigate is under which conditions a large home market can outweigh higher emission taxes so that trade liberalization leads to lower emissions. We here focus the discussion on this latter case and analyze the conditions under which the HME can dominate the PHH.

Using (17), global emissions can be expressed as

$$E^w = n_h e_h + n_f e_f = n_h \frac{\alpha F(\sigma - 1)}{t_h} + n_f \frac{\alpha F(\sigma - 1)}{t_f}. \quad (34)$$

From (20),  $n_h + n_f$  is constant so global emissions are for given taxes solely determined by the allocation of firms between the two markets. It also follows that trade costs cease to affect emissions once all firms are concentrated in one market.

The share of firms in home,  $s_n \equiv \frac{n_h}{n_w}$  follows from (20) and (21):

$$s_n = \frac{s_L \beta \alpha (\sigma - 1) (1 - \phi^2) + \sigma (T^{-\alpha(\sigma-1)} \phi - (1 - s_L) \phi^2 - s_L)}{\beta \alpha (\sigma - 1) (1 - \phi^2) + T^{\alpha(\sigma-1)} \phi \sigma + \sigma (T^{-\alpha(\sigma-1)} \phi - \phi^2 - 1)}, \quad (35)$$

which suggests that the location of firms is affected by the relative tax rate  $T$ , but not by the level of taxes. On the contrary, emissions do depend on the level of taxes in addition to the relative tax rate.

The change in global emissions from a change in trade openness, as long as there are firms in both countries, is given by differentiation of (27):

$$\frac{\partial E^w}{\partial \phi} = \frac{\sigma (t_h - t_f)}{\left( \frac{\sigma}{\beta \alpha (\sigma-1)} - 1 \right)} \frac{L_w}{t_f t_h} \left[ \begin{array}{l} \left\{ s_L (\phi^2 + 1) \beta \alpha (\sigma - 1) - ((s_L - 1) \phi^2 + s_L) \sigma \right\} T^{\alpha(\sigma-1)} + \\ T^{-\alpha(\sigma-1)} [(s_L - 1) \beta \alpha (\sigma - 1) - \sigma s_L] + \\ [2 (1 - 2s_L) \phi + T^{-\alpha(\sigma-1)} (s_L - 1)] (\beta \alpha (\sigma - 1) - \sigma) \end{array} \right]. \quad (36)$$

The effect of trade liberalization on emissions will depend on the counter-balancing interaction of the PHH and the HME. The PHH draws firms to the small low tax market whereas the

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<sup>11</sup>The effect is driven by the assumption that tax revenues are redistributed back to consumers. When firms relocate into an economy, they boost tax revenues and therefore aggregate demand. This, in turn, creates an HME, which is particularly strong when taxes are high. The effect would not occur if revenues e.g. were used for the production of a public good. For such a case, see the working paper version of this paper, Forslid et al. (2015).

HME draws firms to the large high tax economy. Consider first trade liberalization starting at autarky ( $\phi = 0$ ). The movement of firms is in this case dictated by the sign of

$$\frac{\partial s_n}{\partial \phi} \Big|_{\phi=0} = \frac{\sigma (s_L T^{\alpha(\sigma-1)} - (1-s_L) T^{-\alpha(\sigma-1)})}{(\sigma - \beta \alpha (\sigma - 1))} \quad (37)$$

Firms move to the large high tax economy at  $\phi = 0$  if

$$\frac{s_L}{1-s_L} > T^{-2\alpha(\sigma-1)} = \left( \frac{t_h}{t_f} \right)^{2\alpha(\sigma-1)}, \quad (38)$$

and to the small low tax economy if

$$\frac{s_L}{1-s_L} < \left( \frac{t_h}{t_f} \right)^{2\alpha(\sigma-1)}. \quad (39)$$

The conditions clearly show how location is determined by firms trading-off relative market size and relative taxes. The two cases in (38) and (39) are illustrated in Figures 1A and 1B.

Figure 1A shows a case where (38) holds so that HME initially dominates the PHH. The figure plots world emission and the relative number of firms from (27) and (35) for  $\sigma = 5$ ,  $s_L = 0.7$ ,  $\alpha = 0.7$ ,  $\beta = 0.5$ ,  $F = 1$ ,  $L_w = 10$ ,  $t_f = 5.1$ , and  $T = 0.9$ . Firms initially move to the high tax large economy leading to reduced global emissions, but for sufficiently low trade costs, the pattern is reversed and firms start moving to the low tax economy instead. This effect follows from a well established property of these models: the location advantage of the larger market (the HME) is hump-shaped in trade costs and it is strongest for intermediate trade costs.<sup>12</sup> When trade costs are very 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 very low trade costs, firms have no incentive to avoid trade costs. Thus, the advantage of the large market is highest for intermediate trade costs, which implies that the HME is hump-shaped in  $\phi$ . Trade liberalization in Figure 1A therefore first leads to lower emissions as the HME grows stronger, and more firms are drawn to the high-tax economy. 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 emissions. Finally, emissions remain constant once the trade costs are so low that all firms remain located in the low tax economy.

Figure 1B shows a case where tax differences are larger so that the tax difference dominates the size difference, implying that (39) holds. The PHH already at  $\phi = 0$  dominates the HME in this case. Trade liberalization therefore immediately induces firms to move to the low tax country. The figure employs the following parameter values:  $\sigma = 5$ ,  $s_L = 0.7$ ,  $\alpha = 0.7$ ,  $\beta = 0.5$ ,  $F = 1$ ,  $L_w = 10$ ,  $t_f = 6$ , and  $T = 0.85$ . Figure 1B shows that trade liberalization induces firms to continuously move to the lower tax country, and this increases the global emissions until all firms are located here.<sup>13</sup>

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<sup>12</sup>See e.g. Baldwin et al. (2003, ch2).

<sup>13</sup>In principle, it is possible that other patterns than those displayed in Figures 1A and 1B exist. In particular,

Both figures show that the share of firms in the large market declines for sufficiently free trade. This effect depends on the fact that the HME is eventually weakened as trade is liberalized. We can show this property of the model by signing  $\frac{\partial s_n}{\partial \phi}$  at the point where all firms have agglomerated in the low tax economy. This point is referred to as the sustainpoint in the economic geography literature.<sup>14</sup> Differentiating (35) and solving for the trade freeness at which  $s_n = 1$  gives the trade freeness at the sustain point:<sup>15</sup>

$$\phi^s = \frac{\sigma T^{-\alpha(\sigma-1)} - \sqrt{\sigma^2 T^{-2\alpha(\sigma-1)} + (2(\beta\alpha(s_L - 1) - \sigma)s_L + \sigma)^2 - \sigma^2}}{2\sigma(1 - s_L) + (\sigma - 1)2\beta\alpha s_L}. \quad (40)$$

Note that this expression reduces to the standard solution  $\frac{s_L}{1-s_L}$  for  $\alpha = 0$ . Next, plugging this level of trade cost into  $\frac{\partial s_n}{\partial \phi}$  and simplifying gives:

$$\frac{\partial s_n}{\partial \phi} \Big|_{\phi=\phi^s} = \frac{-\sqrt{\sigma^2 T^{-2\alpha(\sigma-1)} + (2(\beta\alpha(s_L - 1) - \sigma)s_L + \sigma)^2 - \sigma^2}}{\left(T^{\alpha(\sigma-1)}\phi^s\sigma + T^{-\alpha(\sigma-1)}\phi^s\sigma + (1 - (\phi^s)^2)\beta\alpha(\sigma - 1) - \sigma(1 + (\phi^s)^2)\right)^2} < 0, \quad (41)$$

which shows that the share of firms in the high tax economy will always decline in trade liberalization close to  $\phi = \phi^s$ . As a consequence, global emissions will always increase in trade liberalization at this point.

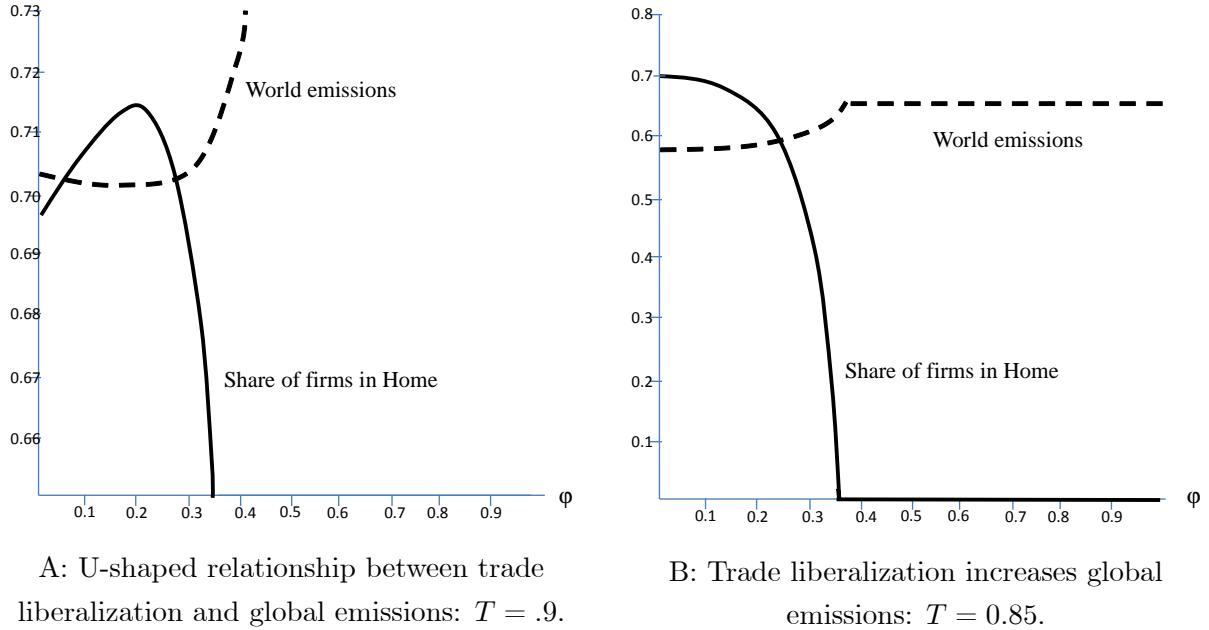
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firms could first move to the low tax economy, thereafter revert to the large high tax economy for intermediate trade costs when the HME is maximal, and then finally go back to the low tax economy for deep enough trade liberalization. We have not been able to find this case in spite of extensive numerical simulations, but many models of agglomeration are known to have knife edge cases of this type and therefore, we cannot rule out that this case exists. However, note that the result that the share of firms in the high tax economy always declines in trade liberalization close to  $\phi = 1$ , and that global emissions as a consequence always increase in trade liberalization at this point would hold for any localization pattern.

<sup>14</sup>See e.g. Baldwin et al. (2003).

<sup>15</sup>One non-economic root is discarded noting that  $\sigma T^{-\alpha(\sigma-1)} > 1$  in our case with  $T < 1$ .

Figure 1: The effect of trade liberalization on emissions.<sup>16</sup>



## 5 Endogenous emission taxes: Simulations

So far, our analysis has 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. Therefore, we introduce endogenous taxes, and maintain the assumption that tax revenues are redistributed to consumers in a lump-sum fashion. The combination of asymmetric markets and endogenous taxes cannot be handled analytically, and we therefore proceed by numerical simulation. We consider two settings: first, a non-cooperative setting where emission taxes are set in a Nash game between the two governments and second, a cooperative setting where emission taxes are given by a Nash bargaining solution.

### 5.1 Nash taxes

The government in each country chooses a domestic emission tax to maximize the utility of domestic residents from Equation (2), taking the tax rate of the other country as given. In the simulations, we use the following climate damage function:

$$g(E_w) = \delta E_w^\eta \quad (42)$$

<sup>16</sup>Both plots are generated using the following parameter values:  $\sigma = 5$ ,  $s = 0.7$ ,  $\alpha = 0.7$ ,  $\beta = 0.5$ ,  $F = 1$ ,  $L_w = 10$ , and  $t_f = 5.1$ .

where  $\delta > 0$  and  $\eta \geq 1$  are parameters determining the importance of the disutility related to global emissions. This implies the following indirect utility of residents in Country  $j$

$$V_j = \psi \frac{y_j}{P_j^\beta} - \delta E_w^\eta, \quad (43)$$

where  $\psi \equiv \beta^\beta (1 - \beta)^{(1-\beta)}$  and  $y_j \equiv w + \frac{t_j \cdot E_j}{L_j}$ .

Home's and foreign's first order conditions,  $\frac{\partial V_h}{\partial t_h} = 0$ , and  $\frac{\partial V_f}{\partial t_f} = 0$  may be decomposed according to:

$$a_{1h} \varepsilon_{s_n, t_h}^{(-)} - a_{2h} \varepsilon_{p_h, t_h}^{(+)} + a_{3h} \varepsilon_{s_n, t_h}^{(-)} \left( t_h^{-\alpha(\sigma-1)} - \phi t_f^{-\alpha(\sigma-1)} \right) - a_{4h} \varepsilon_{e_h, t_h}^{(-)} + a_{5h} \varepsilon_{s_n, t_h}^{(-)} (e_f - e_h) = 0 \quad (44)$$

$$\begin{aligned} -a_{1f} \frac{s_n}{1 - s_n} \varepsilon_{s_n, t_f}^{(+)} - a_{2f} \varepsilon_{p_f, t_f}^{(+)} + a_{3f} \frac{s_n}{1 - s_n} \varepsilon_{s_n, t_f}^{(+)} (\phi t_h^{-\alpha(\sigma-1)} - t_f^{-\alpha(\sigma-1)}) \\ - a_{4f} \varepsilon_{e_f, t_f}^{(-)} + a_{5f} \frac{s_n}{1 - s_n} \varepsilon_{s_n, t_f}^{(+)} (e_f - e_h) = 0 \end{aligned} \quad (45)$$

where  $\varepsilon_{k,l}$  is the elasticity of  $k$  w.r.t.  $l$  and the positive coefficients  $a_{1j} \equiv \psi P_j^{-\beta} \frac{\alpha F(\sigma-1)}{L_j}$ ;  $a_{2j} \equiv \psi y \beta P_j^{\sigma-\beta-1} p_j^{1-\sigma} (n^w)^{\frac{\sigma}{1-\sigma}}$ ;  $a_{3j} \equiv \psi y \beta P_j^{\sigma-\beta-1} \frac{(\kappa\sigma)^{1-\sigma}}{(\sigma-1)^{2-\sigma}} (n^w)^{\frac{\sigma}{1-\sigma}}$ ;  $a_{4j} \equiv \delta \eta E_w^{\eta-1} e_j$ ;  $a_5 \equiv \delta \eta E_w^{\eta-1}$ , where  $j \in (h, f)$ . Consider the effect of an increase of  $t_j$ . The first term picks up the negative income effect stemming from lower tax revenues as firms relocate to the other country. The second term is a direct effect on the price index, which increases since a higher domestic tax results in higher domestic prices. The third term shows the effect of relocation on the price index. Relocation to the other country tends to lead to a higher domestic price index since more varieties are imported and thereby subject to trade costs. However, the effect goes the other way if the foreign price (tax) is so low that it outweighs the trade cost. The fourth term shows the positive utility effect of lower domestic emissions. Finally, the fifth term shows how the relocation of firms affects global emissions, and relocation to the other country decreases global emissions if the other country is a high tax country.

The first order effect of trade liberalization can be seen from the third term in both Home and Foreign's first order conditions in (44) and (45), respectively.<sup>17</sup> Consider a case where home is large and has a higher emission tax at the outset when trade costs are high. Trade liberalization (a higher  $\phi$ ) leads to a lower  $t_h$  to balance the expression in the parenthesis, and it will for the same reason lead to a lower  $t_f$ . This in turn gives rise to new rounds of feed-back. As the foreign country lowers its tax rate the domestic economy must respond with a lower tax as seen from the third term in the FOCs. However, the response to a foreign tax reduction is muted by the fact that  $\phi < 1$ , and the system therefore converges to a new equilibrium with lower taxes. It is also seen from the same expression that taxes must be more and more alike as  $\phi$

<sup>17</sup>Trade liberalization has naturally also several general equilibrium effects.

approaches one. Thus, trade liberalization leads to falling and converging tax rates. Intuitively lower trade costs erode the advantage of the large market and therefore make it difficult for the large country to have a higher emission tax than the small country. The effect is also seen in the simulations below, where trade liberalization leads to falling and converging tax rates.

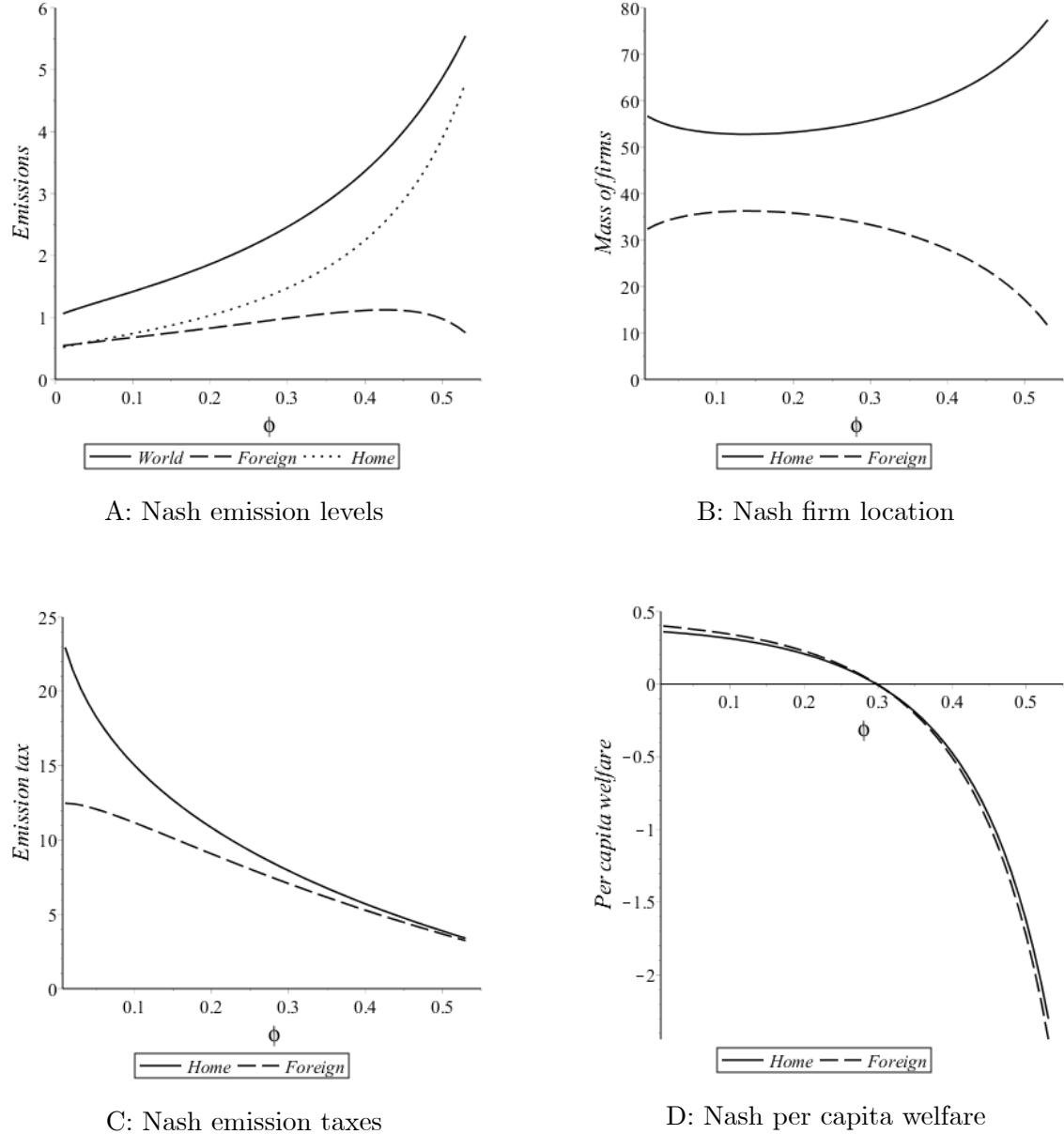
We start by simulating a case with a relatively strong HME, where the relative market size of the two countries  $s_L = 0.65$ . The other parameters values are:  $\sigma = 4, F = 0.1, \alpha = 0.7, \eta = 2, \beta = 0.3, \varepsilon = 0.1, L_w = 100$ . We refer to these parameter values as our baseline case, and below we discuss the sensitivity of our results to varying parameters. Figure 2 shows the outcome when  $s_L = 0.65$ . The larger home country sets a higher emission tax (in Panel C). Firms relocate to the smaller low tax foreign market in the early stages of trade liberalization in accordance with the PHH, but this process is reversed for deeper liberalization, when the HME becomes the dominating force (in Panel B). The flow of firms then goes from the small low tax economy to the large high tax country. That is, for a range of  $\phi$ , the movement of firms is the opposite of what the PHH would predict: a pollution haven does not materialize when trade liberalization is deep enough. This movement of firms leads to a decrease in emissions from the low-tax foreign country and an increase in emissions from the high-tax home country. However, trade liberalization increases the intensity of the tax competition between the Home and Foreign governments, creating a race to the bottom as illustrated in Figure 2 Panel C. The result is therefore increasing global emissions in spite of firms moving to the high tax economy.

Since taxes fall and emissions rise, welfare declines sharply as trade is liberalized as shown in Panel D of Figure 2.<sup>18</sup> Welfare is higher in the small country at autarky ( $\phi = 0$ ). The small country adopts a low emission tax, because its emission tax has a relatively small effect on global emissions. Thus, the small country is essentially free-riding on the emission reductions of the large economy, which leads to a higher welfare in the small economy. As trade is liberalized, the large country sharply decreases taxes to attract firms, and as the HME leads to an increasing number of firms in the large country, the large country welfare surpasses that of the small country.

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<sup>18</sup>The small country welfare would be hump-shaped in trade liberalization if welfare was less dependent on emissions, e.g. if  $\alpha$  was low.

Figure 2. Simulation results for the non-cooperative outcome with a strong HME:  $s_L = 0.65$ .<sup>19</sup>

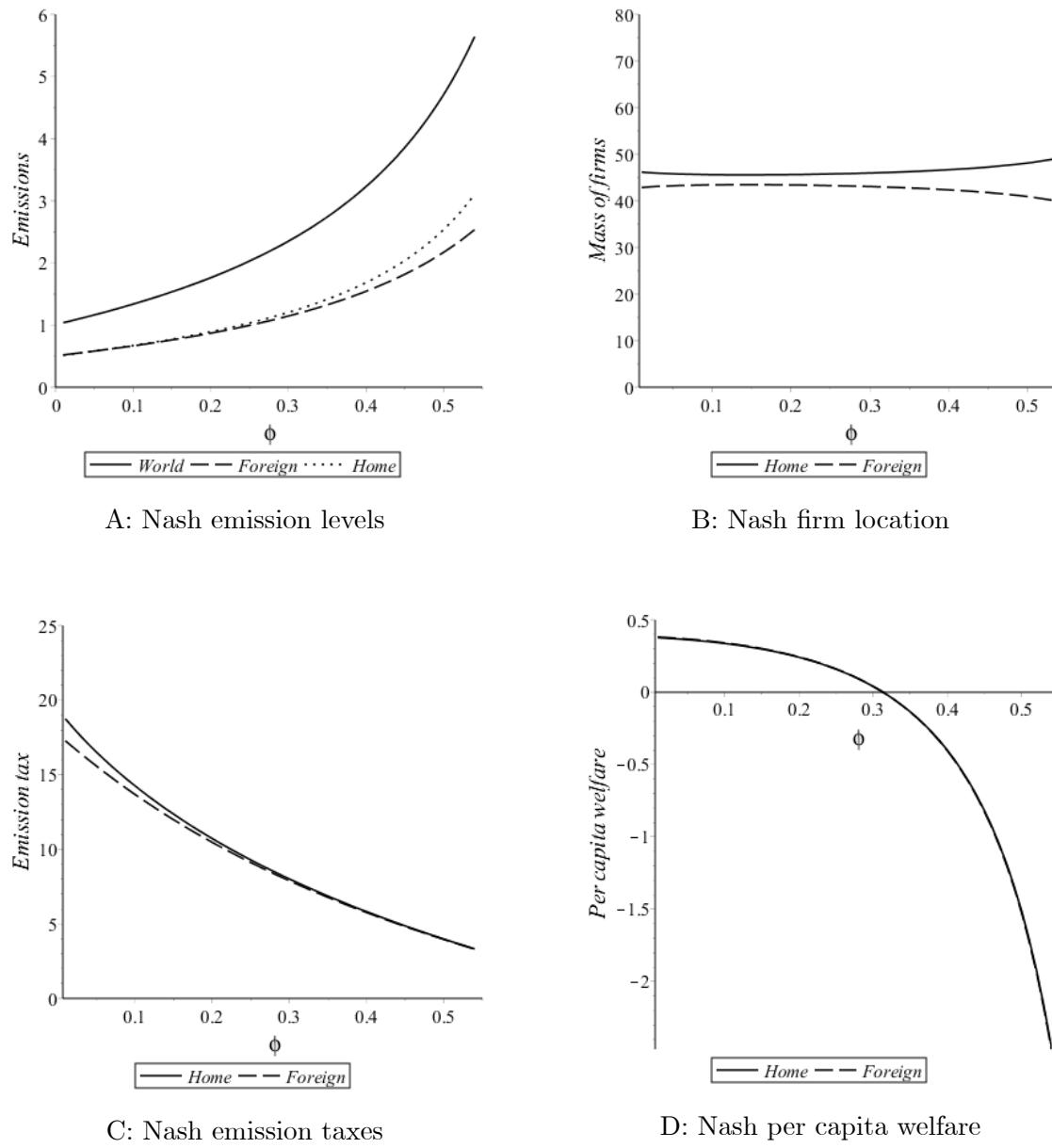


What if the HME is weak? We simulate this case with a smaller size difference between the countries ( $s = 0.52$ ), while all other parameters are unchanged ( $\sigma = 4$ ,  $F = 0.1$ ,  $\alpha = 0.7$ ,  $\eta = 2$ ,  $\beta = 0.2$ ,  $\varepsilon = 0.1$ ,  $L_w = 100$ ). The results are reported in Figure 3. Once more, the PHH dominates and firms relocate to the smaller low tax foreign market, in the early stages of trade liberalization, but the process is reversed for deeper liberalization when the HME becomes

<sup>19</sup>The other parameter values are:  $\sigma = 4$ ,  $F = 0.1$ ,  $\alpha = 0.2$ ,  $\eta = 2$ ,  $\beta = 0.3$ ,  $\varepsilon = 0.1$ ,  $L_w = 100$ .

the dominating force. Thus, once more, a pollution haven does not materialize when trade liberalization is deep enough. Nash taxes fall during all stages of trade liberalization, the result of tax competition and, as a result, trade liberalization once more leads to higher emissions in both countries. Welfare displays a similar pattern as above although the welfare levels are more equal between countries.

Figure 3: Simulation results for the non-cooperative outcome with a weak HME:  $s_L = 0.52$ .<sup>20</sup>



<sup>20</sup>The other parameter values are:  $\sigma = 4$ ,  $F = 0.1$ ,  $\alpha = 0.7$ ,  $\eta = 2$ ,  $\beta = 0.3$ ,  $\varepsilon = 0.1$ ,  $L_w = 100$

Our simulations show that the HME eventually outweigh the PHH in this type of model when taxes are set endogenously in a Nash game. Firms will eventually concentrate to the large economy even though it sets higher emission taxes. The simulations nevertheless show that global emissions increase as trade is liberalized.

## 5.2 Cooperative taxes: Nash bargaining

The Nash equilibrium tax game in the previous section does not yield Pareto efficient taxes: cooperatively set emission taxes raise the welfare in both countries. Negotiations between the two governments determine how the gains from cooperation are divided. We shall assume that the division of these gains is given by the Nash bargaining solution.

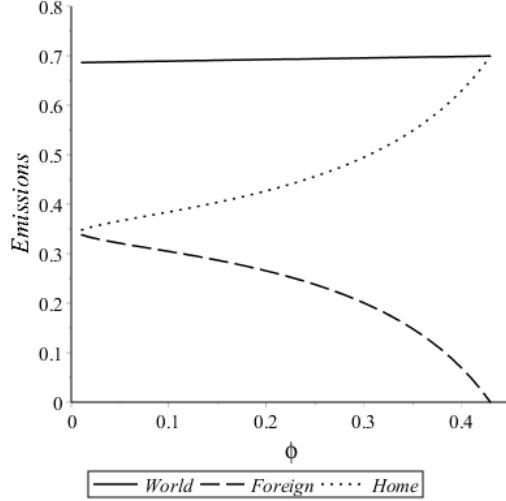
The Nash bargaining problem is

$$\max_{t_h, t_f} s_L \cdot \log(V_h - V_h^N) + (1 - s_L) \cdot \log(V_f - V_f^N), \quad (46)$$

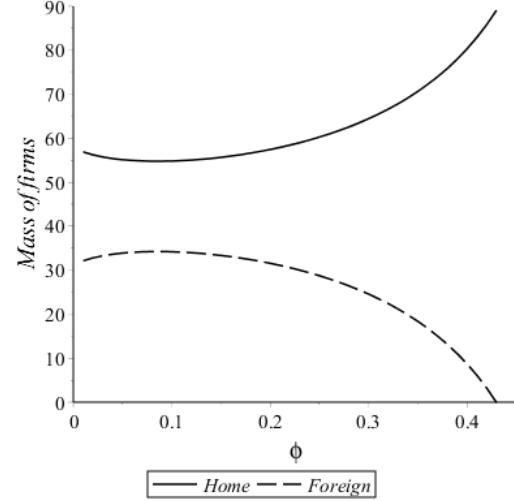
where  $V_j$  is the welfare of country  $j$  defined in (43), and  $V_j^N$  is the welfare of country  $j$  at the disagreement point: in the absence of a negotiated agreement, the outcome is the noncooperative Nash equilibrium studied in the previous subsections. The larger country has bargaining power over the smaller country, which is captured by  $s_L$ , the relative population size of the larger country.

The effect of trade liberalization in the Nash bargaining solution when HME is strong ( $s_L = 0.65$ ) is reported in Figure 4. All other parameter values used for this simulation are identical to those employed for the non-cooperative Nash case. Emissions are lower when taxes are set by Nash bargaining. Once more, the larger home country sets a considerably higher emission tax at autarky ( $\phi = 0$ ) than the small country that has a more limited influence on world emissions. This is shown in Panel C. Therefore, welfare is higher in the small country at the autarky point (panel D). Trade liberalization leads to converging tax rates, but not to a race to the bottom as in the non-cooperative case. Global emissions therefore increase very little in trade liberalization (c.f. the non-cooperative case in Panel A in Figure 2). Trade liberalization eventually strengthens the HME enough to allow the large country to attract all firms, which leads to significantly higher welfare in the large country and lower welfare in the small country (Panel D).

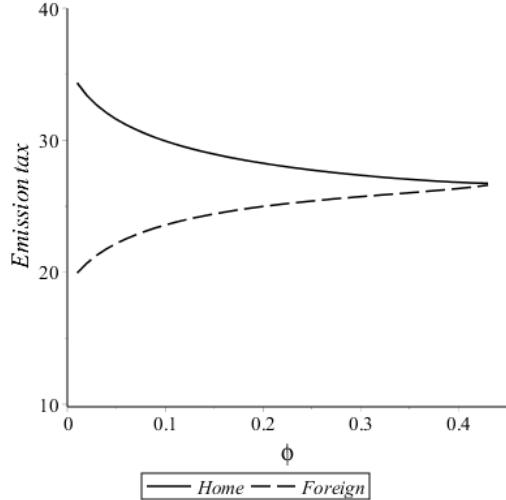
Figure 4. Simulation results for the cooperative outcome with a strong HME:  $s_L = 0.65$ .<sup>21</sup>



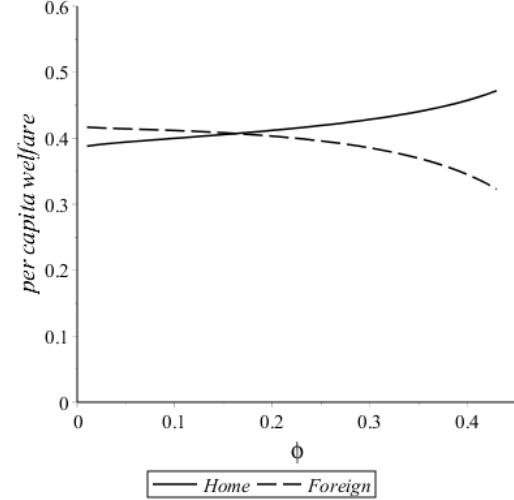
A: Nash bargaining emission levels



B: Nash bargaining firm location



C: Nash bargaining emission taxes



D: Nash bargaining per capita welfare levels

Simulation results for the case with a weak HME ( $s = 0.52$ ) yield the same patterns, and they are therefore not reported. 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.

<sup>21</sup>The other parameter values are unchanged from the simulations for the non-cooperative Nash equilibrium.

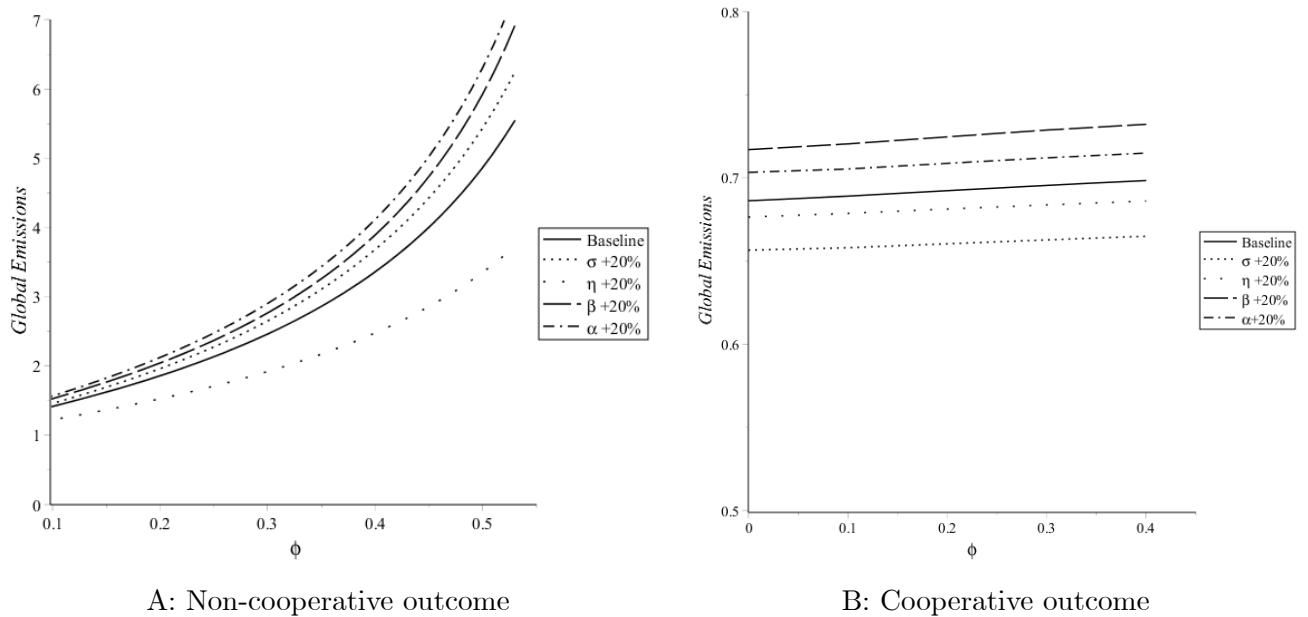
### 5.3 Sensitivity analysis

How sensitive are our results concerning the effects of trade liberalization on global emissions to the specific parameter values chosen? Figure 5 shows the effects of a 20 percent increase in various key parameters of the model for both the non-cooperative and the cooperative outcomes with  $s_L = 0.65$ : the baseline non-cooperative case reported in Figure 2; and the cooperative case reported in Figure 4.

Figure 5 Panel A shows the non-cooperative case. Here a higher  $\sigma$  increases the emissions. A higher  $\sigma$  weakens the HME which pulls firms to the large country, and this tends to increase the emissions since the larger country has higher emission taxes. However, it also dampens tax competition (because the value of having firms located in your home market decreases), which tends to increase taxes and reduce emissions. In Panel A, the first effect dominates and global emissions increase with a higher  $\sigma$ . Second, a higher  $\eta$  implies that consumers are more sensitive to emissions which results in higher emission taxes and lower emissions. A higher  $\beta$ , in turn, will increase emissions because a higher share of consumer spending falls on the polluting M-sector. Finally, a higher  $\alpha$  implies that abatement is less efficient and global emissions increase as a consequence.

In Figure 5 Panel B, global emissions are lower with cooperatively set emission taxes. The outcome of an increase in the parameter values has the same sign as in the non-cooperative Nash case except for  $\sigma$ . Here, the increased taxes due to weaker tax competition dominate which means that a higher  $\sigma$  leads to lower global emissions.

Figure 5: Sensitivity analysis of global emission when the HME is strong,  $s_L = 0.65$ .<sup>22</sup>



<sup>22</sup>The other parameter values are unchanged from the simulations for the non-cooperative Nash equilibrium.

Even though the curves in Figure 5 shift as the parameters are varied, they maintain their basic shape. This is a salient property of our simulations. We have searched (running loops on loops) over a parameter space defined by:  $0.2 \leq \beta \leq 0.8$ ;  $2 \leq \eta \leq 6$ ;  $0.2 \leq \alpha \leq 0.8$ ;  $1.2 \leq \sigma \leq 8.2$ ;  $0.1 \leq F \leq 10$ ;  $0.5 \leq s_L \leq 0.9$ ;  $0 \leq \phi \leq 0.7$ . This has consistently produced both non-cooperative and cooperative taxes that fall, and global emissions that rise as trade is liberalized, even if the latter effect may be very slight.<sup>23</sup>

## 6 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 primary 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 tends to increases global emissions as firms relocate to the low tax economy.

Then, we analyze 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 liberalized, both the HME and the PHH draw firms to the larger market which results in a 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, trade liberalization will first result in a decrease in global emissions as firms are drawn to the large high-tax economy, but later to an increase in emissions as the HME weakens for lower trade costs and the movement of firms is reversed.

Then, we allow for endogenous emission taxes numerically simulating a Nash game between the governments. We show that, for sufficiently low trade costs, the PHH is always dominated by the HME in the Nash case. Even if firms at early stages of trade liberalization are drawn to the small low tax economy, they eventually always relocate to the larger high-tax economy as trade is liberalized. This would seem to imply lower emissions. However, trade liberalization intensifies tax competition between the countries, leading to lower emission taxes in both countries. Global

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<sup>23</sup>We have also tried to cook-up extreme parameter values that would produce falling world emissions, but we have not succeeded.

All simulations are restricted to parameter values that give an economically meaningful solution and that satisfy second-order conditions.

emissions do therefore always increase in our simulations, even when firms move to the high-tax economy, and welfare decreases for deeper liberalization as tax competition forces down emission taxes, thereby increasing emissions and climate damages.

We finally simulate a case where taxes are set cooperatively by Nash bargaining. The larger country has a higher cooperatively set tax than the smaller country. Firms eventually relocate to the larger high-tax economy as trade is liberalized. However, in contrast to the non-cooperative case, tax competition is mitigated and, as a consequence, global emissions increase very little as trade is liberalized. Moreover, the level of global emissions is lower as compared to the Nash case. Moreover, the per capita welfare of the larger country increases monotonically as trade is liberalized. The per capita welfare of the smaller country falls with trade liberalization. These 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. They also underscore that the importance of international cooperation increases as trade becomes freer.

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 a pollution haven could be due to the fact that the larger market is large enough to attract firms in spite of its stricter environmental standards, e.g. in the case of U.S. and Mexico. Our results also suggest that trade liberalization with a large economy with low environmental standards, such as China, may be particularly troublesome for global emissions.

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