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TRADE, TRANSPORTATION AND THE ENVIRONMENT

Abstract

This paper analyzes the environmental impact of emissions related to trade and trans- portation. It is shown that transportation may in principle lower global emissions if the production sector is dirtier than the transport sector. The measure of a sector's dirtiness is related to the emissions taxes and the abatement efficiency within that sector. It is shown that a firm's abatement efficiency can be calculated from the emission-to-cost ratio times the emissions tax. Using Swedish data to rank 5-digit industries in terms of their dirtiness reveals that several production sectors have a higher dirtiness index than transportation does.

JEL Classification: N/A

Keywords: Emissions, Trade, Transportation

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This paper analyzes the environmental impact of emissions related to trade and transportation. It is shown that transportation may in principle lower global emissions if the production sector is dirtier than the transport sector. The measure of a sector's dirtiness is related to the emissions taxes and the abatement efficiency within that sector. It is shown that a firm's abatement efficiency can be calculated from the emission-to-cost ratio times the emissions tax. Using Swedish data to rank 5-digit industries in terms of their dirtiness reveals that several production sectors have a higher dirtiness index than transportation does.

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1 Introduction

The transport sector is a very significant greenhouse gas (GHG) emitter. It was responsible for approximately 23 % of global energy-related CO2 emissions (6.7 GtCO2) in 2010.[1] The figure is higher in many developed countries. In 2017, for example, transportation was responsible for about 29 percent of total GHG emissions in the US, and about 41 percent in California.[2] Reducing emissions from the transport sector has therefore been identified as very important for reducing global GHG emissions. Cristea et al. (2013) report that international transport is responsible for 33% of world trade-related emissions, and e.g. maritime shipment of goods (excluding bulk cargo) to and from Europe results in CO2-emissions comparable to the emissions of the 38 million passenger cars in Italy.[3] There have therefore been calls to consume locally produced goods, and suggestions that international trade may have to be reduced.

This paper shows how general equilibrium effects can overturn the common view regarding the environmental effects of transportation. I use a model with monopolistic competition for manufacturing production and I have perfect competition in the transport sector. Both

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[1] Sims et al. (2014)

[2] UnitedStatesEnvironmentalProtectionAgency (2019) and California Air Resources Board (2019)

[3] See for Transport and AISBL (2019).

transport services and production lead to environmental emissions, and both sectors engage in abatement. I find that trade and transportation may lead to lower global emissions than does domestic production when the production sector is dirtier, as defined by the model, than the transport sector. The paper also suggests a new measure for how environmentally harmful a specific sector is, related to that sector's emissions tax and the abatement efficiency of firms within it. An implication of this is that the oft-used measure of emissions per transported unit may not be the most relevant measure for the environmental effects of transportation, when general equilibrium effects are taken into account.

I show in this paper that the emissions-to-cost ratio, together with the emissions tax, can be used to calculate a firm's abatement efficiency. I use this to calculate a dirtiness index for 5-digit Swedish industries. Among the industries are two transport sectors: road transport of goods and rail transport of goods. The calculated dirtiness index reveals that road transport is less environmentally friendly than rail, but also that quite a few sectors (e.g. sugar production) have a higher index than both of these transport sectors. This implies that importing may actually lead to lower global emissions than domestic Swedish production in these sectors.

The literature analyzing the effects on international trade on the environment has largely focused on the risk that international trade makes it possible for firms to concentrate production in pollution havens - that is, countries with low environmental taxes or standards. While there is considerable theoretical support and intuitive appeal for the existence of pollution havens, they have been hard to identify empirically, and 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.[4] It has also been pointed out that trade encourages technological upgrading, firm selection, and abatement investments, which tend to decrease emissions (see e.g. Levinson (2009) and Forslid et al. (2018)). Finally, trade increases income, which in general tends to increase the demand for a clean environment.

The model in this paper incorporates neither pollution-haven effects nor technological upgrading. This isolates the environmental effects of international transportation caused by trade. The paper uses a general equilibrium trade model *à la* Dixit-Stigliz without any form of comparative advantage, or any asymmetric emissions taxes, that could lead to pollution-haven effects. However, the model does allow for endogenous abatement decisions by firms, a la Copeland and Taylor (2003). The main result is that international transportation may increase or decrease global environmental emissions depending on how dirty the transport sector is compared to other sectors, or more precisely depending on the abatement efficiency and emissions taxes in the sectors.

The paper also relates to a large research field in energy and environmental analysis that uses various decomposition methods to establish the most important driving forces of aggregate

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[4] 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).

emissions (see, e.g., Ang and Zhang (2000) for a survey). Decomposition methods are very useful for establishing which factors are the most important drivers of emissions. However, the present paper points out that a "ceteris paribus" may be misleading when one component of the decomposition is changed to assess the effects on aggregate emissions. The reason for this is that sectors are interdependent in general equilibrium. For example when less labor is used in one sector it will instead be used somewhere else, and this should be taken into account when assessing the effects on aggregate emissions.

Section 2 analyzes the model, and section 3 provides an illustrative empirical analysis using firm-level data from Sweden. Section 4, finally, presents conclusions.

2 The Model

This paper builds a monopolistic competition model with emissions, environmental taxes and endogenous abatement, where the transport sector is explicitly modelled.[5] I start with a model of a closed economy without transport costs, which will generate a benchmark to which the open economy with international transportation is compared. Note that even if the setting here refers to international trade, the countries in the trade model could equivalently be interpreted as regions within a country. Transportation would in that case refer to domestic transportation between the regions.

2.1 A closed economy without transport costs

The economy consists of a manufacturing sector M, and a service sector A. There is a single primary factor of production. This may be a composite factor but, for the sake of simplicity, I shall refer to it as labor (L). The M-sector is characterized by increasing returns and monopolistic competition. Production by firms in the M-sector generates emissions of a transboundary pollutant that is a pure public bad. The government levies a tax on pollution, and the revenues are used for an outside public good.[6] The A-sector produces a homogeneous good, and it operates under constant returns to scale and perfect competition. This sector does not cause any pollution. Consumers have CES-preferences over the differentiated varieties within the M-sector, and they have the utility function

$$U = C_M^{\mu} C_A^{1-\mu} - g(E), \tag{1}$$

where C_M is consumption of a CES-aggregate of differentiated good, and the function, $g(E)$, captures the effect of emissions such as climate damages. $g'(E) > 0$. Differentiated goods from

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[5] The model is essentially the same as the one in Forslid et al. (2017) extended with a polluting transport sector.

[6] This assumption is for analytical convenience. An alternative would be to redistribute tax revenues to consumers in a lump-sum fashion. This makes the model difficult to solve analytically, but numerical simulations of such a case reveal that qualitatively similar results are obtained.

the manufacturing sector enter the utility function through the index C_M, defined by

$$C_M = \left[\int_0^n c_i^{(\sigma-1)/\sigma} di \right]^{\sigma/(\sigma-1)} , \tag{2}$$

where n is the mass of varieties in the differentiated goods sector, c_i is the amount of variety i consumed by an individual, and $\sigma > 1$ is the elasticity of substitution between varieties.

Income consists of wage incomes:

$$Y = wL. \tag{3}$$

The demand for a variety i is

$$x_i = \frac{p_i^{-\sigma}}{P^{1-\sigma}} \mu Y, \tag{4}$$

where p_i is the consumer price of variety i, and

$$P \equiv \left(\int_0^n p_i^{1-\sigma} di \right)^{\frac{1}{1-\sigma}} \tag{5}$$

is the price index of manufacturing goods. All firms are symmetric in equilibrium, and I therefore drop subscript i from now on.

The unit factor requirement of the homogeneous A-sector good is one unit of labor, and since it is also chosen as numeraire, we have

$$p_A = w = 1, \tag{6}$$

w being the wage.

To capture emissions from manufacturing activity, I follow Copeland and Taylor (1994) and assume that each firm produces two outputs: a manufactured good (x) and emissions (e).[7] The government levies an emission tax (production tax). A firm can reduce the emissions by diverting a fraction θ of the primary factor, labor, away from the production of x. Firms pay a fixed cost, and the joint production of output and emissions is thereafter given by

$$x = (1 - \theta) \frac{l}{a}, \tag{7}$$

$$e = \varphi(\theta) \frac{l}{a}, \tag{8}$$

where l is labor used in the variable cost term, a is the labor input coefficient, and $0 \leq \theta \leq 1$ is the share of labor that is used in abatement. Firm-level emissions, given θ, are determined by

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

the abatement function

$$\varphi(\theta) \equiv (1-\theta)^{1/\alpha}, \tag{9}$$

which is characterized by $\varphi(0) = 1$, $\varphi(1) = 0$, $\varphi'(.) < 0$, and $0 < \alpha < 1$. $\frac{1}{\alpha}$ is a measure of the effectiveness of the abatement technology. Using (8) and (9) to substitute for θ in (7) yields

$$x = e^{\alpha}\left(\frac{l}{a}\right)^{1-\alpha} \tag{10}$$

from which the variable-cost function is derived. Substituting out θ with the fixed cost being sunk, gives the following cost function:

$$\Psi = \kappa a^{1-\alpha} t^{\alpha}(x+F) \tag{11}$$

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

A firm's demand for emissions (as input to production) is derived by applying Shephard's lemma to the cost function:

$$e = \alpha\kappa a^{1-\alpha} t^{\alpha-1}(x+F). \tag{12}$$

Profit maximization by a manufacturing firm leads to the producer and consumer price

$$p = \frac{\sigma}{\sigma-1}\kappa a^{1-\alpha} t^{\alpha}. \tag{13}$$

Free entry implies that the operating profits in the M-sector, $px - MC \cdot x$, must equal the fixed cost in equilibrium. From (13) price is a constant mark-up on the marginal cost , which yields the equilibrium scale of a firm

$$x = F(\sigma-1). \tag{14}$$

Substituting the firm's equilibrium output from (14) into (12) gives firm-level emissions in the M-sector:

$$e = \alpha\kappa a^{1-\alpha} t^{\alpha-1} F\sigma. \tag{15}$$

The expression shows how a higher emissions tax decreases firms' emissions.

2.1.1 Equilibrium

Demand for $M-$sector varieties equals the zero-profit production level from (14) in equilibrium:

$$F(\sigma-1) = \frac{p^{-\sigma}\mu Y}{P^{1-\sigma}}. \tag{16}$$

Using (16), (5), and (13) gives the equilibrium number (mass) of firms

$$n = \frac{\mu L}{\kappa a^{1-\alpha} t^{\alpha}\sigma F}, \tag{17}$$

which using (15) gives the economy-wide equilibrium emissions

$$E_{aut} \equiv ne = \frac{\alpha \mu L}{t}. \tag{18}$$

Emissions in a closed economy increase with the size of the economy and decrease with the environmental tax rate. They also decrease with the abatement efficiency in manufacturing production (with a decrease in α).

2.1.2 Welfare

The indirect utility function with a global pollutant is given by

$$V_{aut} = k\frac{w}{P^{\mu}} - g(E^{w}_{aut}), \tag{19}$$

where $k \equiv \mu^{\mu}\left(1-\mu\right)^{1-\mu}$.

Substituting (5), (13), (17), and (18) into (19) gives:

$$V_{aut} = \frac{(\mu L)^{\frac{\mu}{\sigma-1}}}{(\sigma F)^{\frac{\mu}{\sigma-1}}\left(\frac{\sigma}{\sigma-1}\right)^{\mu}\left(\kappa a^{1-\alpha}t^{\alpha}\right)^{\frac{\mu\sigma}{\sigma-1}}} - g\left(\frac{\alpha\mu(L_j+L_k)}{t}\right), \tag{20}$$

Utility increases in productivity $(1/a)$. For changes in country size, L, and the environmental tax rate (t) there is a trade-off between consumption gains and losses from increasing emissions. The welfare outcome of changes in these depends on the properties of the loss function g.

2.2 Two Trading Economies

I now turn to an open economy where there are two trading countries of different size, indexed by j and k.[8] Countries are otherwise symmetric. There are no trade costs in the A-sector, but international trade in the M-sector is subject to trade frictions as well as transport costs. The trade frictions are border formalities, standardization costs, and the like. The transport costs are associated with a transport sector that produces transport services and gives rise to environmental emissions.[9]

The transport sector, T, produces a homogeneous good (transport services), has free entry, and operates under perfect competition.[10] It is also subject to an emissions tax, t_T, that may differ from the emissions tax on production. Finally, the transport sector has access to a similar abatement technology as the M-sector, but with a sector-specific abatement efficiency $\frac{1}{\beta}$. Its cost function is given by

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[8] These could equivalently be interpreted as two regions within a country.

[9] Having both frictional trade costs and transport costs allows for an analysis of the effect of freer trade, while maintaining the polluting transport sector.

[10] This assumption is consistent with transportation being a fairly homogeneous good, and it is quite natural for, e.g., transport by road (trucks).

$$\Psi^T = \lambda {a_T}^{1-\beta} t_T^{\beta} x, \tag{21}$$

where $\lambda \equiv \beta^{-\beta}(1-\beta)^{(1-\beta)}$, and x is the quantity transported. This means that the marginal cost of transportation, c^T, is

$$c^T = \lambda {a_T}^{1-\beta} t_T^{\beta}. \tag{22}$$

Using Shephard's lemma on (21) gives emissions per transported unit, $\beta\lambda {a_T}^{1-\beta} t_T^{\beta-1}$, and the transport emissions for an exporting firm are

$$e_{jk}^T = \beta\lambda {a_T}^{1-\beta} t_T^{\beta-1} x_{jk}. \tag{23}$$

Trade frictions and transport costs constitute a wedge between the producer price, given by (13), and the consumer price in the foreign country. The iceberg trade friction implies that for one unit of good in market j to arrive in market k, $\tau_{jk} > 1$ units must be shipped. The trade frictions are assumed symmetric between markets $\tau_{jk} = \tau \ \forall \ j, k$. Goods sold in the domestic market are not subject to trade frictions or transport costs implying that $\tau_{jj} = \tau_{kk} = 1$, and $c_{jj}^T = c_{kk}^T = 0$. The consumer price of a good produced in country j and sold in country k is given by:

$$p_{jk}^c = \tau \left(\frac{\sigma}{\sigma - 1} \kappa a^{1-\alpha} t^{\alpha} + c_{jk}^T \right), \tag{24}$$

which includes the unit transport cost c_{jk}^T.

Free trade in the A-sector implies factor price equalization:

$$w_j = w_k = 1$$

The demand for a variety from country j is

$$x_j = \frac{p_j^{-\sigma}}{P_j^{1-\sigma}} Y_j + \frac{\phi (p_j + c^T)^{-\sigma}}{P_k^{1-\sigma}} Y_k, \tag{25}$$

where $\phi \equiv \tau^{1-\sigma} \in [0, 1]$ is a measure of the absence of trade frictions, $\phi = 0$ implies infinite frictions and $\phi = 1$ implies frictionless trade. Equilibrium is defined by the condition that equilibrium supply of a firm in each country, from (14), equals demand:

$$F(\sigma - 1) = \frac{p_j^{-\sigma}}{n_j p_j^{1-\sigma} + n_k \phi (p_k + c^T)^{1-\sigma}} \mu L_j + \frac{\phi \left(p_j + c^T\right)^{-\sigma}}{n_j \phi (p_j + c^T)^{1-\sigma} + n_k {p_k}^{1-\sigma}} \mu L_k, \tag{26}$$

$$F(\sigma - 1) = \frac{\phi \left(p_k + c^T\right)^{-\sigma}}{n_j p_j^{1-\sigma} + n_k \phi (p_k + c^T)^{1-\sigma}} \mu L_j + \frac{p_k^{-\sigma}}{n_j \phi (p_j + c^T)^{1-\sigma} + n_k {p_k}^{1-\sigma}} \mu L_k, \tag{27}$$

Using (13), (22), (26), (27) gives

$$\sigma\kappa a^{1-\alpha}t^{\alpha}F = \frac{1}{n_j + \phi\psi n_k}\mu L_j + \frac{\phi\psi^{\frac{\sigma}{\sigma-1}}}{\phi\psi n_j + n_k}\mu L_k \tag{28}$$

$$\sigma\kappa a^{1-\alpha}t^{\alpha}F = \frac{\phi\psi^{\frac{\sigma}{\sigma-1}}}{n_j + \phi\psi n_k}\mu L_j + \frac{1}{\phi\psi n_j + n_j}\mu L_k \tag{29}$$

where $\psi \equiv \left(1 + \frac{\sigma-1}{\sigma}\frac{\lambda}{\kappa}\frac{t_T^{\beta}}{t^{\alpha}}\frac{a_T^{1-\beta}}{a^{1-\alpha}}\right)^{1-\sigma} \in [0,1]$, is a measure of the "ease" of transportation (an inverse measure of the cost of transportation).

Using (28) and (29) to solve for n_j gives

$$n_j = \frac{\mu\left(1+\phi\psi^{\frac{\sigma}{\sigma-1}}\right)(L_j - \phi\psi L_k)}{\sigma\kappa a^{1-\alpha}t^{\alpha}F\left(1-\phi^2\psi^2\right)}, \tag{30}$$

and by symmetry

$$N \equiv n_j + n_k = \frac{\mu\left(1+\phi\psi^{\frac{\sigma}{\sigma-1}}\right)(L_j + L_k)}{\sigma\kappa a^{1-\alpha}t^{\alpha}F\left(1+\phi\psi\right)}, \tag{31}$$

where N is the global mass of manufacturing firms. The equation shows that the global mass of M-sector firms decreases with trade liberalization (a higher ϕ). That is because more trade implies that more consumer expenditures end up in the transport sector. The global mass of firms would be independent of ϕ, as in the standard Dixit-Stiglitz model, without the transport sector (for $\psi = 1$).

The model displays what Helpman and Krugman (1985) calls the "home market effect", which implies that firms disproportionately locate to the larger market to save on trade and transport costs. This effect is seen by first calculating the share of firms in region j, $s_n^j \equiv \frac{n_j}{n_j+n_k}$, which from (30) and (31) is given by:

$$s_n^j(\phi\psi) = s_L^j\frac{1-\frac{s_L^k}{s_L^j}\phi\psi}{(1-\phi\psi)}, \tag{32}$$

where $s_L^j \equiv \frac{L_j}{L_j+L_k}$. A disproportionate share of firms locate in the larger region since the term $\frac{1-\frac{s_L^k}{s_L^j}\phi\psi}{(1-\phi\psi)} > 1 \; iff \;\; s_L^j > s_L^k$. It is also seen that trade liberalization or lower transport costs mean that more firms relocate to the larger region since $\frac{\partial s_n^j(\phi\psi)}{\partial(\phi\psi)} = \frac{\left(s_L^j - s_L^k\right)}{(1-\phi\psi)^2} > 0 \; iff \;\; s_L^j > s_L^k$.[11]

The emissions generated by country j consist of emissions from local production plus those from the transport of its exports:

$$E_j = n_j e_j + n_j\beta\lambda {a_T}^{1-\beta}t_T^{\beta-1}x_{jk}. \tag{33}$$

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[11] The expression (32) also defines the sustainpoint, which is the level of trade freeness and transport ease at which all manufacturing firms are located in the larger region: $(\phi\psi)^{sust} = \frac{s_L^k}{s_L^j}$.

Global emissions under trade, $E^W_{trade} = E_j + E_k$, may now be calculated using (30), (15), (25), (13) and (33):

$$E^W_{trade} = \frac{\alpha\mu\left(L_j + L_k\right)}{\left(1+\phi\psi\right)t}\left(1+\phi\psi^{\frac{\sigma}{\sigma-1}}\left(1+\frac{\sigma-1}{\sigma}\frac{\beta {a_T}^{1-\beta}t_T^{\beta-1}}{\alpha a^{1-\alpha}t^{\alpha-1}}\right)\right). \tag{34}$$

Note that this expression from (18) may be written as

$$E^W_{trade} = E^W_{aut}\cdot\frac{\left(1+\phi\psi^{\frac{\sigma}{\sigma-1}}\left(1+\frac{\sigma-1}{\sigma}\frac{\beta {a_T}^{1-\beta}t_T^{\beta-1}}{\alpha a^{1-\alpha}t^{\alpha-1}}\right)\right)}{\left(1+\phi\psi\right)}. \tag{35}$$

From this follows that $E^W_{trade} \gtrless E^W_{aut}$ whenever $\left(1+\frac{\sigma-1}{\sigma}\frac{\beta {a_T}^{1-\beta}t_T^{\beta-1}}{\alpha a^{1-\alpha}t^{\alpha-1}}\right) \gtrless \psi^{\frac{1}{1-\sigma}} = \left(1+\frac{\sigma-1}{\sigma}\frac{\lambda}{\kappa}\frac{t_T^{\beta}}{t^{\alpha}}\frac{a_T^{1-\beta}}{a^{1-\alpha}}\right)$ so a critical condition for many comparative static exercises is whether $\frac{\beta {a_T}^{1-\beta}t_T^{\beta-1}}{\alpha a^{1-\alpha}t^{\alpha-1}} \gtrless \frac{\lambda}{\kappa}\frac{t_T^{\beta}}{t^{\alpha}}\frac{a_T^{1-\beta}}{a^{1-\alpha}}$. Using the definition of κ, and λ gives

PROPOSITION 1 $E^W_{trade} \gtrless E^W_{aut} \quad iff \quad \frac{\beta^{1+\beta}}{t_T(1-\beta)^{(1-\beta)}} \gtrless \frac{\alpha^{1+\alpha}}{t(1-\alpha)^{(1-\alpha)}}$.

Proof**.** In the text.

This implies that trade tends to lead to lower emissions when β is low compared to α (implying a higher abatement efficiency in transportation), and when the relative emissions tax on manufacturing, $\frac{t}{t_T}$, is low. The proposition is illustrated in Figure 1 that plots $\frac{t}{t_T} = \frac{\alpha^{1+\alpha}(1-\beta)^{(1-\beta)}}{\beta^{1+\beta}(1-\alpha)^{(1-\alpha)}} = \frac{\lambda}{\kappa}\frac{\alpha}{\beta}$ for different values of β holding α constant ($\alpha = 0.3$).[12] The area below the curve represents combinations of taxes and abatement efficiencies that imply that trade and transportation leads to lower global emissions. Trade will be beneficial for the environment at a sufficiently high tax on transportation. This result is interesting in the light of the discussion of how to tax international transportation, and it is notable that bunkerfuel (used by cargo ships and tankers) as well as air fuel are normally taxed at very low rates.

There are several interesting special cases: Symmetry where the abatement efficiency is equal in the transport sector and in the production sector, $\alpha = \beta$, and where emissions taxes are identical in the two sectors , $t = t_T$, gives

$$E^W_{trade} = E^W_{aut} = \frac{\alpha\mu(L_j + L_k)}{t}. \tag{36}$$

That is, global emissions from two trading countries are in this case the same as from two closed economies without trade and transportation. This is an important benchmark result, which is summarized in the following proposition:

PROPOSITION 2 *World emissions are unaffected by international trade and transportation when* $\alpha = \beta$ *and* $t = t_T$.

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[12] Thus, the figure is a slice from a 3-dimensional plot with α and β on the x- and y-axis.

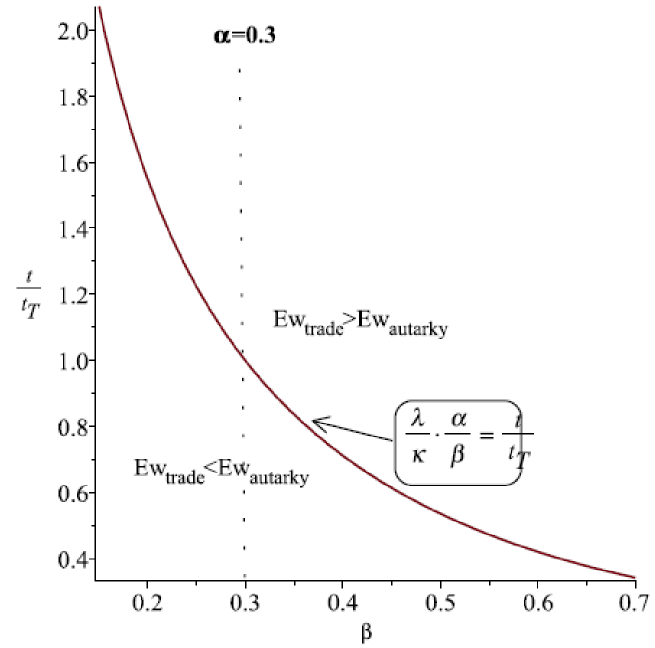

Figure 1: Parameter spaces for which trade and transportation leads to lower global emissions.

Proof. Proposition follows from (36).

Note also that global emissions in this case are independent of the unit-input coefficient in the transport sector, a_T, as well as of the relative size of countries. This implies that global emissions are unaffected by the division of primary resources among the sectors and countries. The reason for this is simply that all activities are equally dirty in these economies and the fact that more primary resources are directed towards transportation instead of production does not affect the level of global emissions. Naturally ,this result will not hold when the symmetry is broken.

Consider first the case when $\alpha \neq \beta$, but where the assumption that $t = t_T$ is maintained. The crucial expressions from Proposition 1, $\frac{\beta^{1+\beta}}{(1-\beta)^{(1-\beta)}}$ and $\frac{\alpha^{1+\alpha}}{(1-\alpha)^{(1-\alpha)}}$, are monotone and increasing in the interval $[0, \chi]$, where χ is close to one ($\chi \approx 0.95$). Proposition 1 then implies:

Proposition 3 $E^{W}_{trade} < (\geq)\ E^{Aut}$ *iff* $\beta < (\geq)\ \alpha$ *when* $t = t_T$, *and* $0 < \alpha, \beta < \chi$

Proof. In the text.

This is a stark result. International trade leads to higher global emissions when $\beta > \alpha$, but trade and transportation actually reduce global emissions when $\beta < \alpha$. The reason for this is again that all primary factors are employed in equilibrium. Some of these factors are employed in transportation when there is trade, and this reduces global emissions if the production of transport services is cleaner (has more efficient abatement technology) than the production of goods, and it increases global emissions when the transport sector is dirtier than the production of goods.

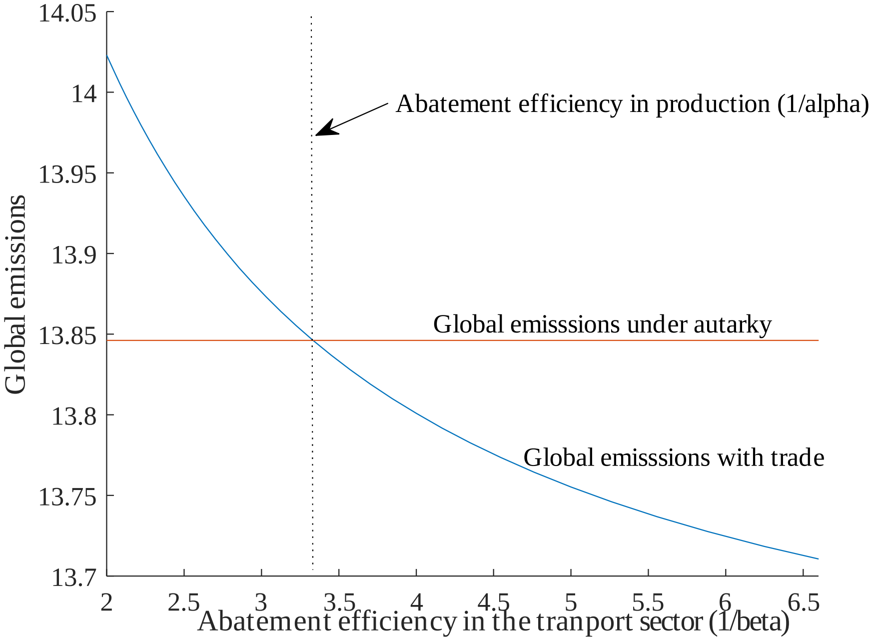

Figure 2: The abatement efficiency in the transport sector and global emissions.

Proposition 3 is illustrated in Figure 2, which plots global emissions under trade from (34) and global emissions under autarky from (36) for different levels of β when $\sigma = 5, \mu = 0.3, L_1 = 110, L_2 = 90$, $F = 1$, $a = 1.2$, $a_T = 1.2$, $t = 1.3$, $\tau = 1.2$, $\alpha = 0.3$. There is no transportation under autarky and therefore no transport-related emissions. This means that global emissions are unaffected by β in the autarky case, as shown by the horizontal line. However, global emissions are affected by the emissions intensity in the transport sector when there is trade. The vertical dotted line shows the level of abatement efficiency in production. The emissions under autarky and trade coincide where the curves cross. As consistent with Proposition 2, this is the point where the abatement efficiency is the same in transportation and production ($\alpha = \beta$). Global emissions are higher under trade to the left of the crossing point where the abatement efficiency is lower in the transport sector than in the production sector ($\beta > \alpha$). To the right of the crossing, global emissions are lower under trade and transportation. Here the abatement efficiency in the transport sector is higher than in the production sector ($\beta < \alpha$).

Finally, consider the case where the abatement technology is identical in the two sectors ($\alpha = \beta$) but where taxes differ ($t \neq t_T$). In this case we have from Proposition 1:

Proposition 4 $E^W_{trade} < (\geq)\ E^W_{aut}$ *iff* $t < (\geq)\ t_T$

Proof. In the text

With symmetric abatement technology in production and transportation, the tax rate determines which sector is cleaner. Trade and transportation will lead to lower global emissions when emissions taxes in the transport sector are higher than in the production sector (for equal abatement efficiencies), and the opposite holds when emissions taxes are lower in the transport sector.

2.2.1 Trade liberalization

The next issue is how lower trade frictions, such as fewer border formalities, affect emissions. Trade costs are quite substantial, and Anderson and Van Wincoop (2004), for instance, put the ad valorem cost at 170% on average for manufactured goods. The bulk of these costs consists of frictional barriers given the relatively low tariffs on manufacturing goods.

Trade liberalization in the form of lower frictional trade costs will from (35) amplify the difference between global emissions under trade and under autarky:

Proposition 5 $\frac{\partial E^W_{trade}}{\partial \phi} < (\geq)\ 0$ *for* $E^W_{trade} < (\geq)\ E^{Aut}$

Proof. In the text

Lower frictional trade costs means more trade, and this implies lower global emissions whenever the case is one where trade leads to lower global emissions.

2.2.2 Transport efficiency

The emissions per transported unit are from (23) given by

$$\frac{e^T}{x} = \beta \lambda {a_T}^{1-\beta} t^{\beta - 1}. \tag{37}$$

It is generally considered better for the environment if a good is transported by a means of transport that has a lower level of emissions per transported unit. From (37) this would mean that a transport sector with an identical production technology except for a lower input coefficient, a_T, is superior. However, as shown here this is not necessarily true when general equilibrium effects are taken into account. The reason for this seemingly counterintuitive result is that, even though transportation uses more resources (labor) and emits more when a_T is higher, it also draws more resources from the production sector that potentially emits even more per labor unit. Global emissions therefore decrease with a higher a_T when the transport sector is cleaner than the manufacturing sector.

Figure 3 and Figure 4 plot global emissions from (35) against a_T in two cases. First Figure 3 shows a case when the demand elasticity is low, $\sigma = 2$, implying that trade volumes are relatively insensitive to transport costs (all other parameters have the same values as above: $\mu = 0.3, L_1 = L_2 = 100, a = 1.2, t = 1.3, \tau = 1.2$ and $\alpha = 0.3$). We see that a higher input coefficient in the transport sector, a_T, indeed leads to higher global emissions when the transport sector is relatively dirty ($\beta > a$). However, a higher input coefficient in the transport sector, meaning higher emissions per transported unit, actually leads to lower global emissions when the transport sector is relatively clean ($\beta < a$). The reason for this is that, even though transportation uses more resources (labor) and emit more when a_T is higher, it also draws

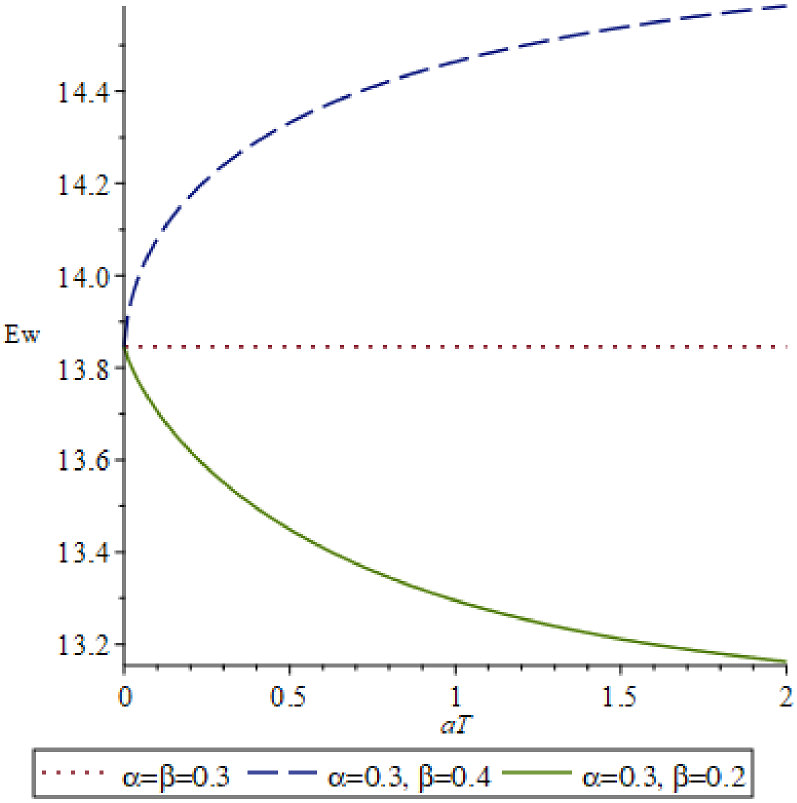

Figure 3: Global emissions and the efficiency of the transport sector ($\sigma = 2$).

more resources from the production sector, which emits even more per labor unit. In this case, therefore, global emissions decrease when a_T increases.

The picture is more complicated when the demand elasticity is high, $\sigma = 5$, and trade volumes react more strongly to changes in transport costs. The relationship between a_T and global emissions is hump-shaped, as shown in Figure 4. A higher a_T implies that transportation uses more resources per unit transported, but higher transport costs also means lower demand for imports, which decreases the number of traded units. The latter effect dominates except for low a_T. A higher a_T implies, to the right of the hump, that less labor is used in the transport sector, which means that global emissions fall if $\beta > \alpha$, and that global emissions increase if $\beta < \alpha$.

2.2.3 The abatement efficiency

The above analysis illustrates that a key factor for gauging the effects of transportation on the environment is the abatement efficiency of the transport sector (β) as compared to the abatement efficiency of the manufacturing (α). It is difficult to find a direct measure of this measure in data, but using the expression for firm-level emissions together with the cost function, (12) and (11), gives

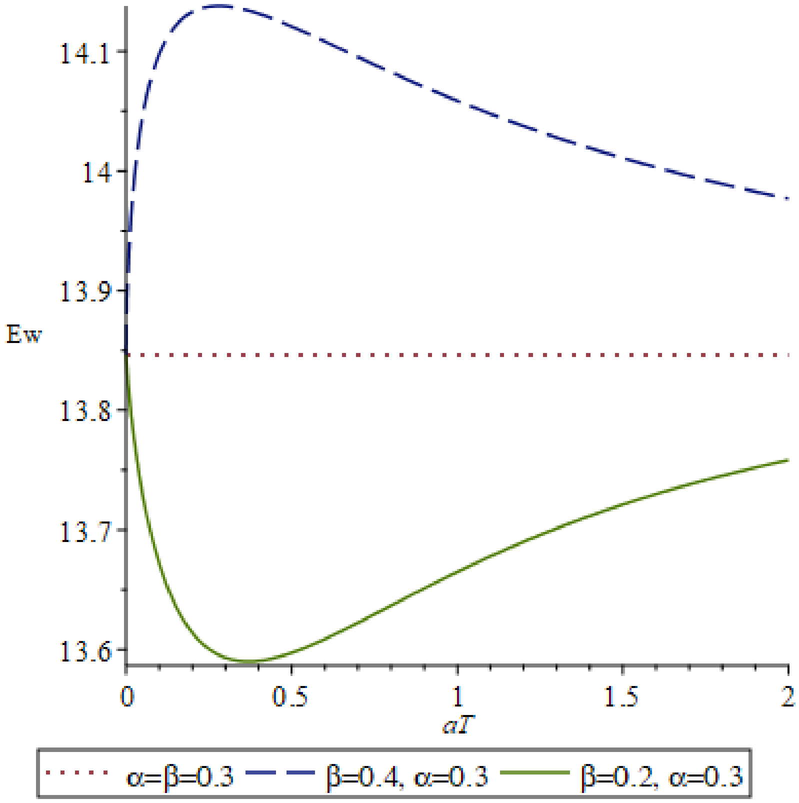

Figure 4: Global emissions and the efficiency of the transport sector ($\sigma = 5$).

$$\alpha = t \cdot \frac{e}{\Psi}, \tag{38}$$

where $\Psi = \kappa a^{1-\alpha} t^{\alpha}(x + F)$ is total costs of a manufacturing firm. The same calculation for the transport sector, using (21) and (23), gives

$$\beta = t_T \cdot \frac{e^T}{\Psi^T}, \tag{39}$$

where $\Psi^T = \lambda {a_T}^{1-\beta} t_T^{\beta} x$. Thus, the emissions-to-cost ratios $\frac{e}{\Psi}$ and $\frac{e^T}{\Psi^T}$ together with the emissions-tax rates, can be used to calculate a measure of the abatement efficiencies. I will use this below when comparing the "dirtiness" of different sectors in Swedish data.

2.3 Welfare

The welfare index of a country j in an environment with international trade is found by using (19) and substituting (30) and (24) into $V_{j,trade} = \frac{1}{\left(n_j p_j^{1-\sigma} + n_k (p_k + c^T)^{1-\sigma}\right)^{\frac{\mu}{1-\sigma}}} - g\left(E^W_{trade}\right)$. This gives

$$V_{j,trade} = \frac{\left(1 + \psi^{\frac{\sigma}{\sigma-1}}\right)^{\frac{\mu}{\sigma-1}} (\mu L_j)^{\frac{\mu}{\sigma-1}}}{(\sigma F)^{\frac{\mu}{\sigma-1}} \left(\kappa a^{1-\alpha} t^{\alpha}\right)^{\frac{\sigma\mu}{\sigma-1}} \left(\frac{\sigma}{\sigma-1}\right)^{\mu}} - g\left(E^W_{trade}\right) \tag{40}$$

We see, when comparing to (19), that the welfare from consumption in a trading country is higher by a constant factor $\left(1+\psi^{\frac{\sigma}{\sigma-1}}\right)^{\frac{\mu}{\sigma-1}}$. Thus, trade leads to higher welfare in any case where $E^W_{trade} \leq E^W_{aut}$. The welfare ranking of trade and autarky in cases where $E^W_{trade} > E^W_{aut}$ will depend on a trade-off between consumption gains and losses from emissions.

3 Some illustrative data

Here I compare the average "dirtiness," as defined in the theory above, of firms in 5-digit NACE-sectors in Sweden. The data, from Statistics Sweden, is for the years 2007 and 2008, and there are two goods-transport sectors among the sectors in the data: that by road (49410) and that by rail (49200). The data contains balance-sheet information such as output, costs, and the use of intermediates and energy. The data also contains information about which firms are affected by the European Union Emissions Trading System (EU-ETS). CO2 emissions at the plant level are calculated from the energy use of all plants with 10 or more employees. The energy statistics include all types of fuel use, from which CO2 emissions (kg) can be calculated using fuel-specific CO2-emission coefficients provided by Statistics Sweden. CO2 emissions are accurately calculated from fuel inputs since a technology for capturing CO2 was not operational in 2007 and 2008. The calculated plant-level emissions are aggregated to the firm level.

I first disregard any CO2-tax differences among sectors. This means that Proposition 3 applies, and that a comparison of sectors can be based solely on the abatement efficiency. The abatement efficiency of firms from (38) can be calculated from the ratio of CO2-emissions to costs times the CO2-tax. I calculate the emissions ratio for each firm, where costs are measured as the sum of wages, raw materials and intermediates. This gives 8439 observations over 4831 individual firms. The firm-level data is thereafter aggregated (averaged) to the 5-digit (NACE Rev.2) level, which gives observations for 305 sectors.[13] Figure 5 shows CO2 emissions (kg) per production costs (SEK) for the 5-digit sectors that have emissions ratios close to the two transport sectors in the data set. Goods transport by road and by rail are marked in the figure. The transport sectors are relatively dirty seen over the entire sample of sectors that have a median emissions ratio of 0.0023. However, many sectors also have far higher emissions per cost ratios than transportation does, with manufacturing of cement on top with a ratio of 0.92 followed by kraft pulp with a ratio of 0.58. This means there are quite a few cases where transportation gives lower emissions than production, given that CO2 taxes are the same for all firms and that the foreign production technology is not dirtier than the domestic one. One such example, from the figure, is cheese-manufacturing (sector 10511), which has a somewhat higher CO2-emissions-to-cost ratio than does rail transport (but a lower emissions ratio than road transport).

However, Swedish CO2-taxes were not identical for transportation and production.[14] A

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[13] Some 5-digit sectors have no observation at all, and thus drop out.

[14] A higher tax on transportation by itself will make transportation more attractive from an emissions per-

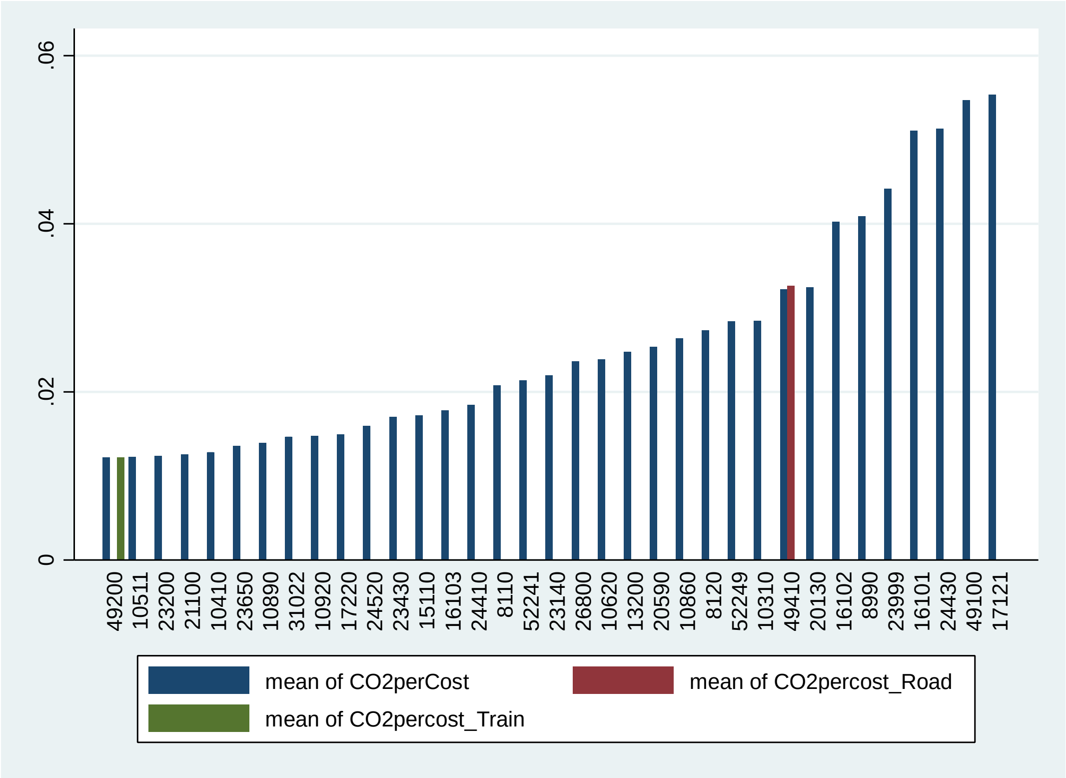

Figure 5: CO2 dirtiness ranking for equal emission taxes.

number of Swedish firms were also part of the European Union Emissions Trading System (EU-ETS), which affected their cost of emitting CO2, and the dirtiness ranking should be adjusted for this.

Sweden enacted a tax on carbon emissions in 1991. The tax was a general one, and it applied to all sectors, but manufacturing industries were granted a tax credit from the start, which meant that these sectors only paid 21 percent of the CO2-tax in 2007 and 2008 (Hammar and Åkerfeldt (2011)). Thus production had a considerably lower CO2-tax than the two transport sectors in our sample. The Swedish CO2-tax was 930 SEK/ton (101EUR/ton) and 1010SEK/ton (105EUR/ton) in 2007 and 2008 respectively.

The price of CO2-emissions in Sweden was also affected by the EU-ETS, of which Sweden is a member. The EU-ETS, which was set up in 2005, applied to over 700 of the most energy-intensive Swedish plants.[15] The first trading period of the EU-ETS (2005-2007) was a "learning-by-doing" phase. It started with the scheme's launch on 1 January 2005, and ended on 31 December 2007. The total of allocated emissions permits was higher than verified 2005 greenhouse-gas emissions, and the price of the emissions permits fell to essentially zero by January 2007 and onwards. The cap on allowances was reduced during the second phase of EU-ETS

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spective. However, taking the different tax rates into account as well, from (38) and (39), means that β is underestimated compared to α, which goes the other way.

[15] These firms are primarily in the energy-intensive industries of paper and pulp (17), coke and refined petroleum products (19), chemicals (20), nonmetallic mineral products (23), and basic metals (24).

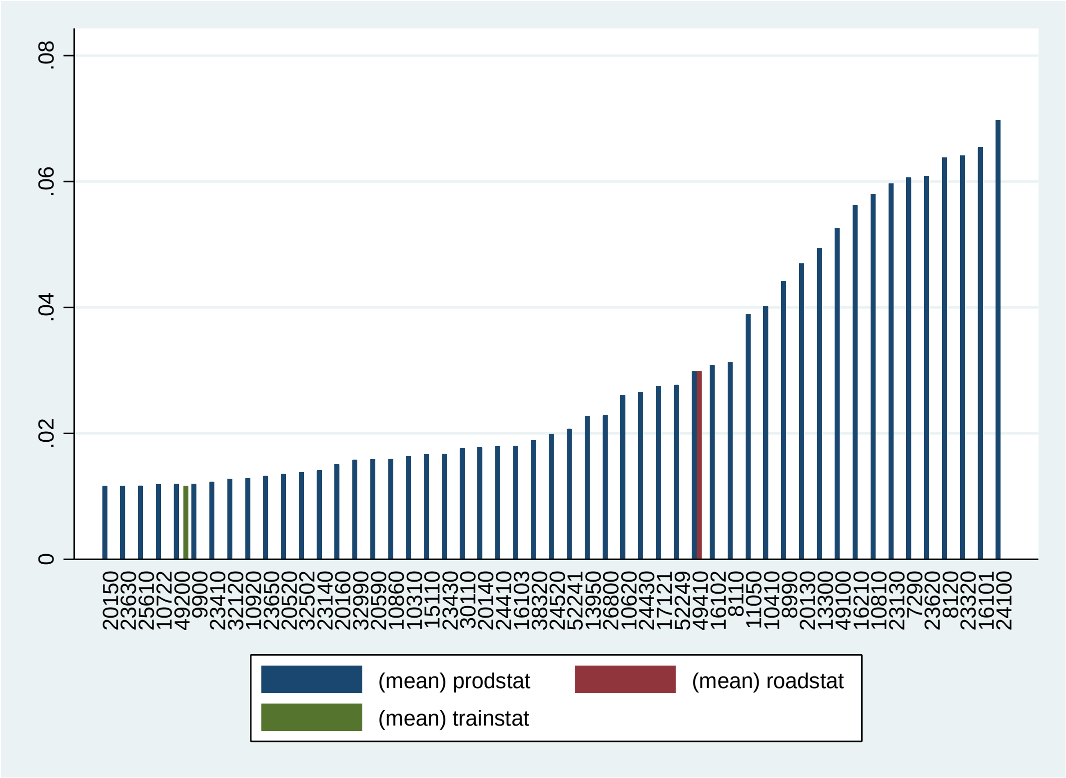

Figure 6: CO2 dirtiness ranking adjusted for emission taxes and EU-ETS.

(2008-2018). The price of allowances was initially considerably higher, but it declined from mid-2008, as the economic crisis led to emissions reductions that were greater than expected. I will use a price of zero for 2007 and an average price of 20 euros per ton for 2008. Finally, Swedish firms that were part of the EU-ETS in 2008 had a reduction in the Swedish CO2-tax, paying 15 percent of this tax.

Figure 6 ranks sectors in terms of "dirtiness," using the critical statistic from Proposition 1, taking tax differences as well as the effects of EU-ETS into account .[16] The figure is centered around the two transport sectors, leaving out the dirtiest and the cleanest sectors. It is still the case that road transport is dirtier than rail transport, and the dirtiest sectors, which are not shown in the figure, are again cement (0.82) followed by kraft pulp (0.58). The mean of the 305 sectors (0.018) lies between transport by rail (0.012) and transport by road (0.030). 59 sectors have a higher dirtiness index than rail transport, and 30 sectors have a higher index than road transport. Thus, there are a large number of cases where transportation is cleaner than production, and where trade and transportation therefore lead to lower CO2-emissions than does no trade, under the assumption that the foreign production is not dirtier than the domestic one. One example seen in the figure is sugar manufacturing (10810), which is dirtier than any of the transport sectors, and where Swedish imports may therefore reduce global CO2-emissions.

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[16] The figure shows the mean of the statistic for 2007 and 2008.

4 Conclusions

This paper stresses that general equilibrium effects should be taken into account when gauging the environmental effects of trade and transportation. It shows, using a standard trade model with monopolistic competition, that trade and transportation may lead to lower global emissions than domestic production does when the transport sector is cleaner than the production sector. The crucial measure of clean here relates to the emissions-tax rate and the abatement efficiency of firms in the sector. This new measure differs from commonly used indicators of how dirty a sector is, and it implies that emissions per transported unit may not be the relevant measure for how a particular means of transport affects global emissions. Instead it is here proposed that a tax-adjusted measure of emissions per resource usage should be used. I show that the abatement efficiency may be calculated from a firm's emissions-to-cost ratio adjusted for the emissions tax. Using this method, I calculate a "dirtiness" index of Swedish firms with respect to CO2-emissions. The measures are then aggregated to 5-digit industries. Two goods-transport sectors ares part of the sample: transport by road and transport by rail. The analysis shows that several sectors have a higher dirtiness index than transportation does, which implies that imports could create lower global CO2-emissions than local production in these sectors, as long as not the foreign production is not dirtier than the domestic one.

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