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The suboptimal nature of applying Pigouvian rates as border adjustments*

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ABSTRACT

We consider a North-South trade model with cross-border environmental damage where the North imports the relatively dirty good. The North sets domestic production taxes according to each industrys contribution to environmental degradation (Pigouvian taxes), but this exacerbates cross-border damages. It is well understood that a large economy in this situation can use border taxes to mitigate the damage, but a large economy also has an incentive to use trade policy to extract rents (Markusen, 1975). We formulate a model that neutralizes the rent-seeking incentives, through an endogenous transfer, to focus only on environmental incentives. We find that setting the North's import tariff at the Pigouvian rate is above the optimal, because it indirectly reduces the North's exports, favoring consumption of the dirty good in the South. Even in the case of full border tax adjustment, where the import tariff is partially canceled out by an export subsidy set at the Pigouvian rate for the export industry, trade is taxed too much. Considering the inherent general equilibrium nature of trade policy, the North's optimal border adjustment to mitigate the cross-border damage is a net import tariff set below the Pigouvian rate.

Keywords: climate policy, border tax adjustments, carbon leakage, trade and carbon taxes.

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1 Introduction

Faced with subglobal policy options to address climate change, border adjustments have become a key topic of research and debate. Interest in border adjustments has been driven by the observation that unilateral domestic policies (such as carbon taxes or cap and trade schemes) can stimulate emissions of carbon in unregulated countries. By distorting international prices, domestic carbon policy can create "carbon leakage," offsetting domestic reductions. In response, one possible recourse for a country that imports carbon intensive goods is to impose trade restrictions. These proposed border adjustments are often based on the domestic carbon tax and advertised as leveling the playing field for domestic industry. The justification follows the logic of a Pigouvian price instrument, which should be equalized across sources of environmental damage. In a critique of this Pigouvian logic, we draw on well established lessons from trade theory. Most directly we look to Markusen (1975) to develop intuition regarding the effects of tax and trade policy on cross-border externalities.[1] As noted in Copeland and Taylor (2005), economic intuition developed in a closed economy does not necessarily hold in a world with international trade. We use a simple general-equilibrium simulation model to illustrate the inherent inefficiency of setting the import tariff and, or, the export rebate at the domestic Pigouvian rate. We note that although we are motivated by the carbon leakage issue, the model used and the insights gained are applicable to a broad range of transboundary pollution problems.

We consider a conventional two-good North-South trade model with cross-border environmental damage where the North imports the relatively dirty good. The North sets domestic production taxes according to each industry's contribution to environmental degradation (Pigouvian taxes). Following Böhringer et al. (2010a), we include a hypothetical endogenous transfer payment in the model between regions to eliminate any strategic (i.e

[1] In a related paper, Yonezawa et al. (2012) extend Markusen (1975) to analytically prove a number of the results developed in this paper.

non-environmental) incentive that the North may have to use trade taxes to extract rents from the South. While Markusen (1975), Ludema and Wooton (1994) and Copeland (1996) have shown that optimal trade taxes may include a strategic component to exploit terms-of-trade (i.e. international prices), the inclusion of endogenous transfer payments removes this consideration from the determination of optimal trade taxes. Thus, we isolate the purely environmental incentives in setting an optimal trade tax. This innovation is consistent with international commitments to a cooperative trade equilibrium, while allowing for recourse related to transboundary environmental damage.

We demonstrate several important results with strong policy relevance. First, in the absence of an export policy, setting the North's import tariff at the Pigouvian rate is above the optimal tariff level, because it distorts consumption and production in both countries. While the tariff discourages the North's imports of the dirty good, moving the South to more production of the clean good, it indirectly encourages consumption of the dirty good in the South and production of the dirty good in the North.

Second, trade is still penalized too much under a policy where both import tariffs and export rebates are based on the Pigouvian rates, a policy referred to as *full* border tax adjustment in the literature. Although full border tax adjustment has a number of proponents in the economic literature (not to mention representatives of export firms seeking to avoid environmental taxes), such a policy is suboptimal. Given that an import tariff is equivalent to an export tax [Lerner symmetry–Lerner (1936)], only one trade instrument is necessary to achieve the optimal environmental tax on trade. Granted, the addition of the redundant trade instrument would be innocent if full border tax adjustment achieved efficiency, but this is not the case.[2] Full border tax adjustment, even when set at the Pigouvian rates, still

[2] In our simple general equilibrium there is, in fact, a redundant domestic instrument as well. Taxing both industries at their marginal environmental damage results in an optimal resource allocation (conditional on simultaneously setting trade taxes optimally), and this allocation could be achieved with a single (lower) tax on the dirtier industry. Using both instruments set at the Pigouvian rate, however, has the virtue of establishing a simple rule for achieving the proper domestic allocation. Our fundamental point is that this

fails to achieve the proper net trade tax. The North's optimal border adjustment to mitigate the cross-border damage (in the context of our simulations) is a *net* import tariff set below the Pigouvian rate.

Finally, we show that if the domestic production taxes are set optimally, the optimal level of the import tariff is independent of the level of the production taxes. This follows from the fact that at the optimum the trade instruments are only used to manipulate foreign production. If the domestic taxes are set suboptimally, however, the optimal level of the import tariff adjusts to attack both the foreign and domestic margins of distortion. Similarly, if the tariff is not set optimally, the mix of domestic taxes adjusts to attack both the foreign and domestic margins of distortion. An example of this is found in Böhringer et al. (2010a), where they consider the potential benefits of differential domestic carbon pricing as a remedy for leakage.

We proceed with the paper as follows: Section 2 reviews the literature on trade theory and carbon policy. Section 3 presents the model used in our analysis with results presented in Section 4. Section 5 offers concluding remarks.

2 Background and Literature

To begin our examination of policy reactions to cross border externalities it is useful to review a few fundamental lessons from trade theory. One can review these tenets in a good trade text that uses a general equilibrium approach [e.g., Markusen et al. (1995) or Bhagwati and Srinivasan (1983)]. We have already mentioned the important lesson of Lerner symmetry: an import tariff has the same general equilibrium effects as an export tax. In the context of our problem, if we have an environmentally motivated import tariff combined with an export subsidy, there will be offsetting effects.

rule does not apply to the trade instruments.

The second lesson we would like to emphasize is that production and consumption taxes have different effects in an open economy. With trade, a consumption tax on the imported good reduces imports but does not directly distort domestic production decisions. The only effect on domestic production must work through the terms of trade. The consumption tax reduces global demand for the imported good and as world prices fall domestic production falls. In fact, for a small open economy (facing fixed world prices), the consumption tax has no effect on domestic production. Similarly, because of trade opportunities, production taxes only indirectly affect consumption decisions through the terms of trade.

As a third lesson, tariffs (and export taxes) directly distort both production and consumption decisions. An import tariff favors the import competing industry because the relative price of the import good is above the international price, and consumers faced with these higher prices reduce their consumption of the imported good. Combining the second and third lessons there are specific combinations of policy instruments that yield equivalent general equilibrium effects. For example, an import tariff on good X combined with a production tax on good X has the same effect as a consumption tax on X. This type of interaction is a critical consideration in the context of finding appropriate policies to deal with cross border externalities.

The final lesson we would like to emphasize from trade theory is that the optimal tariff is positive. That is, countries can generally exploit their market power and extract rents from their trade partners. Clearly, for a country (of some size relative to the rest of the world) the marginal revenue from exports is below the world price. The policy authority can improve the terms of trade by marking up exports with an export tax (which we know is equivalent to using an import tariff to the same end). One country gains at the expense of another and global efficiency falls. This feature of open economy theory complicates the analysis of cross-border externalities as the optimal environmental policy is inherently entangled with strategic incentives to extract rents from other countries. We isolate strategic trade considerations from the problem of cross border externalities using an endogenous transfer, which results in an optimal tariff set to zero in the absence of cross border environmental damages.

Moving from general trade theory to the particular problem of climate change and international trade, it has been long recognized that any unilateral, subglobal climate policy will need to include carbon trade policy to address the problem of carbon leakage (Aldy et al., 2010). A number of papers have examined the effects of subglobal climate policies with and without border adjustments for carbon imports and exports (Babiker, 2005; Babiker and Rutherford, 2005; Fischer and Fox, 2009; Elliott et al., 2010; Böhringer et al., 2010b). While such studies have illuminated the economic and environmental impacts of various carbon trade policies such as import tariffs, export rebates and full border tax adjustment, limited attention has been paid to the optimal levels of those border measures. These papers have typically assumed that imported carbon is taxed at the same rate as domestic carbon, an assumption that we show to be suboptimal.

The consensus in the climate policy literature seems to be consistent with the theoretic discussion in Elliott et al. (2010). They show in a simple setting that full border tax adjustment effectively converts domestic production taxes into consumption taxes. Considering a situation where the environmentally-engaged North imports the relatively dirty good, a consumption tax is preferable to a production tax. Elliott et al. (2010) argue, however, that it may be difficult to impose a carbon-based consumption tax directly, so the same outcome can be achieved by applying production taxes combined with full border tax adjustment. Although we generally agree with this reasoning, we would point out that restricting trade policy instruments to have the same values as the domestic instruments eliminates our ability to affect foreign production independent of domestic production. We show that better outcomes can be achieved.

In the context of transboundary pollution in general, an older strand of literature considered optimal trade and environmental policies, notably Markusen (1975), Ludema and Wooton (1994), and Copeland (1996). A key area of focus in these studies is the extent to which strategic trade policy can be used to extract rents from other countries, a feature absent from our study due to the imposition of endogenous transfer payments (Böhringer et al., 2010a). Markusen (1975) lends some crucial insight, however, into the optimal setting of trade and production taxes. He shows that the optimal production tax follows the Pigouvian prescription, while the optimal tariff has two terms: a strategic term (exploiting terms-of-trade effects) and an environmental term (dependent on terms-of-trade effects). As we have eliminated the strategic aspects of trade, our focus is solely on the second environmental term. Crucially, this environmental term represents the Pigouvian rate adjusted by the impact of domestic imports on world prices which in turn affect foreign production.[3] The suboptimality of the Pigouvian prescription for trade taxes follows from the fact that the optimal trade tax must be adjusted for these trade effects. To solidify the intuition, consider the following simple thought experiment: consider the choice of an optimal carbon tariff from the perspective of a small open economy. By definition, this small open economy does not affect world prices. As the only rationale for a carbon import tariff is to alter world production, and the only mechanism to affect world production is via price changes, the optimal carbon tariff for the small open economy is zero. This result follows directly from Markusen (1975, p. 20)

3 Model

To illustrate the suboptimal nature of applying Pigouvian tax rates on trade flows, we investigate the problem in a familiar and relatively transparent trade model. The formulation is a

[3]Golombek et al. (1995) examines the optimal design of subglobal carbon taxes in a world that includes international trade. Though they do not explicitly make the connection with Markusen (1975), they note that the optimal tariff depends on the home country's impact on global prices and thus global production.

standard two-good two-country Heckscher-Ohlin model elaborated to consider a cross-border externality. The Pigouvian prescription is given the best chance of success by eliminating many real-world complexities. The environmental damage from each good is proportional to output and the same across countries. Technologies are identical, and there are no intermediate goods. Thus, the environmental damage associated with a given trade flow is well specified. Further, we neutralize beggar-thy-neighbor incentives by including an endogenous transfer payment between countries. The simplicity of our setting allows us to generate a relatively strong statement that supports the Pigouvian prescription for domestic taxes, but not for trade taxes.

Let us first define the symbolic elements of our model in Table 1. Each endogenous variable is associated with an equation representing an equilibrium condition. Production and trade activities are associated with zero profit and arbitrage conditions, and prices are associated with market clearance conditions. Technologies and preferences are Cobb-Douglas and represented by direct specification of dual cost and expenditure functions.[4]

3.1 Production and Trade

Each region has the same constant-returns production technology, and perfect competition drives profits to zero. Output is determined by a condition that sets the net-of-tax price equal to the unit cost function. For good X production we have the following zero profit conditions for the North and the South:

$$\begin{aligned} (1 - t_X) PX_N &= w_N^{1-\beta} r_N^{\beta} \\ PX_S &= w_S^{1-\beta} r_S^{\beta}. \end{aligned} \tag{1}$$

[4] The formulation follows the conventions established by Rutherford (1995) and Rutherford (1999) for formulating Arrow-Debreu general equilibrium models as nonlinear Mixed Complementarity Problems (MCP).

Table 1: Symbolic Definitions

Sets		
$r \in \{N, S\}$	Regions - North and South	
Variables		**Associated Equation**
X_r	Output of X in r	(1)
Y_r	Output of Y in r	(2)
MX_r	Imports of X by r ($MX_S = 0$)	(3)
MY_r	Imports of Y by r ($MY_N = 0$)	(4)
U_r	Welfare in r	(5)
PX_r	Consumer Price of X in r	(6)
PY_r	Consumer Price of Y in r	(7)
w_r	Price of labor in r	(8)
r_r	Price of capital in r	(9)
PE	Marginal environmental valuation (N only)	(10)
P_r	True-cost-of-living index in r	(11)
RA_r	Representative agent income in r	(12)
T	International transfer payment (N to S)	(13)
Policy Instruments (North only)		
t_X	Production tax on good X	
t_Y	Production tax on good Y	
τ	Import tariff	
σ	Export subsidy	
Parameters		
$\bar{L}_r = \{9, 11\}$	Endowment of labor in r	
$\bar{K}_r = \{11, 9\}$	Endowment of capital in r	
$\phi_X = 0.2$	Proportional environmental damage from X	
$\phi_Y = 0.02$	Proportional environmental damage from Y	
$\alpha = 0.5$	Value share of X in private consumption	
$\beta = 0.4$	Value share of K in X production	
$\gamma = 0.6$	Value share of K in Y production	
$\delta = 0.2$	Value share of the environment in North's Utility	
$\bar{E} = 9.4$	Environmental endowment	

We have a similar set of conditions associated with good Y production:

$$
\begin{aligned}
(1 - t_Y)PY_N &= w_N^{1-\gamma} r_N^{\gamma} \\
PY_S &= w_S^{1-\gamma} r_S^{\gamma}.
\end{aligned}
\tag{2}
$$

Trade volumes are determined by arbitrage conditions. We only consider equilibria where the North imports X, the relatively dirty good. (Thus $MX_S = MY_N = 0$.) The North's imports, MX_N, will adjust to satisfy equality between the net-of-tariff price of X in the North and the price in the South:

$$
(1 - \tau)PX_N = PX_S. \tag{3}
$$

A similar arbitrage condition determines the South's imports, MY_S, where the subsidy is applied to the gross price of Y in the North:

$$
PY_S = (1 - \sigma)PY_N. \tag{4}
$$

3.2 Preferences

The representative households in each region share the same preferences over private consumption of X and Y, but we include a preference for environmental services in the North. Consistent with utility maximization, the true-cost-of-living index equals the unit expenditure function in each region:

$$
\begin{aligned}
P_N &= \left[PX_N^{\alpha} PY_N^{1-\alpha}\right]^{1-\delta} PE^{\delta} \\
P_S &= PX_S^{\alpha} PY_S^{1-\alpha}.
\end{aligned}
\tag{5}
$$

3.3 Market Clearance

For each of the prices that appear in the dual specification of preferences and technologies we need a market clearance condition. In general, supply and demand functions are recovered by applying the envelope theorem to the above conditions scaled by their respective activity levels. For commodity X we have:

$$\begin{aligned} X_N + MX_N &= \frac{\alpha(1-\delta)P_N U_N}{PX_N} \\ X_S - MX_N &= \frac{\alpha P_S U_S}{PX_S}; \end{aligned} \tag{6}$$

and for commodity Y we have:

$$\begin{aligned} Y_N - MY_S &= \frac{(1-\alpha)(1-\delta)P_N U_N}{PY_N} \\ Y_S + MY_S &= \frac{(1-\alpha)P_S U_S}{PY_S}. \end{aligned} \tag{7}$$

Determining the wage is the market for labor in each region;

$$\bar{L}_r = (1-\beta)X_r \left(\frac{w_r}{r_r}\right)^{-\beta} + (1-\gamma)Y_r \left(\frac{w_r}{r_r}\right)^{-\gamma}. \tag{8}$$

Determining the return to capital is the market for capital in each region;

$$\bar{K}_r = \beta X_r \left(\frac{w_r}{r_r}\right)^{1-\beta} + \gamma Y_r \left(\frac{w_r}{r_r}\right)^{1-\gamma}. \tag{9}$$

We also represent a market clearance condition for the environment, which determines the relative value of a unit of the environment in the North. The environment is directly consumed by the North, but it is also used in production in proportion to output from each region (although producers bear no costs related to using the environment). The market clearance condition is as follows:

$$\bar{E} = \frac{\delta P_N U_N}{PE} + \phi_X \sum_r X_r + \phi_Y \sum_r Y_r. \tag{10}$$

In this way the consumer in the North is competing with producers for environmental services, and PE indicates their marginal valuation.

3.4 Welfare and Income

Closing the model, we reconcile income with expenditures. In equilibrium, the level of utility equals income scaled by the true-cost-of-living index:

$$U_r = \frac{RA_r}{P_r}. \tag{11}$$

Income includes factor payments, transfers, and—for the North—we must account for net tax revenues and environmental services.

$$\begin{aligned} RA_S &= w_S \bar{L}_S + r_S \bar{K}_S + P_S T \\ RA_N &= w_N \bar{L}_N + r_N \bar{K}_N - P_S T \\ &+ PE \left(\bar{E} - \phi_X \sum_r X_r - \phi_Y \sum_r Y_r \right) \\ &+ t_x PX_N X_N + t_y PY_N Y_N \\ &+ \tau PX_N MX_N - \sigma PY_N MY_S. \end{aligned} \tag{12}$$

The environment term represents the nominal value of environmental services. It is composed of the value of the endowment less the value of the services used in production, which producers do not pay for. This is the source of the initial distortion. The first best free-trade equilibrium could be achieved by making producers pay for these services.[5]

The transfer payment, T, neutralizes any beggar-thy-neighbor benefits that the North may get from the use of policy instruments. The transfer is set such that the South must be made at least as well off as in the benchmark. Let $\bar{U}_S$ indicate the benchmark level of welfare in the South. The transfer is then determined by the following complementarity constraint:

$$U_S - \bar{U}_S \geq 0; \quad T \geq 0; \quad T\left(U_S - \bar{U}_S\right) = 0. \tag{13}$$

Thus if the North's tax and trade policies improve welfare in the South the transfer is zero, but if the policies indicate a shifting of burden to the South, the transfer is set at a value sufficient to return the South to the original level of welfare. In Section 4 we show that this effectively neutralizes the North's market-power incentive to raise trade barriers.

3.5 Policy Environment

We now turn to the policy instruments that the North can use to correct the unpriced externality associated with the use of the environmental input by both the North and the South. We consider four potential policy instruments for the North: domestic production taxes denoted t_X and t_Y, an import tariff τ (on good X), and an export subsidy σ (on good Y). To focus on the optimal selection of the trade instruments, production taxes are fixed at the Pigouvian rates unless stated otherwise:

$$t_X = \phi_X \frac{PE}{PX_N} \tag{14}$$

[5] The same first best equilibrium could be achieved if the North had a full set of Pigouvian tax instruments. That is, if the North were able to tax firms in the South as well as the North. A set of global taxes on X production set at $\phi_X PE/PX_r$ and on Y production set at $\phi_Y PE/PY_r$ achieves the first best free-trade equilibrium.

and

$$t_Y = \phi_Y \frac{PE}{PY_N}. \tag{15}$$

If the North only implements domestic production taxes, environmental damage will be mitigated as resources are reallocated toward the cleaner good, but these gains are partially offset by the increased incentive for the foreign firms to increase production of the dirtier good. In the absence of global cooperation on environmental policy, the remaining instruments available to the North are trade distortions.

Given the Pigouvian tax rates on production above, the North wishes to optimally set the import tariff τ and export subsidy σ considering the full general equilibrium response. We model this decision numerically as a non-linear program (NLP) that maximizes utility of the North subject to the general equilibrium constraints, (1) through (15). This is often called a Mathematical Programming with Equilibrium Constraints (MPEC) in the literature, where the choice variables are the policy instruments, τ and σ.

Prior to moving into the simulations it is useful to consider how the policy instruments interact to alter relative prices. To simplify the notation, let c_{ir} indicate the unit cost (marginal cost) of industry $i \in \{X, Y\}$ in region r.[6] Combining equations (1) through (4) into a set of relative price relationships we have

$$\frac{c_{XS}}{c_{YS}} = \frac{PX_S}{PY_S} = \frac{(1-\tau)PX_N}{(1-\sigma)PY_N} = \frac{(1-\tau)(1-t_Y)c_{XN}}{(1-\sigma)(1-t_X)c_{YN}}. \tag{16}$$

A number of insights are revealed in (16). First, we can see that the North does not possess any policy instruments to alter relative consumer prices and producer prices in the South. Any policy instrument that affects relative prices for producers in the South will also affect relative prices for consumers in the South. Second, we can see Lerner symmetry in that σ and τ will counteract each other. Finally, full border tax adjustment ($\tau = t_X$ and $\sigma = t_Y$)

[6] Unit costs, c_{ir}, are given by the right-hand side of (1) and (2).

eliminates the production side effects. Domestic and foreign producers operate according to the same relative prices. As Elliott et al. (2010) argue, full border tax adjustment transforms the domestic production taxes into consumption taxes. This is informative to our thesis in that applying the Pigouvian rates means that we cannot manipulate foreign relative prices independently of domestic producer prices. However, one might ask, is this necessarily consistent with optimal policy? In fact, we show that having the latitude to set environmental trade taxes independent of domestic taxes does improve outcomes.

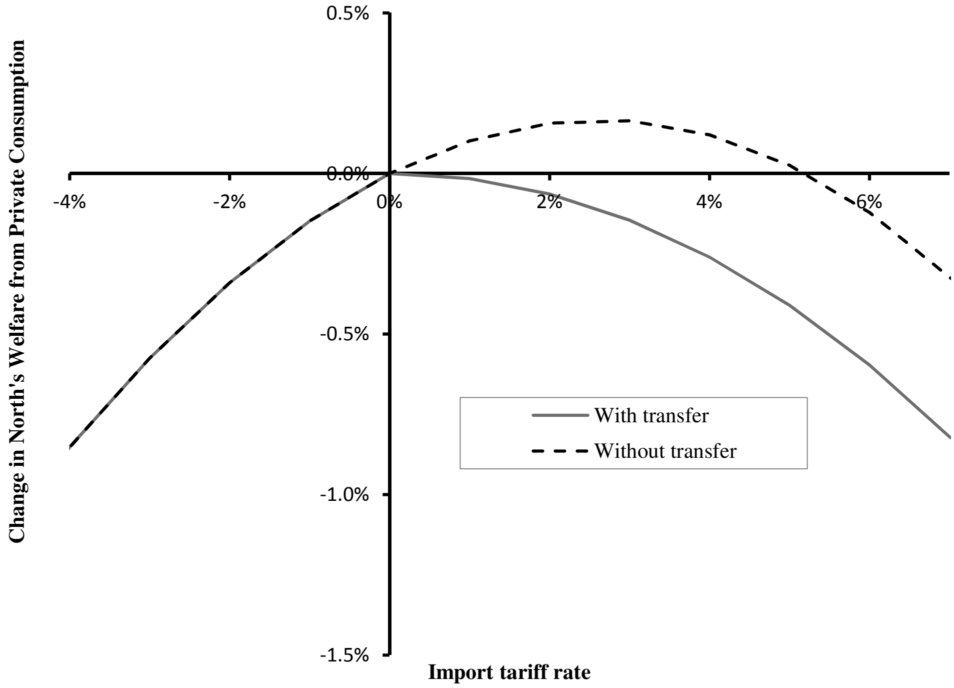
4 Results

In this section, we present a series of simulation results that illustrate the interactions of Pigouvian production taxes and trade instruments. Table 1, in the previous section, shows the central parameter values used in these exercises. The parameters values are illustrative, and we emphasize the qualitative results over the quantitative results. We begin by examining the importance of the transfer constraint (13), which prevents the North from using trade policy to extract rents from the South. Second, we examine the optimal trade policy of the North, specifically comparing the optimal trade taxes with the Pigouvian levels. Finally, we demonstrate that if domestic policy is set optimally, selecting the optimal trade policy can be considered to be independent.

4.1 Neutralizing strategic incentives to extract rents

Böhringer et al. (2010a) use an endogenous transfer to isolate the environmental, as opposed to strategic, incentives for countries to impose differential carbon taxes on domestic industries as a response to carbon leakage. We use the same concept to explore the optimal border adjustment in isolation from strategic trade incentives. In Figure 1 we illustrate how the transfer alters the North's incentive to extract rents through trade policy. We plot the

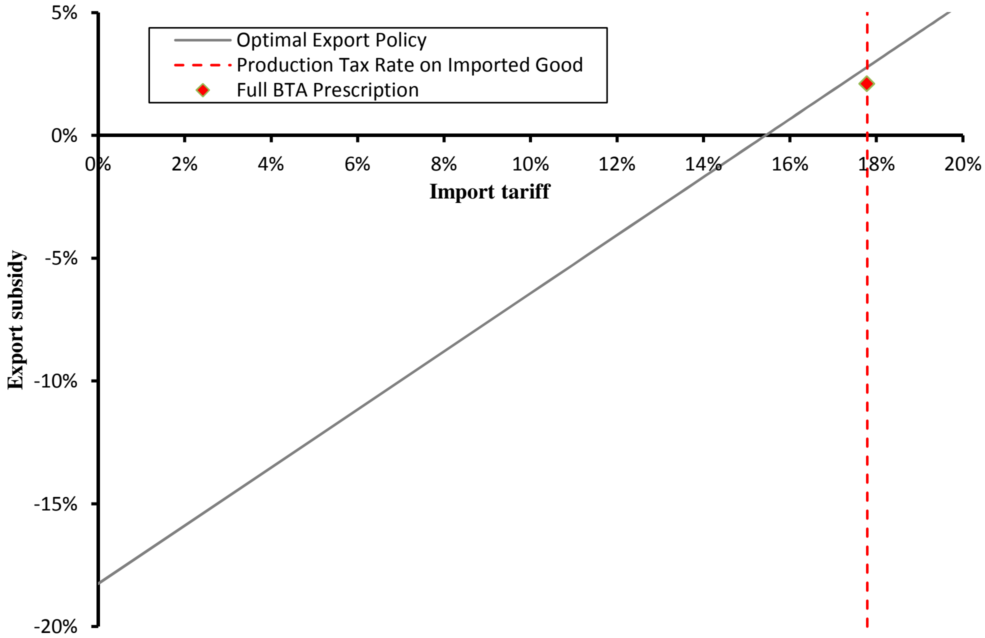
Figure 1: Strategic trade-policy incentives and the transfer



change in the North's welfare from private consumption (of X and Y) as a function of the tariff rate.[7] Considering only welfare from private consumption yields a clean index that is not confounded by environmental benefits. When the transfer is not included (dashed line) the North has the typical strategic incentive to impose a positive optimal tariff. When the transfer constraint is included, however, the optimal tariff is zero. At negative tariff rates the transfer constraint is slack and the welfare effects are identical to the case without the constraint, but at positive tariff rates, rents are being extracted from the South and the transfer is active. By ensuring that the South is returned to $\bar{U}_S$ through the transfer, the North faces only the global efficiency loss generated by the tariff and is unable to capture any rents from the South.

[7]The contribution of environmental services is separable, so we can measure subutility as a function of consumption of the private goods: $\tilde{U}_N(X,Y) = A(X_N + MX_N)^{\alpha}(Y_N - MY_S)^{1-\alpha}$ (where A is a constant). This gives us a clean metric for evaluating the strategic incentive, independent of the environmental externality.

Figure 2: Policy combinations that achieve the optimal environmental tax on trade



In the following simulations we include the transfer constraint, and we measure the North's welfare inclusive of environmental services. In this setting, trade policy instruments can be used to alter environmental outcomes, but there is no strategic incentive to extract rents. This allows us to focus on the setting of the optimal trade policy purely from the perspective of the transboundary externality.

4.2 Optimal trade policy

We now consider how the North should set its optimal trade policy in terms of the import tariff τ and export subsidy σ. Establishing the Pigouvian rates for the domestic production taxes endogenously by (14) and (15) we solve for the optimal $\sigma = \sigma^*$ at given levels for τ. Figure 2 plots the solution σ^* as a function of τ.

Figure 2 reveals three key points. First, there exists a trade policy that is welfare improving. If τ is set to zero, the optimal export subsidy is negative (an export tax). In our simulation the value of the subsidy is $\sigma^*|_{\tau=0} = -18.3\%$ (where the numeric values of the domestic taxes are $t_X = 17.8\%$, and $t_Y = 2.1\%$). Furthermore, Lerner symmetry indicates that the same optimal solution can be achieved from combinations of import tariffs and export subsidies at each point on the line (e.g., on the horizontal axis at $\sigma^* = 0$ the optimal tariff is $\tau = 15.4\%$). This follows directly from equation (16); at the optimum the terms of trade are distorted by $(1-\tau)/(1-\sigma^*) = k$, a constant. From our numeric optimization we find that $k = 1/1.183 = 0.845$, which allows us to recover an algebraic representation of the optimal solutions plotted in Figure 2:

$$\sigma^* = 1.183\tau - 0.183 \tag{17}$$

The optimal export subsidy has a positive correlation with the tariff rate and the relationship is linear [consistent with achieving the optimal set of relative prices in (16)].

The second key point demonstrated in Figure 2 is that the Pigouvian prescription is suboptimal for any single trade instrument. On the vertical axis $\tau = 0$ and $\sigma^* = -18.3\%$ which is not equal to $t_Y = 2.1\%$; and on the horizontal axis $\tau = 15.4\%$ which is not equal to $t_X = 17.8\%$ (at $\sigma^* = 0$).[8]

The final point to take away from Figure 2 is that full border tax adjustment at the Pigouvian rates is also suboptimal. When both instruments are set at the Pigouvian rates ($\tau = t_X = 17.8\%$ and $\sigma = t_Y = 2.1\%$) the subsidy is about 24% below the optimal. Relative to applying a full border tax adjustment policy, welfare can be improved by either increasing the subsidy or decreasing the tariff, implying trade is over taxed under full border tax adjustment. Our simulations indicate that a *net* import tariff set below the Pigouvian

[8]This point suggests that the problem of addressing carbon leakage is not simply a carbon measurement problem. Even if information on the carbon content from trade flows was comprehensively gathered and the carbon footprint properly determined (Peters, 2008; Peters and Hertwich, 2008), the optimal rate at which that carbon should be taxed is not as simple as applying Pigouvian prescriptions.

tax rate on the dirty good is optimal.

The lesson from the above exercise is that the optimal environmental trade policy is *not* the Pigouvian prescription. We can build additional intuition behind this result by reexamining the environmental term in the optimal tariff suggested by Markusen (1975). This environmental term can be summarized as follows: (Pigouvian-rate)$\frac{dX_S}{dPX_S}\frac{dPX_S}{dMX_N}$.[9] The Pigouvian rate gives us the marginal valuation of the environment, but this has to be scaled by two terms: (1) the ability of the North to influence prices in the South by changing import volumes, and (2) the impact of that price change on production in the South. The first scale factor, $\frac{dPX_S}{dMX_N}$, is directly related to the North's market power. As the relative size of the North approaches zero this term must also approach zero. The second term, $\frac{dX_S}{dPX_S}$, is dependent on the technology in the South. Given that the environmental trade tax must work through this chain, the Pigouvian rate applied at the border is too aggressive, as shown above.

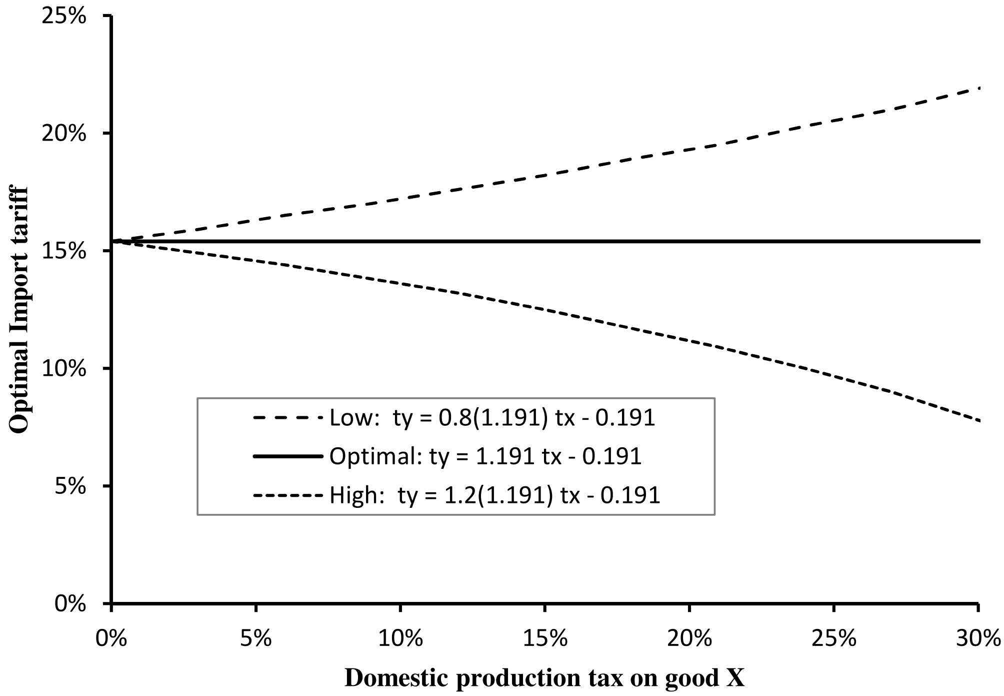
4.3 Trade and Domestic Policy Interactions

We now consider how optimal trade policy interacts with domestic policy. In the previous sections, the production taxes were set at the Pigouvian rates, an assumption we relax for the following exercise. To simplify our presentation we maintain $\sigma = 0$, which is innocent given Lerner symmetry, which implies optimizing over τ is sufficient to achieve the optimal trade policy. Figure 3 plots the optimal $\tau = \tau^*$ as a function of the level of t_X under three different assumptions about the relationship between t_X and t_Y.

If we set $\tau = 15.4\%$ (the optimal tariff value from our previous exercise) we can find the optimal relative values of t_X and t_Y. Numerically, we find that utility is maximized at

[9]In Markusen (1975) environmental damage only comes from one of the goods, so we do not consider good Y at this point of the discussion.

Figure 3: Independence of optimal trade policy at the optimal domestic mix



$(1 - t_X)/(1 - t_Y) = 1/1.191$. Thus, optimal domestic production is achieved when

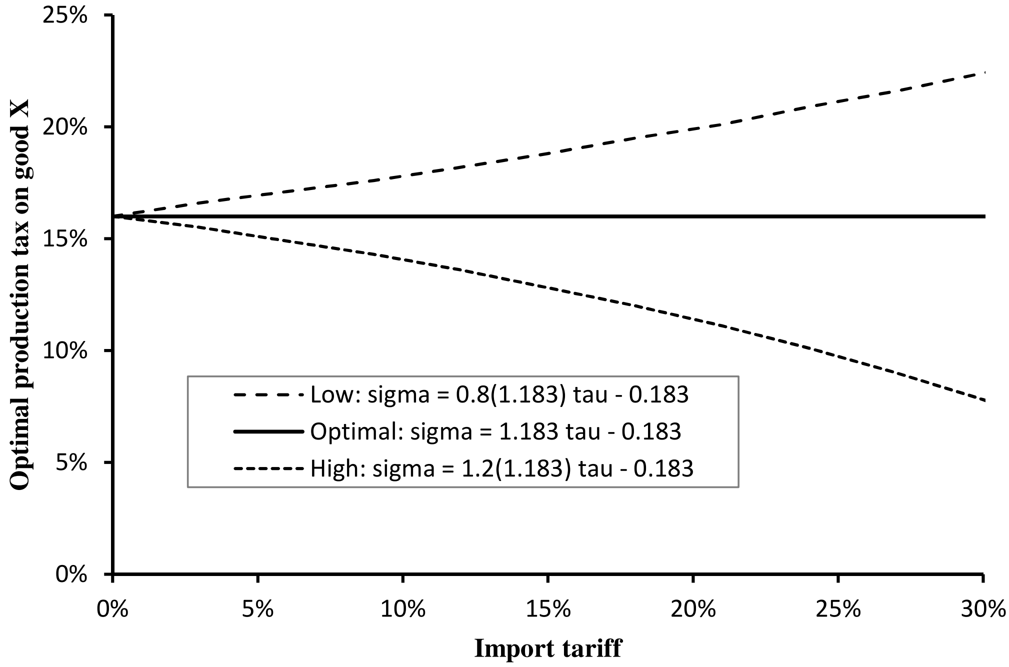
$$t_Y = 1.191 t_X - 0.191. \tag{18}$$

This confirms that our setting of domestic taxes according to the Pigouvian rates (14) and (15) in the previous exercise was, in fact, optimal, because the Pigouvian rates $t_X = 17.8\%$ and $t_Y = 2.1\%$ satisfy (18). In Figure 3 as long as the domestic taxes are set according to (18), the optimal tariff $\tau^* = 15.4\%$. That is, as long as the relative domestic taxes are set optimally, the value of τ^* is independent of the level of t_X.

Now consider setting the relative domestic taxes suboptimally. If t_Y is set 20% too low relative to t_x ($t_Y = 0.8(1.191)t_X - 0.191$) then domestic resources are over allocated to Y production. The optimal trade response is to escalate the tariff above 15.4%, because this has the effect of drawing domestic resources out of Y production. By the same logic when t_Y is too high relative to t_X the optimal tariff will be below 15.4%, which pulls resources into Y production. When domestic policy is set suboptimally, the optimal tariff acts to manipulate production on both the foreign and domestic margins. These effects are shown in Figure 3 (dashed lines). The reason that the curves diverge is that the distortions escalate at higher t_X values. One could imagine a situation where t_X is given by the Pigouvian rate for X, and $\tau^* = t_X$ is the optimal response to incorrectly setting t_Y below the Pigouvian rate for Y.

We can perform a similar exercise where we consider the optimal domestic tax response to suboptimal trade policy. Figure 4 plots the optimal $t_X = t_X^*$ as a function of τ under three different assumptions about the relationship between τ and σ. The intuition follows that if σ is set too low (so trade is over taxed) the optimal production tax t_X is higher to encourage production of the export good which stimulates trade. Conversely, if trade is under taxed by setting σ too high relative to τ, then lowering t_X can compensate by boosting production

Figure 4: Independence of optimal domestic policy at the optimal trade policy mix



in the import competing industry.[10]. When trade policy is set suboptimally, the domestic production taxes can be altered to manipulate production on both the foreign and domestic margins. The Pigouvian prescription no longer holds for even domestic tax rates.

5 Conclusion

In this study, we ask: what is the optimal carbon tariff in a subglobal policy setting? While the conventional wisdom has been to tax imported carbon at the Pigouvian rate (or implement full border tax adjustment at the Pigouvian rate), we show that such a prescription is suboptimal, even when strategic trade considerations are eliminated. This result follows directly from Markusen (1975) who shows that the optimal environmental tariff depends on

[10]This is consistent with the efficiency argument for differential domestic carbon taxes discussed by Böhringer et al. (2010a)

both the marginal social damage of the externality, as well as the ability of the home country to influence foreign prices and thus foreign production. This result is intuitive if we consider a small, open economy that cannot influence world prices and production. In such a setting, the optimal carbon tariff would clearly be zero. As such, it should not be surprising that the optimal tariff for a large, open economy will depend on its ability to influence world markets.

Furthermore, we show that, because of Lerner symmetry, the export rebate component of a full border tax adjustment policy offsets the import tariff component, implying only one trade instrument is necessary to achieve the optimal environmental tax on trade. Full border tax adjustment at the Pigouvian level implies too large of a net tax on trade, relative to optimal levels. Finally, we show that to the extent domestic production taxes are set optimally (relative to each other), the optimal trade policy will be independent of the level of the domestic production taxes. However, if domestic production taxes are set incorrectly, trade taxes should be adjusted to account for both the domestic and the foreign distortions.

While we have shown the suboptimality of the Pigouvian prescription for trade taxes, it is important to note that the Pigouvian prescription does have the advantage of simplicity in applying tariff rates to multiple imported and exported goods. In a multi-country, multi-good setting, the determination of the optimal trade tariffs may be a daunting and perhaps intractable problem. Nonetheless, our findings show that, even in a conventional trade setting, these Pigouvian rates will be suboptimal. Policy makers interested in setting optimal trade border measures will need to compare the welfare gains from correctly setting tariff rates against the costs associated with the determination of those optimal rates compared to the simplicity of the Pigouvian prescription. As such, moving beyond the simple model considered here, a CGE extension that calculates the optimal trade tariffs and corresponding welfare gains relative to the Pigouvian levels could be a valuable exercise.

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