"Carbon Taxes and Border Tax Adjustments:

Might Industrial Organization Matter?"

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Abstract

In this paper, analysis is presented relating to the impact of border tax adjustments for climate policy on the problem of carbon leakage, and the related issue of competitiveness of energy-intensive industries. Implementation of domestic climate policy presents some additional issues in the analysis of border tax adjustments when vertically-related markets can be characterized as a successive oligopoly. Specifically, an appropriate border tax adjustment will depend on the incidence of a domestic carbon tax, the nature of competition in upstream and downstream sectors, as well as the basis for assessing the trade neutrality of any border tax adjustment. If trade neutrality is defined in terms of market volume, even though carbon leakage is reduced, domestic firm competitiveness cannot be maintained. This compares to defining trade neutrality in terms of market share, which results in domestic competitiveness being maintained and global carbon emissions being reduced.

Keywords: carbon taxes, carbon leakage, border tax adjustments, industrial organization

JEL Codes: H87, Q38

Introduction

In the past decade, it has become increasingly obvious that even though negotiation of the Kyoto Protocol on Global Climate Change in 1997 was a useful first step, further efforts to develop a comprehensive multilateral agreement for reducing carbon emissions will be necessary if global climate change is to be properly addressed (Frankel, 2009). However, irrespective of the logic supporting a multilateral approach to dealing with a global public bad, many countries such as the United States and the European Union (EU) have been actively pursuing national efforts to reduce carbon emissions, with proposed legislation calling for some type of border measure to be targeted at energy-intensive imports (Frankel, 2009). The inclusion of border measures in climate change legislation is predicated on two concerns: first, there will be *carbon leakage*, i.e., production by energy-intensive industries will be shifted to countries with less restrictive climate policies; second, there will be a reduction in *competitiveness* of firms in industries most affected by domestic climate policies (WTO/UNEP 2009).

In the environmental economics literature, the focus is on how trade policy instruments might be used to prevent carbon leakage when one group of countries commits to cooperation over climate policy, while a second group free-rides by not implementing climate policy (Hoel, 1996; Mæstad, 1998). Hoel (1996), for example, shows that a social optimum can be obtained if cooperating countries set common carbon taxes, and at the same time use import tariffs (export subsidies) on all energy-intensive traded goods, the objective being to shift the terms of trade against free-riding countries, thereby reducing carbon leakage.

A concern raised by Hoel (1996) is that the use of tariffs and subsidies could be constrained by WTO/GATT rules. However, if such trade policy instruments are treated as *border tax adjustments* (BTAs) rather than border taxes (subsidies), the view of economists is that the principle for their use in the presence of a domestically imposed excise tax is well-founded in the literature on the impact of *origin* vs. *destination*-based taxation systems (Lockwood and Whalley, 2010). A synthesis of the analysis of this issue by Lockwood, de Meza and Myles (1994) shows that as long as a domestic tax is applied uniformly across all goods, and BTAs are set no higher than the domestic tax, if either prices or exchange rates are flexible, movement between an origin and a destination base for taxation has no real effects on trade, production and consumption.

Essentially this principle is captured in the WTO/GATT rules: GATT Article II: 2(a) allows members of the WTO to place on the imports of any good, a BTA equivalent to an internal tax on the like good. However, under GATT Article III: 2, the BTA cannot be applied *in excess* of that applied directly or indirectly to the like domestic good, i.e., they have to be *neutral* in terms of their impact on trade, their objective being to preserve *competitive equality* between domestic and imported goods (WTO, 1997). In addition, with respect to exported goods, WTO/GATT rules allow rebate of the domestic tax on the exported good, as long as the border adjustment does not exceed the level of the domestic tax, it is not regarded as an export subsidy under the GATT Subsidies Code (WTO, 1997). Although there has been discussion by some observers, such as Goh (2004) and Pauwelyn (2007), about the likely permissibility of BTAs for domestic carbon taxes, this paper proceeds upon the assumption that they will be considered legal.

While using BTAs in combination with domestic excise taxes is not a particularly new regulatory issue, there are additional analytical challenges when examining a domestic carbon tax that has the potential to affect several stages of a vertical production system. In this context, the focus of this paper is on modeling a carbon tax targeted at upstream energy production, and its associated incidence on downstream production of energy-intensive goods, paying attention to both upstream carbon leakage effects and downstream competitiveness effects. In analyzing this problem, the current paper is organized as follows: in section 1, a brief discussion of competitiveness is presented along with some stylized facts about the type of vertically-related production system most likely to be affected by developed country climate policy; this is followed in section 2 by description of a model of successive oligopoly, which is then used in section 3 to analyze BTAs for domestic climate policy; finally, a summary of the paper and some conclusions are presented.

1. Competitiveness, Climate Policy and Energy-Intensive Industries

While the issues of carbon leakage and competitiveness are closely connected in the climate policy debate, the latter is a rather more difficult concept to define. Typically, it would be thought of in terms of market share and/or the profit of firms, which in turn are a function of the specific characteristics of an industry subject to domestic climate policy, including factors such as market structure, industry technology and the nature of competition between firms (WTO/UNEP, 2009). In the case of perfectly competitive firms, atomistic firms make normal profits in equilibrium. Consequently, if firms and policymakers are concerned about the effect of unilateral implementation of climate policy on competitiveness as defined above, markets would have to be imperfectly competitive with firms having non-trivial market shares and earning above normal profits in equilibrium. This suggests that climate policy and BTAs are perhaps best analyzed in the context of the literature on trade and environmental policy pioneered by, *inter alia*, Barrett (1994) and Conrad (1993). The key point of this previous literature is that if firms earn above normal profits, implementation of policies such as a carbon tax and/or a BTA may have the effect of shifting profits between domestic and foreign firms, thereby affecting the former's competitiveness.

In analyzing this issue, therefore, it matters what type of industries are most likely to be affected by the unilateral implementation of climate policy. In the case of the US, Houser *et al*. (2009) identify five energy-intensive industries most likely to be affected by domestic climate policy: steel, aluminum, chemicals, paper and cement, where energy accounts for between 10 and 20 percent of total costs. A similar set of industries have been discussed with respect to EU concerns about carbon leakage (Monjon and Quirion, 2010). If both upstream energy and downstream energy-intensive final goods markets are perfectly competitive, then the appropriate treatment of imports of an energy-intensive good such as steel is relatively straightforward: an import tax on imported steel equal to the level of the carbon tax times the extent to which energy enters the cost function for domestically produced steel, would raise marginal costs for the importer of steel by the same amount, and consequently will have a neutral effect on imports of steel, and thereby be WTO/GATT-consistent (see Poterba and Rotemberg, 1995).

It may be more appropriate, however, to assume that both the intermediate energy and energy-intensive final goods markets are oligopolistic. In the case of electricity production markets, with increased deregulation it is now quite commonplace to characterize generating firms in terms of their oligopolistic interaction (Ventosa *et al*., 2005). For example, Borenstein and Bushnell (1999), and Fowlie (2009) both model the Californian electricity market as a Cournot game, while Bolle (1992), Green and Newberry (1992), and Green (1996) all model the UK electricity market as a supply function equilibrium, the upper bound to which is the static Cournot outcome. With respect to the set of downstream energy-intensive industries, several authors analyzing the carbon leakage/competitiveness issue have already modeled firm behavior as oligopolistic, e.g., steel (Demailly and Quirion, 2008; Ritz, 2009) and cement (Ponssard and Walker, 2008), and there is also empirical evidence that firms in these industries may behave less than competitively, e.g., steel (Gallett, 1996); aluminum (Yang, 2001); paper (Mei and Sun, 2008); and cement (Azzam and Rosenbaum, 2001).

Consequently, if the vertical market structure of these industries is best described as one of successive oligopoly, then taxing imports of downstream energy-intensive goods at the same level as the carbon tax imposed on upstream energy production may not have a neutral impact. In order to analyze this possibility, the remainder of the paper consists of the adaptation and use of a vertical-market model developed in an earlier paper by McCorriston and Sheldon (2005).

2. A Model of Successive Oligopoly

Assumptions

The model introduced here is one of successive oligopoly, i.e., both the upstream (intermediate) and downstream (final) sectors are imperfectly competitive, and one that is standard when dealing with policy issues in vertically-related markets (for example, Sleuwaegen *et al*., 1998; Ishikawa and Spencer, 1999). In the downstream sector, the domestic firm competes with a foreign exporter of the energy-intensive final good. In both domestic and foreign upstream sectors, two firms produce a non-traded intermediate input, electricity, which is homogenous once generated and supplied to the electricity transmission system (see figure 1). Production of electricity generates carbon emissions e via the function $e_j = g(x_j^U)$, where x_j^U is total upstream electricity production in countries j =1, 2, where 1 refers to the home country and 2 the foreign country, $g'(x_j^U) > 0$ and we can allow for $g'(x_2^U) > g'(x_1^U)$, capturing the idea that the foreign country's electricity production could generate more carbon emissions e_j for a given level of output. A domestic carbon tax will raise domestic intermediate firms' costs subsequently raising the domestic downstream firm's costs due to the increased price of electricity. The technology linking each sector is one of fixed proportions. Formally, $x_j = \phi x_j^U$, j = 1, 2, where x_j and x_j^U represent output in both the domestic and foreign downstream and upstream sectors respectively, where superscript U denotes the upstream sector, and where ϕ is the constant coefficient of production. To ease the exposition, ϕ is set equal to one in the framework outlined below. Like much of the previous literature on vertical markets, arm's length pricing between the downstream and upstream sectors is also assumed, i.e., the downstream sector takes electricity prices as given (Abiru, 1988; Salinger, 1988).[1]

Following Ishikawa and Spencer (1999), the model consists of a three-stage game. At the first stage, the domestic government commits to a carbon tax and a BTA, while the second and third stages consist of Nash equilibria in the upstream and downstream sectors. The timing of the firm's strategy choice goes from upstream to downstream. Specifically, given costs and the derived demand curve facing the upstream sector, upstream firms simultaneously choose output to maximize profits, which generates Nash equilibrium in the upstream sector. The intermediate input prices are taken as given by the domestic downstream firm which, simultaneously with their foreign competitor, chooses their output to maximize profits, thus giving Nash equilibrium in the downstream sector. In terms of solving the model, equilibrium in the downstream sector is derived first and then the upstream sector. In addition, all equilibria are sub-game perfect.

[1] It should be noted that we assume that there is no bargaining over upstream prices. This is a common assumption in models of successive oligopoly. Adapting a rationale for this provided by Ishikawa and Spencer (1999) it is assumed that the upstream electricity-producing firms sell to a large number of different downstream sectors, reducing any monopsony power one individual downstream sector may have.

Equilibrium in the Energy-Intensive Sector

Let x_1 equal the output choice of the domestic downstream firm and x_2 the output choice of its foreign competitor. The revenue functions can be written as:

(1) $$R_1(x_1, x_2)$$

(2) $$R_2(x_1, x_2)\ .$$

We assume downward sloping demands and substitute final goods.

Given (1) and (2), the relevant profit functions downstream are given as:

(3) $$\pi_1 = R_1\ (x_1, x_2) - c_1 x_1$$

(4) $$\pi_2 = R_2\ (x_1, x_2) - c_2 x_2\ ,$$

where c_1 and c_2 are the domestic and foreign firms' respective costs. Firms' costs relate to the purchase of the intermediate input electricity, other production costs being omitted as arguments.

The first-order conditions for profit maximization are given as:

(5) $$R_{1,1} = c_1$$

(6) $$R_{2,2} = c_2\ ,$$

Equilibrium in the downstream sector can be derived by totally differentiating the first-order conditions (5) and (6):

(7) $$\begin{bmatrix} R_{1,11} & R_{1,12} \\ R_{2,21} & R_{2,22} \end{bmatrix} \begin{bmatrix} dx_1 \\ dx_2 \end{bmatrix} = \begin{bmatrix} dc_1 \\ dc_2 \end{bmatrix}.$$

The slopes of the reaction functions are found by implicitly differentiating the firms' first-order conditions:

(8) $$\frac{dx_1}{dx_2} = r_1 = -\frac{R_{1,12}}{R_{1,11}}$$

(9) $$\frac{dx_2}{dx_1} = r_2 = -\frac{R_{2,21}}{R_{2,22}}\ .$$

With this set-up, we can deal with both strategic substitutes and strategic complements where the variable of interest is the cross-partial effect on marginal profitability, i.e., $\text{sign}\, r_i = \text{sign}\, R_{i,ij}$. Consequently, with reference to equation (8) and (9), if $R_{i,ij} < 0$, then $r_i < 0$. In this case, we have the case of strategic substitutes, and the reaction functions are downward sloping. However, if $R_{i,ij} > 0$, the reaction functions are upward sloping and we have strategic complements. The distinction between strategic substitutes/complements relates to the "aggressiveness" of firm's strategies (Bulow *et al*. 1985). With strategic substitutes, firms' strategies are less aggressive than those associated with strategic complements, i.e., with strategic substitutes (complements), an increase in the output of firm 1 would be met by a decrease (increase) in that of firm 2.[2]

Given (7), the solution to the system is found by re-arranging in terms of dx_i and inverting where Δ is the determinant of the left-hand side of (7):

$$(10) \qquad \begin{bmatrix} dx_1 \\ dx_2 \end{bmatrix} = \Delta^{-1} \begin{bmatrix} R_{2,22} & -R_{1,12} \\ -R_{2,21} & R_{1,11} \end{bmatrix} \begin{bmatrix} dc_1 \\ dc_2 \end{bmatrix}.$$

To simplify the notation re-write (10) as:

$$(11) \qquad \begin{bmatrix} dx_1 \\ dx_2 \end{bmatrix} = \Delta^{-1} \begin{bmatrix} a_2 & b_1 \\ b_2 & a_1 \end{bmatrix} \begin{bmatrix} dc_1 \\ dc_2 \end{bmatrix},$$

where: $a_1 = R_{1,11}$ $a_2 = R_{2,22}$, and $b_1 = R_{1,12}$ $b_2 = R_{2,21}$.

For stability of the duopoly equilibrium, the diagonal of the matrix has to be negative, i.e., $a_i < 0$, and the determinant positive, i.e., $\Delta = a_1 a_2 \; 1 - r_1 r_2 \; > 0$. Given these conditions, further comments can be made about the reaction functions. $r_i = - \; b_i \; / a_i$ from (8) and (9).

[2] Whether we have strategic substitutes or complements in quantity space depends on the second derivatives of the demand function (see Ishikawa and Spencer 1999; and Leahy and Neary 2001).

Hence, if $a_i < 0$, then for strategic substitutes, $b_i < 0$, in order to satisfy $r_i < 0$, and $b_i > 0$ in order to satisfy $r_i > 0$ for strategic complements. The expression for r_i can be substituted into (11) in order to make the comparative statics easier to follow:

$$\text{(12)} \qquad \begin{bmatrix} dx_1 \\ dx_2 \end{bmatrix} = \Delta^{-1} \begin{bmatrix} a_2 & a_1 r_1 \\ a_2 r_2 & a_1 \end{bmatrix} \begin{bmatrix} dc_1 \\ dc_2 \end{bmatrix}.$$

Equilibrium in the Electricity Generating Sector

Given the fixed proportions technology and $\phi = 1$, total output in either the domestic or foreign electricity generating sectors is given by $x_j^U = x_j$. The latter also implies that upstream emissions can be written directly as function of the downstream firm's output, i.e., $e_j = g(x_j^U) \equiv g(x_j)$. It is assumed that in each country there are two upstream firms (*A* and *B*) whose combined output of electricity equals x_j^U, i.e., $x_j^A + x_j^B = x_j^U$. Due to the intermediate good electricity being assumed homogeneous once supplied to the transmission system, the downstream firms are therefore indifferent about the relative proportions of x_j^A and x_j^B used in their production process. Assuming that the downstream firms face no costs other than the price paid for electricity, the inverse derived demand function facing firms in the upstream sector can be found by substituting p_i^U for c_i in (5) and (6) respectively. In countries *j* = 1, 2, firms' profits in the upstream sector are, therefore, given by:

$$\text{(13)} \qquad \pi_j^A = R_j^A(x_j^A, x_j^B) - c_j^A x_j^A$$

$$\text{(14)} \qquad \pi_j^B = R_j^B(x_j^A, x_j^B) - c_j^B x_j^B ,$$

where c_j^A and c_j^B are the upstream firms' costs respectively in country *j*.

Given this, following the outline above, equilibrium in the upstream market, j = 1, 2, is:

(15)
$$\begin{bmatrix} dx_j^A \\ dx_j^B \end{bmatrix} = (\Delta_j^U)^{-1} \begin{bmatrix} a_j^B & a_j^A r_j^A \\ a_j^B r_j^B & a_j^A \end{bmatrix} \begin{bmatrix} dc_j^A \\ dc_j^B \end{bmatrix},$$

where $a_j^A, a_j^B < 0$, and $(\Delta_j^U)^{-1} > 0$ for stability.

3. Carbon Taxes and Border Tax Adjustments

Carbon Taxes and Leakage

Assume initially that the domestic government can only target a carbon tax t^e at its electricity producers.[3] The imposition of the carbon tax t^e on domestic electricity producers raises both c_1^A and c_1^B. In turn, this raises the price of electricity, i.e., the costs to the domestic downstream firm c_1. The cost increase to the domestic downstream firm also affects imports of the energy-intensive final good, given by dx_2 / dc_1. Following Ritz (2009) and Karp (2010), and assuming that domestic electricity producers do not respond to the carbon tax t^e by reducing their intensity of carbon emissions via cleaner technology, carbon leakage l is given as:

(16)
$$l = \frac{de_2}{-de_1} \equiv \left[\frac{g'(x_2^U)}{g'(x_1^U)} . \frac{dx_2^U}{-dx_1^U} \right],$$

i.e., even if intensity of carbon emissions is the same in the domestic and foreign upstream sectors, $g'(x_2^U) = g'(x_1^U)$ there will be positive carbon leakage, l >0, if there is positive output leakage, $dx_2^U / -dx_1^U > 0$. Given that $x_j^U = x_j$, (12) can be used to re-write (16) as:

(17)
$$l = \frac{de_2}{-de_1} \equiv \left[\frac{g'(x_2^U)}{g'(x_1^U)} . \frac{\Delta^{-1} a_2 r_2 dc_1}{-(\Delta^{-1} a_2 dc_1)} \right].$$

[3] Instead of a carbon tax, a cap and trade system could be used to reduce emissions, permit prices having the same effect on upstream firms' costs.

If $l > 0$, there is positive carbon leakage, and if $l < 0$, there is negative carbon leakage in the sense that foreign carbon emissions actually decrease after implementation of the policy. Given $\Delta^{-1} > 0$ and $a_2 < 0$, such that $dx_1 = \Delta^{-1} a_2 dc_1 < 0$, the direction of carbon leakage is given by the sign of r_2, and the extent by the size of $g'(x_2^U)$ relative to $g'(x_1^U)$: if $g'(x_2^U) = g'(x_1^U)$ and $r_2 < 0$ (> 0), then $dx_2 = \Delta^{-1} a_2 r_2 dc_1 > 0 (< 0)$ and $l > 0$ (< 0), i.e., there is positive (negative) carbon leakage if final goods are strategic substitutes (complements); and if $g'(x_2^U) > g'(x_1^U)$, given $|r_2| < 1$, the extent of positive (negative) carbon leakage depends on the intensity of foreign relative to domestic carbon emissions.

LEMMA 1: *With strategic substitutes, a carbon tax causes positive carbon leakage. With strategic complements, a carbon tax causes negative carbon leakage. The extent of positive or negative carbon leakage is determined by the relative intensity of foreign to domestic carbon emissions.*

Border Tax Adjustments and Neutrality

Now assume a BTA t^b can be targeted at imports of the energy-intensive final good, thereby raising the costs of the downstream firm's foreign competitor which, in turn affects the level of imports. This is given by dx_2 / dc_2, which given the assumption of fixed proportions, also feeds back into foreign electricity production, $dx_2 / dc_2 = dx_2^U / dc_2 = d \;\; x_2^A + x_2^B \;\; / dc_2$, which in turn affects foreign carbon emissions e_2, and thereby carbon leakage *l*. Since the WTO/GATT guidelines are not specific in defining 'competitive equality', we consider the cases where the neutral BTA (*neutral BTA*) is defined as *either* the change in c_2 that keeps the *volume* of final good imports constant given the environmental tax t^e, *or* as the change in c_2 that keeps the domestic *market share* of final good imports constant given t^e.

Import-Volume Neutrality

If neutrality is defined in terms of import volume, the appropriate BTA is given as:

$$\text{(18)} \qquad neutral\ BTA = \frac{(dx_2 / dc_1)\ t^e}{-(dx_2 / dc_2)}.$$

When markets are competitive, then $|dx_2 / dc_2| = |dx_2 / dc_1|$, the net effect being such that $dx_2 = 0$, there being no carbon leakage, i.e., the appropriate BTA should be set equal to the domestic carbon tax. Specifically, with a domestic carbon tax t^e, the BTA is effectively based on the carbon embodied in the domestically produced final good. This, rules out the domestic policymaker setting $t^b > t^e$ when $g'(x_2^U) > g'(x_1^U)$, i.e., given binding WTO/GATT rules, the appropriate BTA cannot be based on the carbon embodied in the foreign produced final good.[4]

In contrast, when markets are imperfectly competitive, setting the BTA equal to the domestic carbon tax will lead to a non-neutral outcome, $dx_2 \neq 0$.

LEMMA 2: *With strategic substitutes, the appropriate import policy to ensure neutrality is an import tax. With strategic complements, import volume neutrality requires an import subsidy.*

Consider first of all the effect of the import tax on the imports of the final good. Using (12), $dx_2 = \Delta^{-1} a_1 dc_2$, since $\Delta^{-1} > 0$ and $a_1 < 0$, the border tax (as expected) reduces the level of final good imports, i.e., $dx_2 < 0$. From the previous section, the effect of the domestic carbon tax on final good imports $dx_2 = \Delta^{-1} a_2 r_2 dc_1$ depends on the sign of r_2. In the case of strategic substitutes, $r_2 < 0$, which results in $dx_2 / dc_1 > 0$, i.e., import volume neutrality requires an import tax. Necessarily, if $dx_2 = 0$ there will be no carbon leakage.

[4] In recent empirical analysis, Mattoo *et al*. (2009) find significantly different trade effects of BTAs depending on whether they are based on the carbon content embodied in final goods produced in the importing country or the carbon content embodied in the imported goods.

In the case of strategic complements $r_2 > 0$, so that $dx_2 / dc_1 < 0$, suggesting that the carbon tax has a non-neutral impact on imports of the final good, as it further reduces output. Specifically, the carbon tax imposed on domestic electricity production reduces domestic output in the downstream sector *and* imports of the final good. From (18) this implies that with strategic complements, since $dx_2 / dc_1 < 0$, to restore neutrality, the appropriate policy is an import *subsidy* rather than an import tax. However, this outcome, while satisfying WTO/GATT rules, is not actually necessary to reduce carbon leakage. This is due to the fact that the domestic carbon tax, by causing the foreign downstream firm to reduce its output, actually results in negative carbon leakage.

The appropriate border tax adjustment for a domestic carbon tax that ensures import volume neutrality is summarized in the following proposition:

PROPOSITION 1: *The BTA required to ensure import volume neutrality depends on (a) whether the nature of competition is strategic substitutes or complements; (b) the effect of a change in costs in the final market; and (c) the extent to which the domestic carbon tax, t^e, is transmitted into an increase in domestic downstream firm's costs.*

Part (a) of Proposition 1 follows directly from Lemma 2. Relating to parts (b) and (c), whether the expansion of imports due to the carbon tax matches the contraction due to the BTA depends on two factors: the effect of the change in costs on the downstream sector, and the extent to which the domestic carbon tax, t^e, is transmitted into an increase in the downstream firm's costs, dc_1. Focusing, first of all, on the former, even if $dc_1 = dc_2$, the impact of the domestic carbon tax will likely be less than the BTA. For example, if $a_1 \approx a_2$, as $|r_2| < 1$, then $a_2 r_2 < a_1$. Second, consider the likelihood of $dc_1 = dc_2$. This depends on the incidence of the upstream carbon tax on the downstream firm's cost function, i.e., $dp^U_{1,1} / (dc^A_1 + dc^B_1)$ the extent to which the price of domestic energy rises as a result of the domestic carbon tax. Since electricity is homogenous at the point of consumption downstream, then:

(19) $$dp_1^U = p_{1,1}^U(dx_1^A + dx_1^B).$$

Using (15):

(20) $$dp_1^U = p_{1,1}^U \ (\Delta^U)^{-1}[dc_1^A a_1^B(1+r_1^B) + dc_1^B a_1^A(1+r_1^A)] \ = \{p_{1,1}^U D\}t^e,$$

where $p_{1,1}^U < 0$, and $D = (\Delta^U)^{-1}[a_1^B(1+r_1^B) + a_1^A(1+r_1^A)] < 0$. Therefore, domestic downstream costs will increase with imposition of a carbon tax upstream, i.e., $dc_1 = dp_1^U > 0$. For reasonable characterizations of the demand function, there will be under-shifting of the carbon tax $\{p_{1,1}^U D\}t^e < 1$.[5]

Using (12), and (18)-(20), the appropriate BTA implied by Proposition 1 can generally be given as (assuming $a_1 \approx a_2$):

(21) $$\textit{neutral BTA} = -r_2\{p_{1,1}^U D\}t^e = -r_2\ dc_1.$$

It is clear that the form of the BTA, i.e., whether it is an import tax or subsidy, depends on the nature of competition in the downstream sector.[6] Further, the size of the appropriate BTA depends on the nature of competition in both the downstream and upstream sectors. Also, note that if the appropriate BTA is set, i.e., $dx_2 = 0$, there will be no carbon leakage. As with the case of perfect competition noted earlier, the BTA cannot be used to target foreign final good production when $g'(x_2^U) > g'(x_1^U)$ as this would violate the import-volume neutrality constraint. Given this, the following corollary can be stated:

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[5] For example, a linear, or more generally a weakly convex demand function will generate under-shifting.

[6] Note that including the upstream sector generalizes the impact of the domestic carbon tax and hence what the appropriate BTA should be. If the upstream sector were perfectly competitive, then the incidence of the carbon tax in the upstream sector would not matter**.** In this case $dc_1 = 1$ the *neutral BTA* being equal to $-r_2$.

COROLLARY 1: *To be WTO-consistent, a border tax adjustment cannot be based on the level of carbon embodied in the foreign produced final good, implying that* $t^b \leq t^e$ *, even if foreign production of the final good is more carbon-intensive* $g'(x_2^U) > g'(x_1^U)$*.*

<u>Import-Share Neutrality</u>

In the case of import-share neutrality, the appropriate BTA is defined as one where the net effect of the carbon tax t^e on x_1 and x_2 must equal the net effect of the BTA on x_1 and x_2. In this case, the neutral BTA is defined as:

$$\text{(22)} \qquad neutral\ BTA = \frac{t^e[(dx_2/dc_1) + (dx_1/dc_1)]}{[(dx_1/dc_2) + (dx_2/dc_2)]},$$

PROPOSITION 2: *Defining competitive equality in terms of market share leads to a policy that does not depend on the existence of strategic substitutes or complements. However, the BTA required will be lower in the strategic complement case compared to that required for the strategic substitute case.*

Using (22) and assuming $a_1 \approx a_2$, the neutral *BTA* can be re-written as:

$$\text{(23)} \qquad neutral\ BTA = \frac{(r_2+1)t^e}{(r_1+1)} = \frac{(r_2+1)\,dc_1}{(r_1+1)}.$$

It is clear from (23) that defining 'competitive equality' in terms of market shares does not lead to the 'sign' of the policy. However, the magnitude of the BTA is still dependent on the nature of competition between the downstream firms. Specifically, in the case of strategic substitutes, $r_i < 0$, and given that $|r_1| > |r_2|$, the appropriate BTA exceeds that for the case of import-volume neutrality as given in (21).[7] For strategic complements, $r_i > 0$, and given that $|r_1| > |r_2|$, the neutral *BTA* is lower than in the strategic substitutes case. However, whether final goods are strategic substitutes or complements, the domestic carbon tax combined with the BTA

[7] This assumption relates to the relative slopes of the reaction functions, implying that firm 1's reaction function is steeper, in absolute terms than that of firm 1, which is necessary to ensure stability of equilibrium.

"facilitates" collusion, a result similar to that when import restrictions are defined in terms of market share (Denicolo and Garella, 1999). As a result, even though the BTA is not set above the domestic carbon tax in order to be WTO-compliant, global carbon emissions are actually reduced below that prior to implementation of the domestic carbon tax.

Border Tax Adjustments and Competitiveness

While appropriate BTAs that ensure trade neutrality can be defined in the presence of imperfect competition, thereby ensuring no carbon leakage, the downstream competitiveness effects of the two definitions of neutrality are quite different. This is important since even though the appropriate BTA will keep imports of the final good at the same level, re-distribution of profits between domestic and foreign downstream firms can still occur. This can be summarized in the following proposition.

PROPOSITION 3*: With import volume neutrality, an appropriate BTA for a domestic carbon tax reduces profits of the domestic downstream firm, thereby reducing its competitiveness, while increasing the profits of the foreign downstream firm. With the import share rule, the domestic downstream firm improves its competitiveness, both domestic and foreign downstream firms gaining additional profits.*

Specifically, under *import-volume neutrality*, and for either strategic substitutes or complements, the combination of domestic carbon tax and BTA reduces output and profits of the domestic downstream firm, and raises profits of the foreign downstream firm. Under the rule that $dx_2 = 0$, the change in output of the domestic downstream firm is derived from (12), and assuming $a = a_1 \approx a_2$:

$$dx_1 = \Delta^{-1} a(dc_1 + r_1 dc_2). \tag{24}$$

Given $\Delta^{-1} > 0, a < 0, dc_1 > dc_2$, and $|r_1| < 1$, then $dx_1 < 0$ for both $r_1 < 0$ and $r_1 > 0$, i.e., even if the BTA is trade neutral, the domestic firm still reduces its output with a carbon tax. In the case of profits, totally differentiate (3) and (4):

(25) $$d\pi_1 = R_{1,1}dx_1 + R_{1,2}\,dx_2 - c_1 dx_1 + \pi_{1,c_1}dc_1$$

(26) $$d\pi_2 = R_{2,2}dx_2 + R_{2,1}\,dx_1 - c_2 dx_2 + \pi_{2,c_2}dc_2$$

Again, based on the rule that $dx_2 = 0$, and $\pi_{1,c_1}dc_1 = -x_1 dc_1$ from (3), it is easy to see that $d\pi_1 < 0$, i.e., domestic downstream firm profits fall. For the foreign downstream firm, and assuming, $a = a_1 \approx a_2$, (26) can be re-written as:

(27) $$d\pi_2 = R_{2,1}\,dx_1 + \pi_{2,c_2}dc_2 = x_2[\,\Delta^{-1}\,p_{2,1}\,a\,(\,dc_1 + r_1 dc_2) - dc_2\,].$$

Given $\Delta^{-1} > 0, p_{2,1} < 0, a < 0,$ and $r_1 < 0,$ as long as $. > 0$, then $d\pi_2 > 0$, i.e., foreign downstream firm profits increase. The reason for this is that the BTA has been set appropriately and is less than the domestic carbon tax. If $r_1 > 0$, and an import subsidy is used, as can be seen from (25), $d\pi_1 < 0$, i.e., the domestic downstream firm's profits still decline. In the case of the foreign downstream firm, from (27), as long as $dc_1 > |r_1 dc_2|$, and $. > 0$, then $d\pi_2 > 0$, i.e., the downstream foreign firm's profits increase. In other words, even with an appropriately set BTA, which results in no carbon leakage, the domestic downstream firm still suffers a loss of competitiveness.

For *import-volume neutrality*, the competitiveness effect is illustrated in figure 2 for the case of strategic substitutes. The initial Nash equilibrium is *N* is where the downward-sloping reaction functions for the domestic downstream F_1 and foreign downstream firms F_2 cross each other, their equilibrium outputs being x_1 and x_2 respectively, with associated profits of π_1 and π_2. If only a domestic carbon tax is imposed upstream, we assume this is passed through to the domestic downstream firm as a change in its costs dc_1, which shifts its reaction function to F_1' the new Nash equilibrium being at *N**. The net result is that the foreign downstream firm increases its output as well as profits which comes at the expense of the domestic downstream firm, i.e., there is a loss in the latter's competitiveness as well as positive carbon leakage in the foreign country.

If a BTA is allowed for, the pass-through of the domestic carbon tax still shifts the domestic downstream firm's reaction function to F_1' while the BTA shifts the foreign downstream firm's reaction function from F_2 to F_2' the new Nash equilibrium being N', such that the foreign downstream firm's output remains at $x_2 = x_2'$, resulting in no foreign carbon leakage. However, even with a trade neutral BTA, the domestic downstream firm reduces its output to x_1', its profits falling to π_1', while the foreign downstream firm's profits increase to π_2'. Consequently, while the carbon leakage problem can be solved, competitiveness of the domestic downstream firm cannot be maintained.

Under *import-share neutrality*, the combination of the carbon tax and BTA increases the profits of both the domestic and foreign downstream firms in both the strategic substitutes and complements cases. In order to see this, first derive dx_1 and dx_2 from (12), assuming $a = a_1 \approx a_2$, and substituting in for dc_2 from (23):

(28) $$dx_1 = \Delta^{-1}\left[\ a\, dc_1\left(1 + r_1\left\{\frac{(r_2+1)}{(r_1+1)}\right\}\right)\right]$$

(29) $$dx_2 = \Delta^{-1}\left[a\, dc_1\left(r_2 + \left\{\frac{(r_2+1)}{(r_1+1)}\right\}\right)\right].$$

As $\Delta^{-1} > 0, a < 0, dc_1 > 0$, and for strategic substitutes, $r_i < 0$, then $dx_1 < 0$ and $dx_2 < 0$. For strategic complements, $r_i > 0$, so again, $dx_1 < 0$ and $dx_2 < 0$.

Substituting (28) and (29) into (25) and (26):

(30) $$d\pi_1 = x_1 dc_1 \left\{ p_{1,2}\Delta^{-1} a \left[r_2 + \left(\frac{r_2+1}{r_1+1} \right) \right] - 1 \right\}$$

(31) $$d\pi_2 = x_2 \left\{ p_{2,1}\Delta^{-1} adc_1 \left[1 + (1+r_1) \left(\frac{r_2+1}{r_1+1} \right) \right] - dc_2 \right\}.$$

For strategic substitutes, $r_i < 0$, and in addition, in (30), $p_{1,2} < 0, \Delta^{-1} > 0, a < 0,$ and $. > 0,$ while in (31), $p_{2,1} < 0, \Delta^{-1} > 0, a < 0,$ and $. > 0$. Therefore, as long as $p_{1,2}\Delta^{-1}a \;. > 1$ in (30), and also that $p_{2,1}\Delta^{-1}adc_1 \;. > dc_2$ in (31), then it follows that $d\pi_1 > 0$, and $d\pi_2 > 0$. The same holds for strategic complements.

For *import-share neutrality*, the competitiveness effect is illustrated in figure 3 for the case of strategic substitutes. The initial Nash equilibrium is again at *N*, equilibrium outputs being x_1 and x_2 respectively, with associated profits of π_1 and π_2. Note that this equilibrium lies on the line denoted $k = \{x_2 / (x_2 + x_1)\}$. This line represents constant market share for the foreign firm, where in figure 2 it is drawn to show a symmetric equilibrium of $k = 0.5$, i.e., the foreign downstream firm has a fifty percent market share. Pass-through of the domestic carbon tax shifts the domestic downstream firm's reaction function to F_1', the new Nash equilibrium again being at *N**. The net result is that the foreign downstream firm increases its market share as well as profits which comes at the expense of the domestic downstream firm, i.e., there is a loss in the latter's competitiveness as well as positive carbon leakage in the foreign country.

If a BTA is allowed for, the pass-through of the domestic carbon tax still shifts the domestic downstream firm's reaction function to F_1' while the BTA shifts the foreign downstream firm's reaction function from F_2 to F_2' the new Nash equilibrium being *N'*. The net result is that domestic and foreign downstream firms decrease their output to x_1' and x_2' respectively, the foreign downstream firm's market share remaining constant at *k*. Importantly, reduction in the foreign firm's output not only generates negative carbon leakage, but profits of the domestic downstream firm also increase to π_1' as collusion between the domestic and foreign downstream firm is facilitated, i.e., competitiveness of the former is more than maintained through use of the BTA.

While there is no explicit political economy set-up in this model, one would expect the domestic downstream firm to lobby for trade neutrality to be defined in terms of market-share as it improves its competitiveness by moving into the Pareto-superior profit set bounded by the iso-profit contours π_1 and π_2. In contrast, its foreign competitor would prefer trade neutrality to be defined in terms of market-volume where it maintains its exports, and earns higher profits, moving the domestic downstream firm outside of the Pareto-superior profit set. Of course, in either case, even though trade neutrality and no carbon leakage are ensured, the aggregate reduction in output of the final good generates a deadweight loss to consumers. Minimizing the costs of the latter distortion would necessarily have to be taken into account if the carbon tax were being set optimally.[8]

4. Summary

Assuming that the WTO/GATT rules apply in the context of a carbon tax initially borne by producers of an intermediate good but passed on to producers of a final good, the focus of this paper has been on analyzing whether downstream border tax adjustments will jointly resolve the

[8] While the domestic carbon tax is treated as exogenous in this paper, it could be derived explicitly from maximizing a social welfare function that takes into account consumer surplus, profits of downstream domestic firm(s) as well the externality due to carbon emissions (see Conrad, 1996).

issues of carbon leakage and loss of competitiveness by domestic downstream firm(s). Using a model of successive oligopoly where an intermediate good, electricity, is used in the energy-intensive production of a final good such as steel, it has been shown that the level of any downstream border tax adjustment is dependent on the nature of oligopolistic competition between upstream firms and downstream firms, vertical incidence of the carbon tax, and how competitive equality between domestic and foreign downstream firms is defined. Importantly, if the WTO/GATT rules on border tax adjustments are based on maintaining the volume of final good imports, there will be no carbon leakage, but domestic firm(s) incur a reduction in output and lost profits and hence their competitiveness. Alternatively, if the WTO/GATT rules on border tax adjustments are interpreted in terms of maintaining the share of final good imports, global carbon emissions are actually reduced, and the competitiveness of domestic firm(s) is improved due to the combination of policy instruments acting to facilitate downstream collusion. In both cases, consumers suffer a deadweight loss as aggregate output of final goods is reduced. Consequently, industrial organization does matter to the analysis of carbon taxes and border tax adjustments.

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Figure 1: Vertical Market Structure

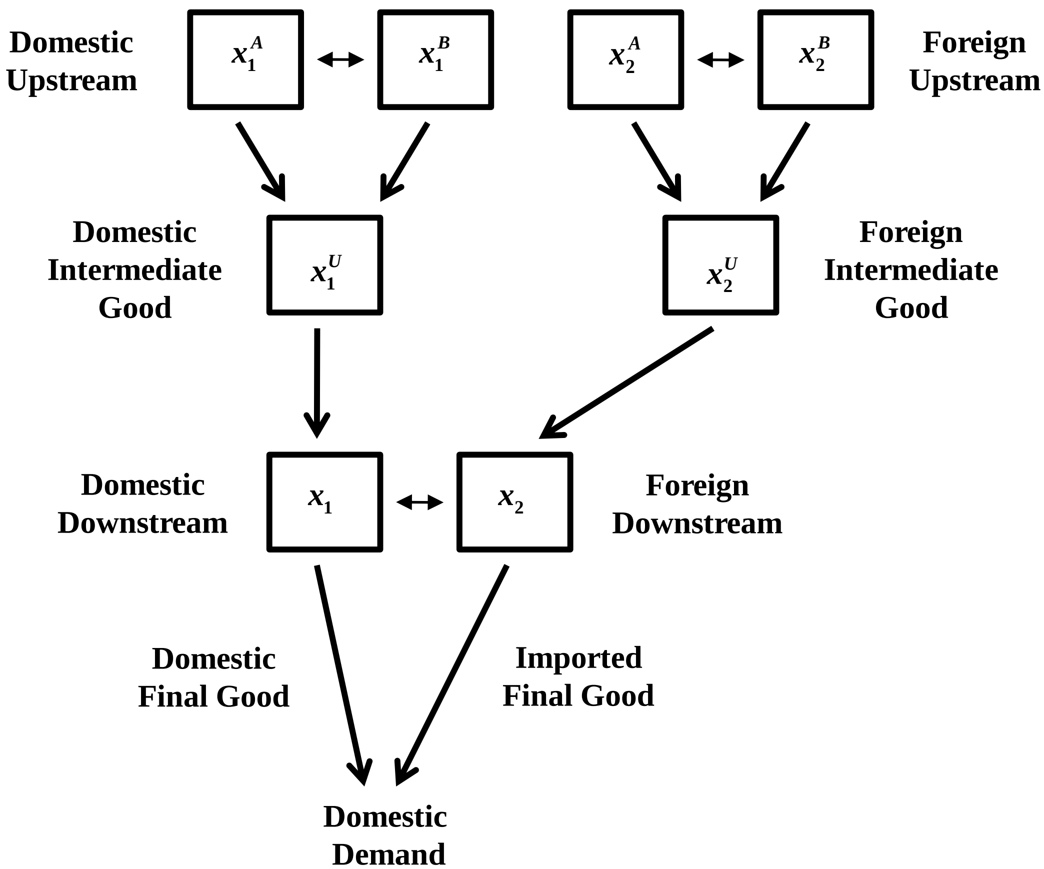

Figure 2: Import Volume Neutrality

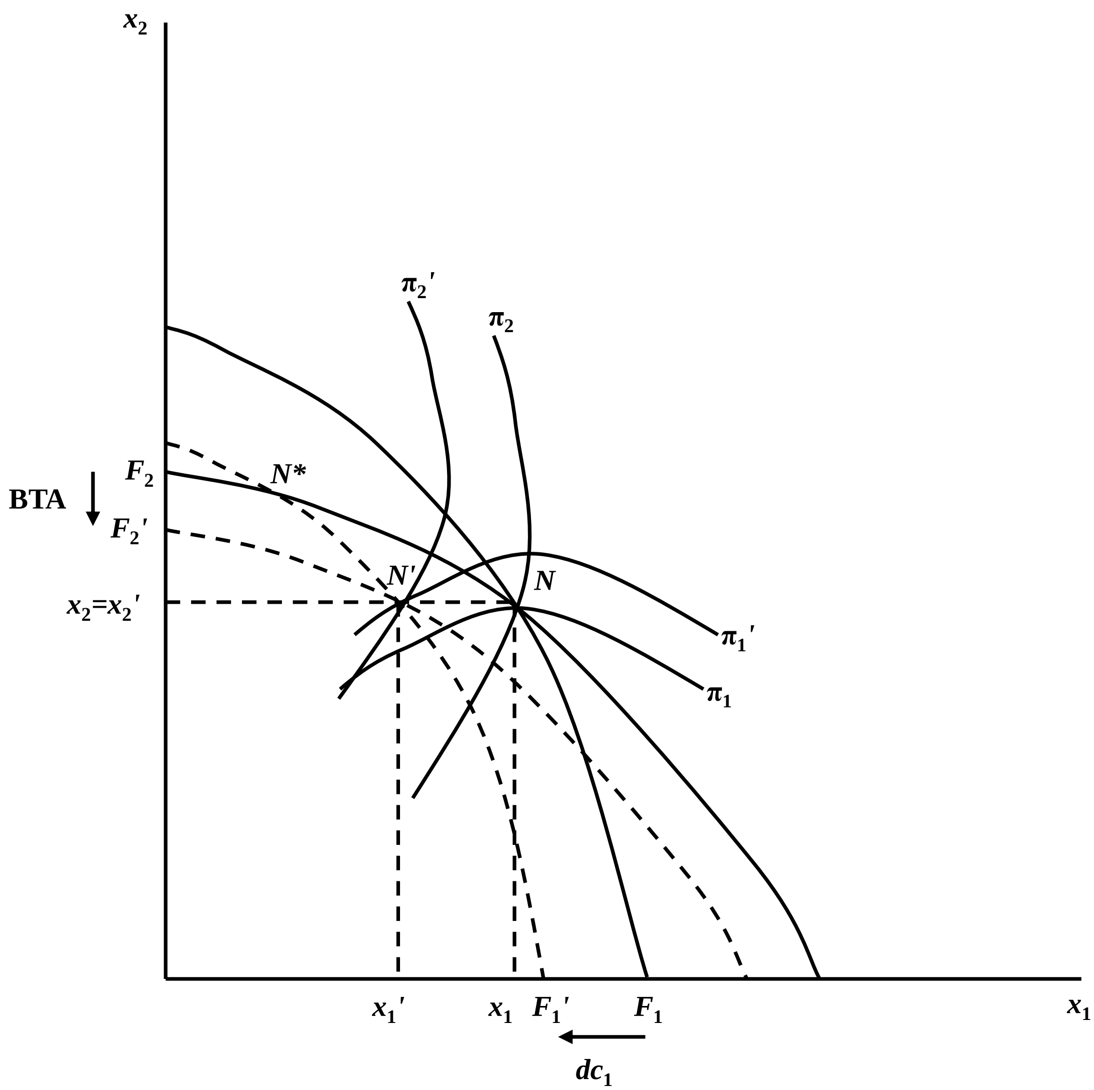

Figure 3: Import Share Neutrality