"Climate Policy, Carbon Leakage, and Competitiveness: How Might Border Tax Adjustments Help?" *

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Abstract

In this paper we examine the impact of introducing neutral border tax adjustments in a duopolistic setting where an import competing firm is faced with a carbon tax on their emissions. In the absence of a border tax adjustment, it is shown in the case of strategic substitutes, an optimal carbon tax will typically be set below marginal damage if there are strong competitiveness effects and positive carbon leakage, as well as concerns about the deadweight loss faced by consumers. In the case of strategic complements, the optimal carbon tax will be set above or below marginal damage, depending on the relative strengths of a positive competitiveness effect versus a deadweight loss effect. Once border tax adjustments are allowed for, the optimal carbon tax will typically be higher as carbon leakage is accounted for, but in the case of strategic substitutes, a negative competitiveness effect cannot be resolved, whereas in the case of strategic complements there will be negative carbon leakage, and a tradeoff between a positive competiveness effect and deadweight loss effect.

Keywords: climate policy, carbon leakage, border tax adjustments

JEL Codes: H87, Q38

1. Introduction

In the past decade, it has become increasingly obvious to many observers 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 a reduction in *competitiveness* of firms in industries most affected by domestic climate policies; second, there will be *carbon leakage*, i.e., production by energy-intensive industries will relocate to countries with less restrictive 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 remission 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 the issues of competitiveness and carbon leakage are closely connected in the climate policy debate, the former 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 oligopolistic with firms earning above normal profits in equilibrium. This suggests that climate policy and BTAs are best analyzed in the context of the strategic trade theory literature pioneered by Brander and Spencer (1984; 1985) and Eaton and Grossman (1986), and subsequently applied in the context of trade an environmental policy by Barrett (1994), Conrad (1993), Kennedy (1993), and Ulph (1996). The key point of the latter literature is that if firms earn oligopolistic rents in equilibrium, governments may have an incentive to shift rents to their own domestic firms via trade and environmental policy instruments, and that there may be tradeoffs between domestic consumers, domestic firms and the environment in the optimal choice of environmental policy.

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. A similar set of industries have been discussed with respect to EU concerns about carbon leakage (Monjon and Quirion, 2010). Several authors in analyzing the competitiveness/carbon leakage 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 some 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).

Previous modeling of BTAs by McCorriston and Sheldon (2005a; 2005b) treated environmental policy as exogenous. In this paper the focus is on how the choice of an optimal carbon emissions tax is affected if BTAs are introduced into a setting where there is oligopolistic competition between a home and foreign firm in the home market. The overall objective of the analysis is to examine the extent to which WTO-consistent BTAs can be targeted at resolving the competitiveness and carbon leakage issues. In the second section of the paper, carbon taxes and BTAs are analyzed for the Cournot case, while in the third section they are analyzed for the Bertrand case. The paper is summarized in the fourth section, and conclusions are drawn about future directions for research on this issue.

2. Carbon Taxes and Border Tax Adjustments – the Cournot Case

The Basic Model

Drawing on a structure originally laid out in Conrad (1996a), assume firm 1 (home) competes with firm 2 (foreign) in the home market, each firm generating carbon emissions through their production activities. Only the home government is active in implementing a tax *t* on carbon emissions and a border tax adjustment *b* on foreign imports. Although the structure of the game is one where the home government moves first in announcing its policy choices, we first analyze the second-stage output game between firms.

The profit functions of the firms, $\pi^i(.), i=1,2$ are:

$$\pi^1(x^1,x^2;t,b) = r^1(x^1,x^2;t,b) - c^1[x^1,z^1(t)] \quad (1)$$

$$\pi^2(x^2,x^1;t,b) = r^2(x^2,x^1;t,b) - c^2[x^2,z^2] - b(x^2) \quad (2)$$

where the home firm produces x^1 generating revenue $r^1(.) = p(X)x^1$, $X = (x^1 + x^2)$, at a cost of $c^1[x^1, z^1(t)]$, $p(.)$ is the inverse demand function in the home market, and z^1 is the price of environmental services used by the home firm, given that it emits carbon into the atmosphere. The foreign firm produces x^2 generating revenue $r^2(.) = p(x^1 + x^2)x^2$ at a cost of $c^2[x^2, z^2]$. All other input prices are assumed constant, and are therefore omitted from the cost functions.

In the presence of an emissions tax, the price of environmental services facing the home firm consists of the cost of abating carbon emissions and the tax incurred on unabated carbon emissions:

$$z^1(t) = ka^1e^1 + t(1 - a^1)e^1 \quad (3)$$

where $k = k(a^1)$ is the unit cost of abatement, which depends on the level of home abatement $a^1 (0 < a^1 < 1)$, e^1 is the home emissions coefficient, e.g., the amount of CO_2 emitted per ton of steel produced, and t is the emissions tax.[1] It is also assumed that $k(a^1)' > 0$ and $k(a^1)'' > 0$, i.e., unit costs of abatement are convex in the degree of abatement. The amount of abatement undertaken by the home firm will be a function of the emissions tax, the actual amount of abatement being decided before production occurs. Specifically, the home firm minimizes the unit costs of using environmental services z^1 with respect to a^1 given t, i.e., $\min_{a^1} z^1(a^1; t)$, such that in equilibrium, the marginal cost of abatement is equal to the emissions tax rate. In the case of the foreign firm, given that it faces no emissions tax, $z^2 = 0$, and it will not undertake any abatement, $a^2=0$.

Home and foreign goods are treated as substitutes, and it is also assumed that increasing the output of one good decreases the marginal revenue of the other, i.e., $r^i_j < 0$ and $r^i_{ij}, i \neq j$. The Nash equilibrium of the output game between the two firms is characterized by the following first-order conditions:

[1] Wang *et al*. (2009) report that emissions by integrated iron and steel mills are about 2 tons of CO_2 per ton of liquid steel produced, 70 percent of emissions being accounted for by blast furnace production of iron. Steel production also accounts for about 5-7 percent of total anthropogenic CO_2 emissions (Kim and Worrell, 2002).

$$\pi_1^1 = p + x^1 p' - c_1^1 = 0 \quad (4)$$

$$\pi_2^2 = p + x^2 p' - c_2^2 = 0 \quad (5)$$

where subscripts refer to the the derivatives of profit with respect to output. The second-order conditions are, $\pi_{1,1}^1 < 0, \pi_{2,2}^2 < 0$, and stability of the equilibrium is ensured by the conditions $\pi_{1,2}^1 < 0, \pi_{2,1}^2 < 0$, implying $\Delta^{-1} = \pi_{1,1}^1 \pi_{2,2}^2 - \pi_{1,2}^1 \pi_{2,1}^2 > 0$, i.e., the own-effects on marginal profit outweigh the cross-effects (Brander and Spencer 1983a; 1983b).

In order to conduct comparative statics, (4) and (5) are totally differentiated with respect to x^i, t and b, resulting in:

$$\begin{bmatrix} dx^1 \\ dx^2 \end{bmatrix} = \Delta^{-1} \begin{bmatrix} \pi_{2,2}^2 & -\pi_{1,2}^1 \\ -\pi_{2,1}^2 & \pi_{1,1}^1 \end{bmatrix} \begin{bmatrix} dt \\ db \end{bmatrix} \quad (6)$$

Assuming in the first stage of the game that the home government commits to an emissions tax but no border tax, the following comparative static results can be derived: $dx^1 / dt = \Delta^{-1} \pi_{2,2}^2 < 0, dx^2 / dt = \Delta^{-1} - \pi_{1,2}^1 > 0$, and $d(x^1 + x^2) / dt = \Delta^{-1}(\pi_{2,2}^2 + \pi_{1,2}^1)$, which can be written as, $\Delta^{-1}\{-(2p' + x^1 p'') + p' + x^1 p''\} = -p'\Delta^{-1} < 0$, i.e., home (foreign) firm output declines (increases) with the emissions tax, and total home output declines with the emissions tax. These results follow from the fact that home and foreign goods are *strategic substitutes*, i.e., firms' reaction functions are downward-sloping in output space (Bulow *et al.*, 1985). Total differentiation of (4) and (5) holding policies constant yields the slopes of the reaction functions, $dx^i / dx^j = -\pi_{ij}^i / \pi_{ii}^i < 0, i = 1, 2, i \neq j$.

Optimal Carbon Taxes without Border Tax Adjustments

Given the basic model, the next step is to characterize the objective function of the home government, given the foreign government chooses not to implement a carbon emissions tax. In order to capture the key components of the debate on uniform implementation of an emissions tax, it is assumed the home government maximizes the sum of consumer surplus, profits of the home firm (competitiveness), and the revenues derived from using any tax instruments, minus the damage from global carbon emissions. The home damage function $d(U^1)$ is defined as:

$$d(U^1) = (1-a^1)e^1v^1 + e^2v^2 \tag{7}$$

where $d'(U^1) > 0$ and $d''(U^2) > 0$; and v^i, i=1,2, is the quantity of environmental services used, derived from using Shepard's lemma, i.e., $c^i_{z^i}(x^i, z^i) = v^i$.

The objective function of the home government is written as:

$$\max_t w(t) = \int_0^X p(\xi)d\xi - p(X)X + \pi^1(x^1, x^2; t) + t(1-a^1)e^1v^1 - d(U^1) \tag{8}$$

The first-order condition of (8), which can be thought of as the home government's reaction function, is given as:

$$\begin{aligned}\frac{dw}{dt} &= p\left(\frac{dx^1}{dt} + \frac{dx^2}{dt}\right) - c^1_1\frac{dx^1}{dt} - c^1_{z^1}\frac{dz^1}{dt} + (1-a^1)e^1v^1 + t(1-a^1)e^1v^1_1\frac{dx^1}{dt} \\ &- p\frac{dx^2}{dt} - x^2\left(\frac{dx^1}{dt} + \frac{dx^2}{dt}\right)p' - md^1\left[(1-a^1)e^1v^1_1\frac{dx^1}{dt} + e^2v^2_2\frac{dx^2}{dt}\right] = 0\end{aligned} \tag{9}$$

where $md^1 = d'(U^1)$ is the marginal damage incurred by home consumers due to global carbon emissions. Expression (9) can be re-arranged in terms of an optimal home emissions tax $\hat{t}$:

$$\hat{t} = md^1\left\{1 + \frac{1}{md^1(1-a^1)e^1v^1_1(dx^1/dt)}\left[\frac{p}{\eta}\left(\frac{x^1}{X}\frac{dx^1}{dt} + \frac{x^2}{X} \times \frac{d(x^1+x^2)}{dt}\right) + md^1e^2v^2_2\frac{dx^2}{dt}\right]\right\} \tag{10}$$

where $\eta < 0$ is the price elasticity of demand in the home market.

Expression (10) indicates that the optimal emissions tax $\hat{t} \neq md^1$, i.e., it will be less than a Pigouvian tax. As $dx^1/dt < 0, d(x^1+x^2)/dt < 0,$ and $dx^2/dt > 0$, then all three terms in square brackets are positive, and when divided by $dx^1/dt < 0,$ the domestic carbon emissions effect, they will be subtracted from unity, i.e., $\hat{t} < md^1$. This result follows from the fact that the home government is concerned not just about the impact of home carbon emissions on its own consumers, but also the following three strategic effects: (i) a deadweight loss effect due to home consumers facing a higher price; (ii) profits being shifted from the home to the foreign firm (competitiveness effect); and (iii) increased carbon emissions by the foreign firm (carbon leakage). Following Ritz (2009) and Karp (2010), we can be more precise about defining carbon leakage *l*:

$$l = \frac{e^2 v_2^2 (dx^2 / dt)}{-\{e^1 v_1^1 (dx^1 / dt)\}} \tag{11}$$

As long as there is positive output leakage, $(dx^2 / dt) / -\{dx^1 / dt\} > 0$, there will be positive carbon leakage, $l > 0$, even if $e^2 v_2^2 \neq e^1 v_1^1$.

Expression (10) captures the key tradeoffs to the home government from unilaterally implementing climate policy. First, the emissions tax reduces home carbon emissions due to the reduction in the home firm's output, the extent depending on how much demand for environmental services by the home firm falls with a reduction in its output. The larger (smaller) is the reduction in domestic carbon emissions, the less (more) important the three countervailing strategic effects. Second, given that the emissions tax causes the home firm to reduce output and the foreign firm to increase output, there is positive carbon leakage, which imposes a negative externality on home consumers. The stronger the carbon leakage effect, the lower the optimal emissions tax. Third, there is a competitiveness effect as the profits of the home firm (foreign firm) fall (rise) with implementation of the emissions tax. This is captured by the fact that the market share of the home firm divided by the price elasticity of demand, $(x^1 / X) / \eta$ is proportional to the home firm's price-cost margin, both of which fall as the home firm's marginal costs increase and its market share falls; at the same time the equivalent expression for the foreign firm $(x^2/X)/\eta$ which is proportional to the foreign firm's price-cost margin, both of which rise due to the market price rising and the foreign firm increasing its market share. The stronger the competitiveness effect, the lower the optimal emissions tax. Fourth due to the fact that the emissions tax results in total output falling in the home market, there is a deadweight loss effect as consumers face a greater oligopolistic distortion in equilibrium. Specifically, the greater is the deadweight loss, the lower the optimal emissions tax. Of course the competitiveness and oligopoly deadweight loss effects disappear if the home market is perfectly competitive, i.e., $\eta = -\infty$ and there are no mark-ups over marginal cost by either the home of foreign firm in equilibrium. In which case, the optimal emissions tax depends only on the extent of carbon leakage. This highlights an important result – while a connection is often made between competitiveness and carbon leakage in discussions of climate policy, they are quite separate effects in this model.

Optimal Carbon Taxes with Border Tax Adjustments

Assume now that a BTA, *b*, can be targeted at imports from the foreign country. Since the WTO/GATT guidelines are not specific in defining 'competitive equality', we consider the case where the neutral BTA (*neutral BTA*) is defined as that *b* which keeps the volume of imports constant given the emissions tax *t*. Following McCorriston and Sheldon (2005a), if neutrality is defined in terms of import volume, the appropriate BTA is given as:

$$neutralBTA = \frac{(dx^2/dt)t}{-(dx^2/db)} \tag{12}$$

Using (6), $dx^2/dt = -\pi^2_{2,1}\Delta^{-1} > 0$, and $dx^2/db = \pi^1_{1,1}\Delta^{-1} < 0$, and given own own-effects outweigh cross-effects, then $-\pi^2_{2,1}\Delta^{-1}/-(\pi^1_{1,1}\Delta^{-1}) < 1$. Therefore, for the BTA to be neutral, $b < t$, and the net effect of the policies is $dx^2 / d(t+b) = 0$. At the same time, implementation of the BTA also affects the output choice of the home firm. Again using (6), $dx^1 / db = -\pi^1_{1,2}\Delta^{-1} > 0$, so that the net effect on the home firm's output of implementation of both policies is $dx^1 / d(t+b) = (\pi^2_{2,2} - \pi^1_{1,2})\Delta^{-1} < 0$, i.e., while the BTA restores some output to the home firm, the own-effect of the emissions tax still outweighs the cross-effect of the BTA.

Given the neutral BTA, the home government's objective function becomes:

$$\max_t w(t)\big|_b = \int_0^X p(\xi)d\xi - p(X)X + \pi^1(x^1, x^2; t, b) + t(1-a^1)e^1v^1 + bx^2 - d(U^1) \qquad (13)$$

and the optimal emissions tax $\tilde{t}$ can be written as:

$$\tilde{t} = md^1 \left\{ 1 + \frac{1}{md^1(1-a^1)e^1v_1^1 \dfrac{dx^1}{d(t+b)}} \left[\frac{p}{\eta}\left(\frac{x^1}{X}\frac{dx^1}{d(t+b)} + \frac{x^2}{X} \times \frac{d(x^1+x^2)}{d(t+b)} \right) + md^1e^2v_2^2 \frac{dx^2}{d(t+b)} \right] \right\} \qquad (14)$$

Expression (14) indicates that the optimal emissions tax $\tilde{t} \neq md^1$, i.e., it will still be less than a Pigouvian tax. As $dx^1 / d(t+b) < 0, d(x^1+x^2)/d(t+b) < 0,$ and $dx^2 / d(t+b) = 0$, then while the third term, the carbon leakage effect is now zero, the first and second terms in square brackets are positive, and when divided by $dx^1 / d(t+b) < 0,$ the domestic carbon emissions effect, they will be subtracted from unity, i.e., $\tilde{t} < md^1$. This result follows from the fact that the home government is still concerned not just about the impact of home carbon emissions on its own consumers, but also the remaining strategic effects: (i) a deadweight loss effect due to home consumers facing a higher price; and (ii) a competitiveness effect of profits being shifted from the home to the foreign firm (competitiveness effect).

Expression (14) captures the adjusted tradeoffs to the home government from unilaterally implementing climate policy in combination with a BTA. First, the combination of emissions tax and BTA has the net effect of reducing home carbon emissions due to the reduction in the home firm's output, the extent again depending on how much demand for environmental services by the home firm falls with a reduction in its output. The larger (smaller) is the reduction in domestic carbon emissions, the less (more) important the two countervailing strategic effects. Second, given that the combination of emissions tax and BTA results in no output change by the foreign firm, there is no carbon leakage, i.e., the optimal emissions tax will be higher, $\tilde{t} > \hat{t}$ Third, there is a competitiveness effect as the profits of the home firm (foreign firm) still fall (rise) with implementation of the emissions tax and BTA. The home firm's price-cost margin falls as its marginal costs increase and its market share falls; at the same time the foreign firm's price-cost margin rises due to the market price rising and the foreign firm increasing its market share, i.e., even though its output does not change, the home firm reduces its output. The stronger this competitiveness effect, the lower the optimal emissions tax, even in the presence of a BTA. Fourth due to the fact that combination of emissions tax and BTA results in total output falling in the home market, there is still a deadweight loss effect as consumers face a greater oligopolistic distortion in equilibrium. The greater is the deadweight loss, the lower the optimal emissions tax.

The net effect of applying an emissions tax and neutral BTA in a Cournot setting is illustrated in figure 1, where the initial Nash equilibrium is *C*. With an emissions tax t , the new Nash equilibrium at *C** results in the foreign firm increasing both its output and profits at the expense of the domestic downstream firm, i.e., there is both a loss in the latter's competitiveness and there is carbon leakage. However, when a neutral BTA is applied, the combination of emissions tax t and b shifts less output and profits away from the home to the foreign firm. Application of t shifts the home firm's reaction function from F^1 to $F^{1\prime}$, output falling to $x^{1\prime}$, and

b shifts the foreign firm's reaction function from F^2 to $F^{2\prime}$, the new Nash equilibrium being C′, such that the foreign firm's output remains at $x^2 = x^{2\prime}$. However, even with a neutral BTA, the home firm still loses market share, and its profits fall to $\pi^{1\prime}$, while the foreign firm's profits increase to $\pi^{2\prime}$. The key point is that the neutral BTA can be used to target the carbon leakage problem, but resolves neither the competitiveness problem of the home firm nor the deadweight loss facing home consumers.

2. Carbon Taxes and Border Tax Adjustments – the Bertrand Case

The Basic Model

As Eaton and Grossman (1986) have shown, the effects from implementing policies in oligopolistic markets are very sensitive to the underlying game being played by firms. Following Conrad (1996b), we assume a similar model structure to the Cournot case, except that firms now play a Bertrand game in prices. Starting with the second-stage price game between firms, the direct demand functions for the home and foreign firm are given as, $x^i(p^i, p^j), i \neq j$, and the profit functions of the firms, $\pi^i(.), i = 1, 2$ in terms of price are:

$$\pi^1(p^1, p^2; t, b) = p^1 x^1(p^1, p^2) - c^1[x^1, z^1(t)] \tag{15}$$

$$\pi^2(p^1, p^2; t, b) = p^2 x^2(p^1, p^1) - c^2[x^2, z^2] - b(x^2) \tag{16}$$

Home and foreign goods are treated as heterogeneous, and it is also assumed that own-price effects on output are negative $x_i^i < 0$, and cross-price effects on output are positive, $x_j^i > 0$, $i \neq j$. The Nash equilibrium of the price game between the two firms is characterized by the following first-order conditions:

$$\pi_1^1 = x^1 + px_1^1 - c_1^1 x_1^1 = 0 \tag{17}$$

$$\pi_2^2 = x^2 + px_2^2 - c_2^2 x_2^2 = 0 \tag{18}$$

where subscripts refer to the the derivatives of profit and output with respect to prices. The second-order conditions are, $\pi_{1,1}^1 < 0, \pi_{2,2}^2 < 0$, and stability of the equilibrium is ensured by the conditions $\pi_{1,2}^1 > 0, \pi_{2,1}^2 > 0$, implying $\Delta = \pi_{1,1}^1 \pi_{2,2}^2 - \pi_{1,2}^1 \pi_{2,1}^2 > 0$, i.e., the own-effects on marginal profit outweigh the cross-effects (Spencer and Jones, 1992).

In order to conduct comparative statics, (17) and (18) are totally differentiated with respect to p^i, t and b, resulting in:

$$\begin{bmatrix} dp^1 \\ dp^2 \end{bmatrix} = \Delta^{-1} \begin{bmatrix} x_1^1 \pi_{2,2}^2 & -x_2^2 \pi_{1,2}^1 \\ -x_1^1 \pi_{2,1}^2 & x_2^2 \pi_{1,1}^1 \end{bmatrix} \begin{bmatrix} dt \\ db \end{bmatrix} \tag{19}$$

Assuming in the first stage of the game that the home government commits to an emissions tax but no border tax, the following comparative static results can be derived: $dp^1 / dt = \Delta^{-1} x_1^1 \pi_{2,2}^2 > 0, dp^2 / dt = \Delta^{-1} - x_1^1 \pi_{2,1}^2 > 0$, and using the demand functions $dx^1 / dt < 0, dx^2 / dt > 0$, i.e., home and foreign prices increase with the emissions tax, while home (foreign) output declines (increases) with the emissions tax. These results follow from the fact that home and foreign goods are *strategic complements*, i.e., firms' reaction functions are upward-sloping in price space (Bulow *et al.*, 1985). Total differentiation of (17) and (18) holding policies constant yields the slopes of the reaction functions, $dp^i / dp^j = -\pi_{ij}^i / \pi_{ii}^i > 0, i = 1, 2, i \neq j$.

Optimal Carbon Taxes without Border Tax Adjustments

Given the basic model, the next step is to characterize the objective function of the home government, given the foreign government chooses not to implement a carbon emissions tax.

Again, it is assumed the home government maximizes the sum of consumer surplus, profits of the home firm (competitiveness), and the revenues derived from using any tax instruments, minus the damage from global carbon emissions. The objective function of the home government is now written as:

$$\max_t \, w(t) = \int_{p^1}^{\bar{p}^1} [x^1(\xi, p^2) + x^2(\xi, p^2)]d\xi + \pi^1(p^1, p^2; t) + t(1-a^1)e^1v^1 - d(U^1) \qquad (20)$$

where $\bar{p}^1$ is the choke price for the home good at which point $x^1(\bar{p}^1, p^2) = 0$. In order that unambiguous results can be obtained from the maximization of (20), we assume that the demand functions are linear:

$$x^1(p^1, p^2) = \alpha^1 - \beta_1^1 p^1 + \beta_2^1 p^2 \qquad (21)$$

$$x^2(p^1, p^2) = \alpha^2 - \beta_1^2 p^2 + \beta_2^2 p^1 \qquad (22)$$

where $\beta_1^i > 0$ and $\beta_2^i > 0$. A necessary and sufficient condition for getting clear results is that $2\eta^{x^1p^1}.\eta^{x^2p^2} - \eta^{x^1p^2}.\eta^{x^2p^1} > 0$, where the own-price elasticities, $\eta^{x^ip^i} < 0, i = 1, 2$, and the cross-price elasticities, $\eta^{x^ip^j} > 0, i = 1, 2, i \neq j$. Given (21) and (22), the choke price is given as, $\bar{p}^1 = (\alpha^1 + \beta_2^1)/\beta_1^1$.

The first-order condition of (20), which can again be thought of as the home government's reaction function, is given as:

$$\begin{aligned}\frac{dw}{dt} &= x^1(\bar{p}^1, p^2)\frac{d\bar{p}^1}{dt} - x^1(p^1, p^2)\frac{dp^1}{dt} + \int_{p^1}^{\bar{p}^1}\frac{dx^1}{dt} + x^2(\bar{p}^1, p^2)\frac{d\bar{p}^1}{dt} - x^2(p^1, p^2)\frac{dp^1}{dt} + \int_{p^1}^{\bar{p}^1}\frac{dx^2}{dt} \\ &+ x^1\frac{dp^1}{dt} + p^1\frac{dx^1}{dt} - c_1^1\frac{dx^1}{dt} - c_{z^1}^1\frac{dz^1}{dt} + (1-a^1)e^1v^1 + t(1-a^1)e^1v_1^1\frac{dx^1}{dt} \\ &- md^1\left[(1-a^1)e^1v_1^1\frac{dx^1}{dt} + e^2v_2^2\frac{dx^2}{dt}\right] = 0\end{aligned} \qquad (23)$$

and (23) can be re-arranged in terms of an optimal home emissions tax $\hat{t}$:

$$\hat{t} = md^1 \left\{ 1 + \frac{1}{md^1(1-a^1)e^1v_1^1(dx^1/dt)} \left[2\frac{\eta^{x^1p^2}}{\eta^{x^1p^1}} \frac{p^1}{p^2} \frac{dp^2}{dt} X + \frac{dp^1}{dt} X + md^1e^2v_2^2 \frac{dx^2}{dt} \right] \right\} \quad (24)$$

Expression (24) indicates that the optimal emissions tax $\hat{t} \neq md^1$. As $dp^2/dt > 0$, the first term in square brackets is negative, and when divided by $dx^1/dt < 0,$ the domestic carbon emissions effect, this will have the effect of pushing the optimal emissions tax $\hat{t}$ above marginal damage. Counter to this as $dp^1/dt > 0$ and $dx^2/dt > 0,$ when divided by $dx^1/dt < 0,$ will have the effect of pushing the optimal emissions tax $\hat{t}$ below marginal damage.

Expression (24) again captures the key tradeoffs to the home government from unilaterally implementing climate policy, but this time under Bertrand competition. First, the emissions tax reduces home carbon emissions due to the reduction in the home firm's output, the extent depending on how much demand for environmental services by the home firm falls with a reduction in its output. The larger (smaller) is the reduction in domestic carbon emissions, the less (more) important the other strategic effects. Second, given that the emissions tax causes the home firm to reduce output and the foreign firm to increase output, there is positive carbon leakage, which imposes a negative externality on home consumers. The stronger the carbon leakage effect, the lower the optimal emissions tax. Third, compared to the case of Cournot competition there is now a positive competitiveness effect multiplied by a factor of two. This follows from the fact that the profits of the home and foreign firm rise with implementation of the emissions tax as the goods are strategic complements. The stronger the competitiveness effect, the higher the optimal emissions tax. Fourth due to the fact that the emissions tax results in both home and foreign prices rising in the home market, there is a deadweight loss effect as consumers face a greater oligopolistic distortion in equilibrium. The greater is the deadweight loss, the lower the optimal emissions tax. Whether or not the optimal emissions tax lies above or below marginal damage will be a function of the competitiveness effect vs. the deadweight loss effect, i.e., $2\eta^{x^1p^2}/\eta^{x^1p^1}\frac{p^1}{p^2}\frac{dp^2}{dt}+\frac{dp}{dt}>0 \;\; iff\, \eta^{x^1p^1}.\eta^{x^2p^2}>\eta^{x^1p^2}.\eta^{x^2p^1}$, the deadweight loss effect is greater than the competitiveness effect, and as in the Cournot case, $\hat{t}<md^1$.

Optimal Carbon Taxes with Border Tax Adjustments

Even though the prices of both home and foreign firm increase under Bertrand competition, due to the fact that home and foreign goods are imperfect substitutes, the home emissions tax causes the foreign firm to increase its output, thereby generating carbon leakage. Assume then that a neutral BTA, *b*, can again be targeted at imports from the foreign country. In this case, as the game is in prices, the level of *b* has to be such that it results in the foreign firm reducing its output by the same amount as it increased output in response to the emissions tax. Given application of the emissions tax, the following comparative static results can be derived: in terms of price and output effects: from (19), the price effects of the BTA are $dp^1/db=\Delta^{-1}-x_2^2\pi_{1,2}^1>0,$ and $dp^2/db=\Delta^{-1}x_2^2\pi_{1,1}^1>0,$ with the cumulative price effects of an emissions tax and a BTA being, $dp^1/d(t+b)=\Delta^{-1}(x_1^1\pi_{2,2}^2+x_2^2\pi_{1,2}^1)>0$, and $dp^2/d(t+b)=\Delta^{-1}(-x_1^1\pi_{2,1}^2+x_2^2\pi_{1,1}^1)>0$; the output effects of the BTA are, $dx^1/db>0$ and $dx^2/db<0$, with the cumulative output effects of an emissions tax and a BTA being, $dx^1/d(t+b)<0$ and $dx^2/d(t+b)<0$, i.e., home and foreign prices increase with both taxes, and home and foreign output declines with both taxes. The latter result is interesting in that even if the BTA properly counteracts the effect of the emissions tax, the combination of both policies actually facilitates collusion in equilibrium.

Given the neutral BTA, the home government's objective function becomes:

$$\max_t w(t)\big|_b = \int_{p^1}^{\bar{p}^1} [x^1(\xi, p^2) + x^2(\xi, p^2)]d\xi + \pi^1(p^1, p^2; t, b) + t(1-a^1)e^1v^1 + bx^2 - d(U^1) \quad (25)$$

and the optimal emisisons tax $\tilde{t}$ can be written as:

$$\hat{t} = md^1 \left\{ 1 + \frac{1}{md^1(1-a^1)e^1v_1^1 \dfrac{dx^1}{d(t+b)}} \left[2\frac{\eta^{x^1p^2}}{\eta^{x^1p^1}} \frac{p^1}{p^2} \frac{dp^2}{d(t+b)} X + \frac{dp^1}{d(t+b)} X + md^1e^2v_2^2 \frac{dx^2}{d(t+b)} \right] \right\} \quad (26)$$

Expression (26) indicates again that the optimal emissions tax $\hat{t} \neq md^1$. As $dp^2 / d(t+b) > 0,$ the first term in square brackets is still negative, and when divided by $dx^1 / d(t+b) < 0,$ the domestic carbon emissions effect, this will have the effect of pushing the optimal emissions tax $\hat{t}$ above marginal damage. Counter to this, as $dp^1 / d(t+b) > 0$, when divided by $dx^1 / d(t+b) < 0,$ it will have the effect of pushing the optimal emissions tax $\hat{t}$ below marginal damage. The final term is now negative in the Bertrand case as $dx^2 / d(t+b) < 0,$ in other words, there is negative carbon leakage, so that when divided by $dx^1 / d(t+b) < 0,$ it will have the effect of pushing the optimal emissions tax $\hat{t}$ above marginal damage.

Expression (26) again captures the key tradeoffs to the home government from unilaterally implementing climate policy. First, the combination of the emissions tax and BTA reduces home carbon emissions due to the reduction in the home firm's output, the extent depending on how much demand for environmental services by the home firm falls with a reduction in its output. The larger (smaller) is the reduction in domestic carbon emissions, the less (more) important the other strategic effects. Second, given that the combination of emissions tax and BTA causes both the home and foreign firm to decrease output, there is negative carbon leakage. The stronger the negative carbon leakage effect, the higher the optimal emissions tax. Third, there is still a positive competitiveness effect multiplied by a factor of two. This follows from the fact that the profits of the home and foreign firm rise even further with implementation of the emissions tax and BTA. The stronger the competitiveness effect, the higher the optimal emissions tax. Fourth due to the fact that the emissions tax an BTA results in both home and foreign prices rising even further in the home market, there is a deadweight loss effect as consumers face an even greater oligopolistic distortion in equilibrium. The greater is the deadweight loss, the lower the optimal emissions tax. Due to the competitiveness and negative carbon leakage effects working in the same direction, it is possible they will outweigh the deadweight loss effect, so that $\hat{t} > md^1$.

The net effect of applying an emissions tax and neutral BTA in a Bertrand setting is illustrated in figure 2, where the initial Nash equilibrium is *B*. With an emissions tax t, the new Nash equilibrium at B' results in both the home and foreign firm increasing their prices and hence profits, i.e., there is both an improvement in the competitiveness of both firms, although there is carbon leakage due to the foreign firm not raising its price by as much as the home firm, thereby allowing it to raise its output. When a neutral BTA is applied to counteract this, the combination of emissions tax t and b causes both firms to restrict output, raise prices and hence profits. Application of t shifts the home firm's reaction function from F^1 to $F^{1\prime}$, prices and profits rising to $p^{1\prime}$ and $p^{2\prime}$ and $\pi^{1\prime}$ and $\pi^{2\prime}$ respectively, the new Nash equilibrium being B', and b shifts the foreign firm's reaction function from F^2 to $F^{2\prime}$, the new Nash equilibrium being B'', prices and profits rising to $p^{1\prime\prime}$ and $p^{2\prime\prime}$, and $\pi^{1\prime\prime}$ and $\pi^{2\prime\prime}$ respectively. The key point in the Bertrand case is that the emissions tax and neutral BTA, by facilitating collusion between the home and foreign firm and thereby improving their competitiveness in terms of oligopoly profits, results in negative carbon leakage, but does not resolve the deadweight loss facing home consumers.

4. Summary and Conclusions

Inclusion of border measures in proposed climate change legislation is predicated on concerns about reduction in the international competitiveness of firms in industries most affected by domestic climate policies, as well as carbon leakage due increases in the output of foreign firms. It has been shown in the environmental economics literature that a social optimum can be obtained if countries that unilaterally set carbon taxes, should at the same time use import tariffs (export subsidies) on all traded goods. However, this literature also speculates that optimal climate and trade policy could be constrained by existing WTO/GATT rules on the use of border tax adjustments. The key objective of this paper therefore has been to examine how such rules might affect the setting of a domestic carbon tax, taking explicit account of the type of markets most likely to be affected by the use of emissions taxes and border tax adjustments. In the absence of a global agreement on climate change, understanding this interaction is important if carbon taxes are to be set optimally and at the same time not run foul of international legal obligations.

In this paper, the focus has been on examining whether the neutral border tax adjustments help or hinder the setting of an optimal domestic carbon tax. We have modelled this issue in a partial equilibrium setting consisting of an import competing, oligopolistic sector that generates extensive carbon emissions, e.g., steel production (other sectors would be aluminium, steel, chemicals, paper and cement, Houser *et al*., 2008). The policy instruments, available to the domestic government consist of a domestic emissions tax and a border tax adjustment targeted at imports of a foreign good.

In this setting, we first considered the welfare-maximizing emissions tax in a setting where border tax adjustments are unavailable. In the absence of a trade instrument, we have shown that the optimal emissions tax will depend on the nature of strategic interaction between home and foreign firms. If goods are strategic substitutes, there is a "race-to-the bottom" in setting domestic climate policy due to the fact that there are incentives to ensure oligopolistic rents are not shifted from domestic to foreign firms, i.e., the competitiveness effect, as well as minimizing the deadweight loss to consumers. In addition, reducing the domestic emissions tax mitigates the negative effects of carbon leakage from foreign firms increasing output. Alternatively, if goods are strategic complements, and subject to minimizing the deadweight losses to domestic consumers, there will be a "race-to the-top" in setting domestic climate policy as it facilitates collusion, which in turn increases both home and foreign oligopolistic rents as well as reducing global carbon emissions, i.e., both home and foreign firms reduce their output in the presence of a domestic emissions tax. While there are neither competitiveness nor carbon leakage concerns, there will be an offsetting concern about the deadweight loss to consumers from the emissions tax increasing oligopolistic prices in equilibrium.

Second, we have examined the welfare impact of allowing for neutral border tax adjustments in combination with a domestic emissions tax. In the case where goods are strategic substitutes, the results of the analysis show that while an optimal emissions tax can be set higher in the presence of a border tax adjustment, subject of course to minimizing the deadweight loss to domestic consumers, the border tax fails to completely prevent a reduction in the competitiveness of home firms. There is also an increase in carbon leakage as foreign firms increase output. Alternatively, if goods are strategic complements, and again taking account of deadweight losses to domestic consumers, the combination of domestic climate policy and border tax adjustment again facilitates collusion, which in turn increases both home and foreign oligopolistic rents as well as reducing global carbon emissions, i.e., both home and foreign firms reduce their output in the presence of a domestic emissions tax and border tax adjustment. While there are neither competitiveness nor carbon leakage concerns, there is again an offestting concern about the deadweight loss to consumers from the combination of emissions tax and border tax adjustment. Essentially, in the case of both strategic substitutes and complements, solving the carbon leakage and competitiveness effects are actually in conflict with consumer welfare due to the fact that two policy instruments are being targeted at three distortions.

Finally, what directions might this research be taken in? First, the definition of a neutral border tax adjustment is based on restoring the volume of imports to their level prior to implementation of the carbon tax. An alternative would be to consider a neutral border tax adjustment based on maintaining import market share. Second, the analysis presented in this paper has focused only on final goods production, ignoring the alternative possibility that home and foreign firms purchase an intermediate input such as electricity that is carbon-intensive in production, and that home production of the intermediate good also faces an emissions tax. In this case, incidence of the carbon tax in a vertical market system will matter, plus the competitiveness of intermediate goods producers will enter into the home government's welfare function, thereby affecting the level of the carbon tax.

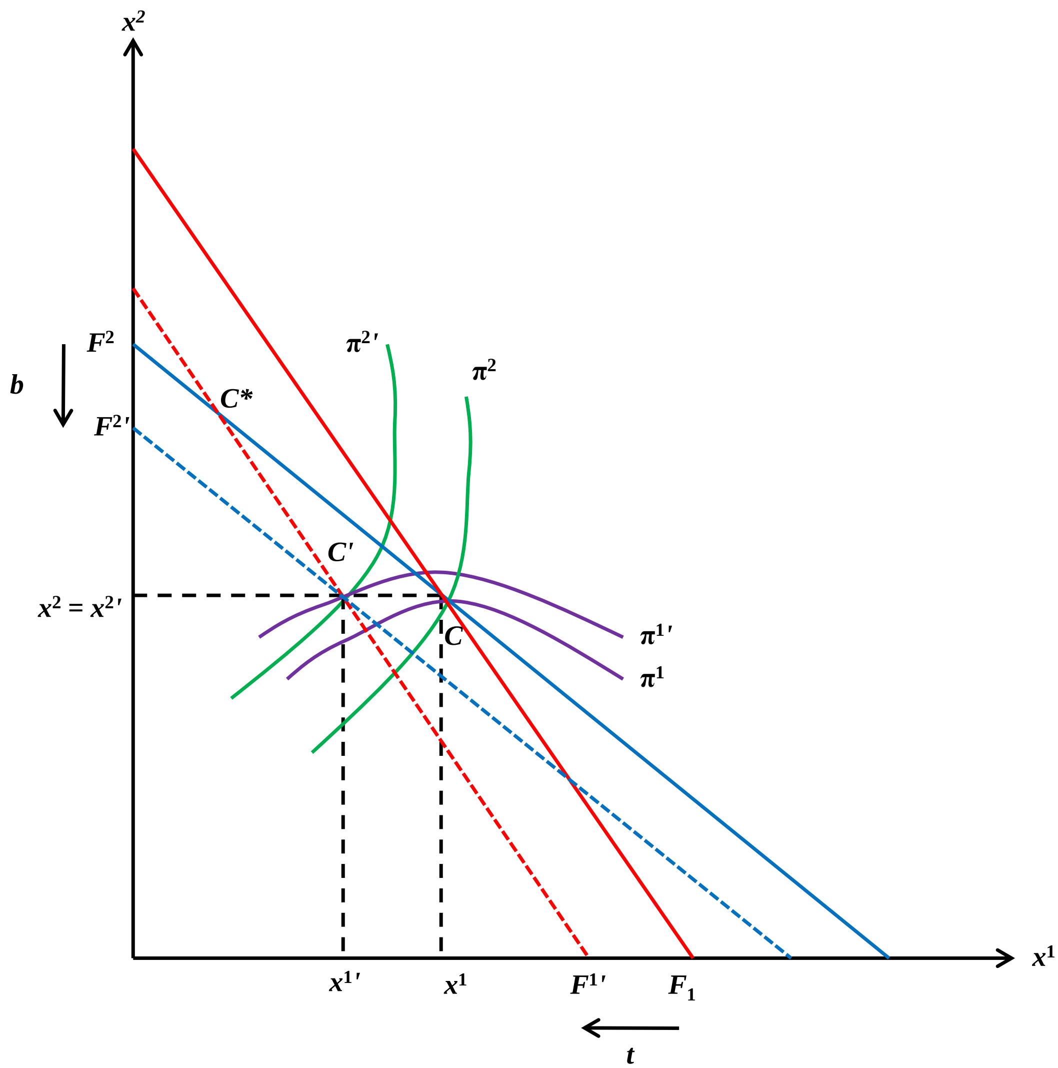

Figure 1. Neutral BTA – Cournot Case

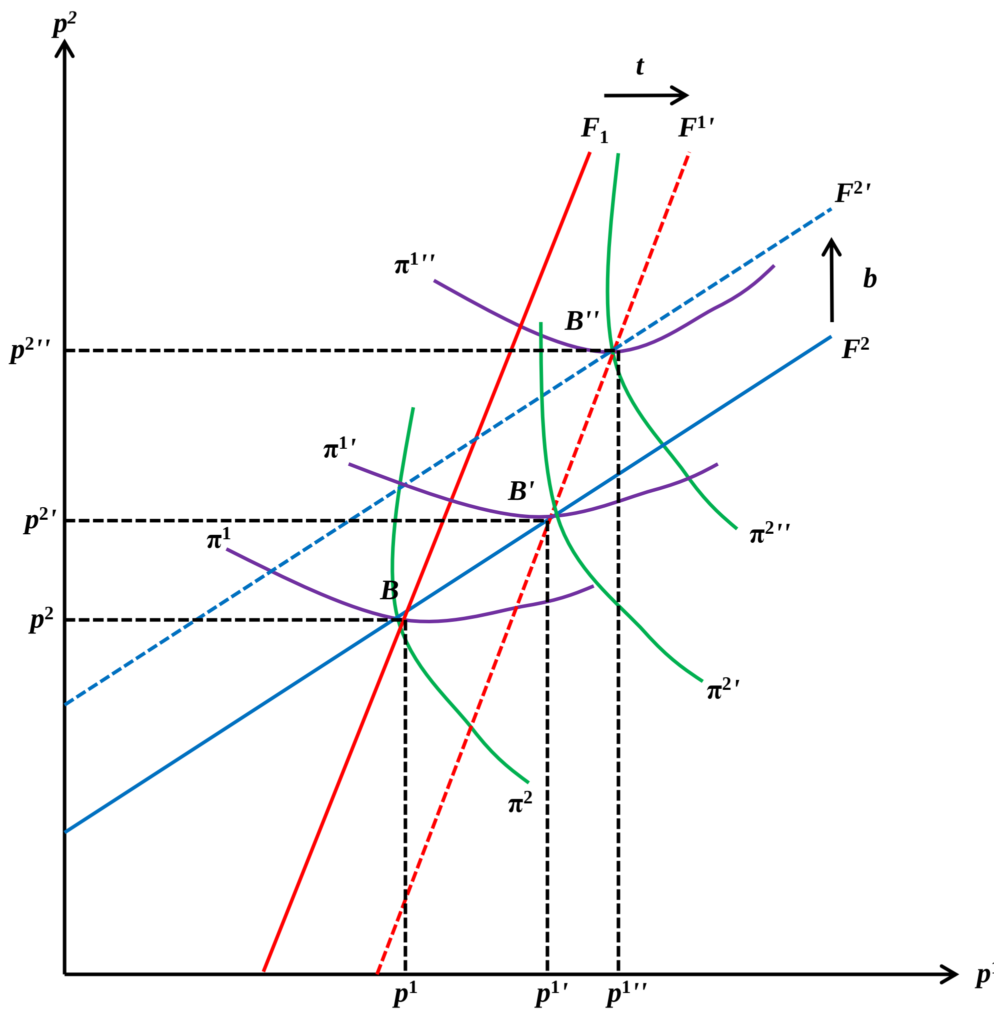

Figure 1. Neutral BTA – Bertrand Case Case

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