Emission Taxes and Border Adjustments for Oligopolistic Industries

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Abstract

One of the controversial issues on trade and climate change policies is the role of Border Tax Adjustments (BTAs). This paper examines the effects of BTAs using a framework of strategic trade and environmental policies. It uses an intra-industry trade model of oligopoly with two countries, in which firms produce homogeneous goods and the production of each firm generates cross-border pollution such as greenhouse gases. It analyzes how BTAs affect an incentive for a national government to use emission tax policy as a strategic instrument for influencing market outcomes. It shows that BTAs raise an emission tax rate in equilibrium due to protectionism motives as well as environmental objectives. Nonetheless, BTAs can improve total welfare since gains from environmental protection outweigh losses of tax burden.

1 Introduction

Climate change policy has been entangled with trade issues for recent years. The United States refused to ratify the Kyoto Protocol because it gives an unfair advantage to manufacturers in nations such as China and India that are not required to cut greenhouse gas emissions. More recently, at the United Nations Climate Change Convention, 15th Conference of the Parties (UNFCCC, COP 15) held in Copenhagen, the United States pushed for the right to impose border adjustments in a draft deal, "tariffs" on

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certain goods from countries like China and India that do not act to limit their greenhouse gas emissions[1]. Some argue that this type of trade policy is an indirect measure for those countries to reduce their greenhouse gas emissions so that the global nature of climate change is taken into account (World Trade Organization, 2009). However, others warn that there could be a backlash from those trading partners that could, in the end, trigger tit-for-tat actions that would hurt exporters (Reuters, 2009).

The border adjustment is not a new idea[2]. Under the definition of General Agreement on Tariffs and Trade and World Trade Organization (GATT/WTO) rules, "a border tax adjustment consists of two situations: (i) the imposition of a tax on imported products, corresponding to a tax born by similar domestic products, and/or (ii) the refund of domestic taxes when the products are exported" (WTO, 2009). Border tax adjustments are commonly used with respect to domestic taxes on the sale or consumption of goods. There is an extensive legal debate over the eligibility of domestic carbon/energy taxes for border tax adjustments (Hufbauer et al., 2009). In trade policy circles, they often express a fear that border adjustments are imposed to protect national commercial interests and they will be used as an instrument for protectionism (Fischer and Horn, 2010). Economists argue that border adjustments based on climate change policy could be justified. Nobel-Prize winning trade economist Paul Krugman sates "what the economics really says is that incentives should reflect the marginal cost of greenhouse gases in all goods, wherever produced - which in this case happens to imply border adjustments (Krugman, 2009)."

We examine the effects of Border Tax Adjustments (BTAs) motivated

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[1] A group of developing countries supported a draft having provisions that restrict the use of unilateral trade measures as a part of climate change policies. European Union, together with other developed countries including Japan, firmly opposed any provisions that would question the parties' right to apply trade measures in the climate change context. As a result, no references to trade are made in *Copenhagen Accord*, but trade related proposals were included in the Chair's draft text.

[2] In 1960s and 1970s, there was an extensive discussion concerning the legality of a Border Tax Adjustment scheme as a means for correcting different forms of indirect taxation. They were not motivated by environmental concerns. In the context of climate change policy, the term Border Adjustment refers to the measure that takes the form of a tax or a regulation imposed at the border aiming at equal treatment of the embedded carbon content of like foreign and domestic products (Horn and Mavroidis, 2010). Horn and Mavroidis use the term Border Carbon Adjustment instead of Border Adjustment. If the measure of Border Adjustment takes the specific form of a tax, then it is called "Border Tax Adjustment."

by climate change policy in the framework of strategic trade and environmental policies. We will consider a variant of a model developed by Brander and Krugman (1983), in which intra-industry trade in homogeneous goods arises in an oligopolistic industry due to imperfect competition and/or scale economies, and production generates pollution that causes cross-border externalities.[3] In climate change policies proposed in developed countries, border adjustments are applied to carbon/energy intensive industries including chemicals, paper, steel, and cement. We use the oligopoly model because the carbon-intensive sectors have features of oligopolistic industries.

Our model differs from the existing work on strategic environmental policy in that countries choose emission tax policies under several rules of BTAs.[4] As a trade measure of BTAs, we will consider a pollution-content tariff which is imposed on an imported product based on the emission-content of the product.[5] We shall consider three different regimes on BTAs, (i) a full BTA (FBTA), (ii) a partial BTA (PBTA), and (ii) no BTA (NBTA). In FBTA, border tax adjustments are applied both to imports and to exports so that an emission tax on domestic products and a pollution-content tariff on like foreign products are imposed at equal rates and the emission tax on exports of domestic products are exempted. In PBTA, border tax adjustments are applied only to imports but countries can differentiate emission tax rates on domestic products according to its sales destination, the domestic market and the foreign market.[6] In NBTA, border tax adjustments are applied neither to imports nor to exports so that an emission tax is imposed on domestic products at equal rates regardless of sales destination and the pollution-content tariff is exempted.

In this setting, we will examine a strategic interaction among countries when they choose emission tax policies under the symmetric regimes of BTAs. If one country applies BTAs to trade with the other country uni-

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[3] Dixit (1984) developed a framework for analyzing trade policy in a reciprocal market model a la Brander and Krugman. We will extend Dixit's framework to a setting in which emission tax policy and BTAs can be examined.

[4] There is an extensive literature on strategic environmental policy, including Kennedy (1994), Conrad (1996), Burguet and Sempere (2003), and Lai and Hu (2008) among others. This paper is similar to these studies in that they examine environmental policy with reciprocal market models. However, none of them examine BTAs motivated by environmental concerns.

[5] The idea of a pollution-content tariff is used in a different context by Copeland (1996).

[6] We will consider this case because border adjustments are often applied only to imports in the schemes of climate change policies proposed in developed countries.

laterally, this targeted country has an incentive to retaliate by using trade measures. As a means of retaliation, the targeted country may use trade measures of BTAs instead of import tariffs and export subsidies because the use of them is constrained due to GATT/WTO trade agreement. We will consider a situation in which there are two countries, the home country and the foreign country, and, given the other country's emission tax policy, each country chooses emission tax policy simultaneously to maximize its total welfare under each of the BTA regimes.

We can show that BTAs affect a country's optimal policy reaction to the other country's emission tax policy. The reason is that BTAs allows each country to impose a pollution-content tariff on imports as an instrument for protectionism motives as well as for environmental objectives. In fact, the home country may raise its emission tax in order to increase its pollution-content tariff on imports if the foreign country promotes its exports to the home country by reducing its emission tax for foreign country's exporters. This strategic effect does not exist in the absence of BTAs.

We also examine the effects of BTAs with respect to economic efficiency and environmental quality. We compare Nash equilibrium outcomes of the policy game under the full border tax adjustment (FBTA) with those under no border tax adjustment (NBTA). Using a numerical example, we show that FBTA is preferred to NBTA in terms of both total welfare and environmental quality if the degree of cross-border pollution is sufficiently high. In fact, climate change is a global environmental problem and the degree of cross-border externalities is sufficiently high. This result suggests that border tax adjustments motivated by climate change policy can improve economic efficiency and environmental quality in spite of their protectionism motives as well as environmental objectives.

There is a glowing literature on border adjustments related to climate change policy. One branch of this literature uses Computable General Equilibrium (CGE) models and examines the quantitative impacts of border measures as a part of unilateral regulation on greenhouse gas emissions, including Matoo et al. (2009), McKibbin and Wilcoxen (2008), Boehringer et al. (2010) among others. While this work is quite useful to evaluate quantitatively the effects of various border adjustments on "international competitiveness" and "carbon leakage," it does not take into account of the

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effect of external costs caused by greenhouse gas emissions on total welfare.[7]

Another branch of this literature theoretically analyzes the effects of border adjustments, including Gros (2009), Horn and Mavroidis (2010), and Tarui, Yomogida, and Yao (2010) among others. They use competitive partial equilibrium settings that include cross-border externalities caused by greenhouse gas emissions. The simple settings allow them to analyze optimal emission tax and import tariff policies chosen by a welfare maximizing government and its implications for total welfare including climate as the environment.[8]

This paper is closely related to the latter and complements the existing work in that it uses a framework of strategic trade and environmental policies for oligopolistic industries. In this framework, intra-industry trade arises so that we can consider a situation of the full border tax adjustment in which BTAs applied to exports of domestic products and imports of like foreign products within an industry, which enables us to compare the effects of the full border tax adjustment with those of no border tax adjustment in terms of efficiency within an industry. Moreover, we can analyze how BTAs affect a government's incentive to use emission tax policy as a strategic instrument for influencing market outcomes and its best reaction to the other country's emission policy.

The rest of this paper is organized as follows. In Section 2, we develop a framework for analyzing emission taxes and BTAs in a reciprocal market model. In Section 3, we consider three different regimes of BTAs and derive optimal emission tax policy under each of the regimes. In Section 4, we examine Nash equilibrium outcomes of the policy games in which countries choose optimal emission tax policies under different situations of BTAs. We also evaluate the effects of the full border tax adjustment on total welfare. In Section 5, we close this paper with concluding remarks.

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[7]Fischer and Fox (2009) examine the effects of BTAs on "competitiveness" and "leakage" in a given sector by using a partial equilibrium model parameterized by simulations of a CGE model.

[8]The interest in the role of BTAs as a correcting device for different forms of indirect taxation resulted in an extensive literature. This research suggests that BTAs are neutral from a trade point of view, i.e., implementation of BTAs transforms an origin-base tax system to a destination base tax system and it does not distort trade under certain conditions. See Horn and Mavroidis (2010) for an excellent review of this literature. For the relevance of this early literature to the current debate on BTAs motivated by environmental objectives, see Lockwood and Whalley (2008).

2 Model

There are two countries, labelled home and foreign. The industry is an oligopoly with given number of firms. Firms are located in each country, produce homogeneous goods, and compete a la Cournot. They do not incur transport costs, but such costs for arbitragers are prohibitively high, so the demand curves in the two markets are independent. The technology for each firm is described by a fixed cost and a constant marginal cost. Production of firms generates emissions of pollution such as greenhouse gases that cause cross-border external costs.

Let n denote the number of firms located in the home country, and let c be the constant marginal cost and f the fixed cost of each firm. Let x denote the sales of each firm to its domestic market and y the sales of each to the other country's market, and $z = x + y$ total output. Let the corresponding variables in the foreign country be denoted by asterisk, $*$. Then, total sales of the home market are $q = nx + n^*y^*$. Let the inverse demand curve in the home country be $p = p(q)$. For the foreign country, total sales are $q^* = n^*x^* + ny$ and the inverse demand function is $p^* = p^*(q^*)$.

The policy instruments include emission taxes and pollution-content tariffs. Let the home country's emission tax for home firm's home sales be denoted by τ_x, its emission tax for home firm's foreign sales by τ_y, and its pollution-content tariff on imports by t. All of them are specific forms. The corresponding instruments for the foreign country are τ_x^*, τ_y^*, and t^*.

Production of firms emits pollution. Emissions of each firm are proportional to its total output. Let a home firm's emission coefficient be denoted by e, and a corresponding coefficient of each foreign firm by e^*. Then, emissions of each home firm are $e(x + y)$ and those of each foreign firm are $e^*(x^* + y^*)$. Let π and π^* denote the profits of the home and foreign firms, respectively:

$$\pi = [p(q) - \tau_x e]x + [p^*(q^*) - (\tau_y + t^*)e]y - c(x + y) - f,$$
$$\pi^* = [p^*(q^*) - \tau_x^* e^*]x^* + [p(q) - (\tau_y^* + t)e^*]y^* - c^*(x^* + y^*) - f^*.$$

With Cournot behavior, each firm maximizes its profit regarding sales of

other firms fixed. Cournot equilibrium conditions in the home market are

$$p(q) + xp'(q) = c + \tau_x e, \tag{1}$$

$$p(q) + y^* p'(q) = c^* + (\tau_y^* + t)e^*. \tag{2}$$

Similarly, in the foreign market,

$$p^*(q^*) + x^* p^{*\prime}(q^*) = c^* + \tau_x^* e^*, \tag{3}$$

$$p^*(q^*) + y p^{*\prime}(q^*) = c + (\tau_y + t^*)e. \tag{4}$$

Notice that equilibrium conditions in the home market are independent from those in the foreign market. With $q = nx + n^* y^*$, (1) and (2) determine x and y^* in market equilibrium. Similarly, with $q^* = n^* x^* + ny$, (3) and (4) determine x^* and y in equilibrium. Thus, the home country's policy instruments τ_x and t affect the home market only while τ_y influences only the foreign market.

Let $u(q)$ denote the gross benefit of home consumers,

$$u(q) = \int_0^q p(z)dz.$$

Home consumer surplus is $u(q) - p(q)q$. Let home country's total pollution emissions be denoted by $E = n(x + y)e$ and corresponding emissions of the foreign country by $E^* = n^*(x^* + y^*)e^*$. Let h denote the external cost of pollution emissions for home consumers,

$$h = h(E + \mu E^*),$$

where μ is a parameter for the degree of cross-border pollution and we assume that $0 < \mu \leq 1$, $h' > 0$ and $h'' \geq 0$. The home government's budget surplus is

$$\tau_x nex + \tau_y ney + tn^* e^* y^*.$$

The total home country welfare is given by

$$w = u(q) - p(q)q + n\left\{p(q)x + [p^*(q^*) - t^* e]y - c(x + y) - f\right\} + te^* n^* y^* - h(E + \mu E^*).$$

3 Emission Tax Policy under Border Tax Adjustments

We will consider three different regimes of emission and trade taxes: (i) a full border tax adjustment (FBTA), (ii) a partial border tax adjustment (PBTA), and (iii) no border tax adjustment (NBTA). Under FBTA, the home country's emission tax for home firm's home sales and its pollution-content tariff on imports must be levied at equal rates, $\tau_x = t$, and its emission tax for home firm's foreign exports is exempted, $\tau_y = 0$. In PBTA, a border tax adjustment is applied only to imports, $\tau_x = t$, and the home country's emission tax for home firm's foreign sales is not exempted and its rate can be lower than that of the home country's emission tax for home firm's home sales. Under NBTA, the home country's pollution-content tariff on imports is not levied and the home country's emission tax for home firm's home sales and its emission tax for home firm's foreign sales must be levied at equal rates, $\tau_x = \tau_y$. Similarly, for the foreign country, these tax regimes can be considered. In the following analysis, we will consider a situation in which countries have symmetric tax regimes and a government of each country chooses emission tax policy to maximize each country's total economic welfare.

3.1 Optimal Emission Tax Policy under PBTA

In this section, we will consider optimal emission tax policy under PBTA. Optimal tax policy under FBTA is obtained as a special case of PBTA. In PBTA, the home country's government chooses τ_x and τ_y to maximize the total home country welfare subject to the constraint $t = \tau_x$. With the use of (2), it is convenient to rewrite w as

$$w = u(q) - ncx + n[p^* - t^*e - c]y + n^*y^{*2}p' - n^*y^*[c^* + \tau_y^*e^*] - nf - h(E + \mu E^*).$$

Then, we find[9],

$$dw = (p - c - eh' + n^*y^{*2}p'')dq + n^*[c + eh' - (c^* + \mu e^*h' + \tau_y^*e^*) + 2p'y^*]dy^*$$
$$+ n[p^* - c - eh' - t^*e + \mu e^*h']dy + (nyp^{*'} - \mu h'e^*)dq^*. \tag{5}$$

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[9]See Appendix A for the derivation.

Under the constraint that $\tau_x = t$, the effect of the home country's emission tax on its welfare is

$$\frac{\partial w}{\partial \tau_x} = (p - c - eh' + n^* y^{*2} p'') \frac{\partial q}{\partial \tau_x} + n^*[c + eh' - (c^* + \mu e^* h' + \tau_y^* e^*) + 2p' y^*] \frac{\partial y^*}{\partial \tau_x}.$$

We shall illustrate the results with a case in which the demand curves and damage functions are linear[10]. In the linear case, we find

$$\tau_x = -\frac{e^* n^* \{\Gamma + (n + 1 - n^*)\Delta\}}{\Gamma^2 + 2n^* \Delta^2} \tau_y^* - \frac{\Gamma\Theta - n^* \Delta\Lambda}{\Gamma^2 + 2n^* \Delta^2}, \tag{6}$$

where $\Gamma = en + e^* n^*$, $\Delta = e^*(n+1) - en$, $\Theta = a + cn + c^* n^* - (n + n^* + 1)(c + e\theta)$ and $\Lambda = 2[a - c^*(n + 1) + cn] + (n + n^* + 1)[c^* + \mu e^* \theta - (c + e\theta)]$. The best response of the home country's emission tax to the foreign country's emission tax for its exports depends on the sign of the coefficient of τ_y^* on the RHS of (6). The sign depends on gaps in emission coefficients and the market concentration between the countries. For instance, if the number of foreign firms is small and the emission coefficient of each foreign firm is large, then the coefficient of τ_y^* would be negative. However, if the number of foreign firms and the emission coefficient of each foreign firm are large, then the coefficient of τ_y^* would be ambiguous.

Suppose that the numbers of firms and marginal production costs are the same across countries. Then, (6) can be simplified as

$$\begin{aligned}
\tau_x = &-\frac{e^{*2}(2n + 1)}{n(e + e^*)^2 + 2[e^*(n + 1) - en]^2} \tau_y^* \\
&+ \frac{(2n + 1)\{(a - c)(e^* - e) + e\theta[e(n + 1) - e^* n] + \mu e^* \theta[e^*(n + 1) - en]\}}{n(e + e^*)^2 + 2[e^*(n + 1) - en]^2},
\end{aligned} \tag{7}$$

The coefficient of τ_y^* is negative regardless of the gap in emission coefficients between the countries. Thus, under the rule of PBTA, the home country would raise its emission tax if the foreign country reduces its emission tax for its exports to the home country.

Proposition 1 *Suppose that the numbers of firms and marginal production costs are the same across countries. Then, under PBTA, the home country raises its emission tax in response to a reduction of the foreign country's*

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[10] See Appendix B for the details of the linear model.

emission tax for its exports to the home country.

This result suggests that the foreign country's favorable treatment given to its exporting firms creates incentives for the home country's government to raise its emission tax under PBTA. The lower emission tax of the foreign country promotes exports by the foreign firms, increasing their profits in the home market at expense of the home country's firms. In response to this effect, the home country raises its emission tax so as to raise its pollution-content tariff, taking back some of rents from foreign firms to home firms. This motive of protecting home firms from foreign competition creates an incentive for the home country to raise its emission tax in response to a fall in the foreign country's emission tax for foreign exports to the home country.

Let us turn to the home country's emission tax for home firm's exports to the foreign country's market. Its effect on the total home country's welfare is

$$\frac{\partial w}{\partial \tau_y} = n[p^* - c - eh' - t^*e + \mu e^* h'] \frac{\partial y}{\partial \tau_y} + (nyp^{*\prime} - \mu h' e^*) \frac{\partial q^*}{\partial \tau_y}.$$

In the linear case, we find

$$\tau_y = \theta - \left(\frac{n^* + 1 - n}{n^* + 1} \right) \left(\frac{b^* y}{e} \right) - \left(\frac{n^*}{n^* + 1} \right) \left(\frac{\mu e^* \theta}{e} \right).$$

The emission tax rate for home firm's exports could be insufficiently lower than the marginal external cost of emissions, θ. There are two reasons for this result. First, the home country government promotes home firm's exports in order to raise its industry profit obtained in the foreign market. The second term on the RHS shows that this effect exists when the number of home firms is small. Secondly, the home government does not have any instrument to internalize cross-border pollution caused by production of the foreign firms for their sales to the foreign market. Lowering the emission tax rate, the home country enlarges home firm's exports so as to reduce the negative effects of cross-border externalities. This effect appears in the third term on the RHS.

The reduced form of the home country's emission tax for home exports is given by

$$\tau_y = \left[\frac{(n^* + 1 - n)\Delta^*}{2n(n^* + 1)e} \right] \tau_x^* - \left[\frac{(n^* + 1 - n)\Xi^*}{2n(n^* + 1)e} \right] + \theta - \left(\frac{n^*}{n^* + 1} \right) \left(\frac{\mu e^* \theta}{e} \right), \quad (8)$$

where $\Delta^* = e(n^* + 1) - e^* n^*$ and $\Xi^* = a^* - c - \theta e + [c^* + \mu \theta e^* - (c + \theta e)]n^*$. Again, the best response of the home government's emission tax for home exports depends on gaps in the number of firms and the size of emission coefficients. If the number of the home firms and the emission coefficient of each home firm are small, then the coefficient of τ_x^* would be negative. However, if the number of the home firms is large and the emission coefficient of each home firm is small, then coefficient of τ_x^* would be positive.

Suppose that the countries are identical in the number of firms and the size of marginal production costs. Then, (8) would be simplified as

$$\tau_y = \left[\frac{e(n+1) - e^* n}{2n(n+1)e} \right] \tau_x^* - \left[\frac{a^* - c - \theta e + [\mu e^* - e]\theta n}{2n(n+1)e} \right] + \theta - \left(\frac{n}{n+1} \right) \left(\frac{\mu e^* \theta}{e} \right). \tag{9}$$

The best response of the home country's emission tax for home exports depends on the gaps in emission coefficients. If the emission coefficient of the foreign firm is sufficiently large, then the coefficient of τ_x^* would be negative. Thus, under the rule of PBTA, the home government would reduce its emission tax for home exports in response to an increase in the foreign country's emission tax. If the emission coefficient of the foreign firm is not so large, the best response would be opposite. The home government would increase its emission tax for home exports when the foreign country's emission tax policy becomes more stringent.

Proposition 2 *Suppose that the countries are identical in the number of firms and the size of marginal production costs. Then, under PBTA, the home country would reduces its emission tax for home exports in response to an increase in the foreign country's emission tax if the home country's production technology is sufficiently less emission-intensive than the foreign country's.*

This result suggests that a country having "greener" technology would provides a more favorable treatment for its exporting firms as an importing country's emission tax policy becomes more stringent under PBTA. Contrarily, a country having "dirtier" technology would raise its emission tax for its firm's export sales in response to a rise in the emission tax of an importing country.

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3.2 Optimal Emission Tax Policy under FBTA

Next, we turn to the optimal emission tax policy under FBTA. Since each country's emission tax for its firm's exports to the other country's market is exempted, $\tau_y = \tau_y^* = 0$. Using this constraint with (7), the optimal emission tax policy for the home country is

$$\tau_x = \frac{(2n+1)\{(a-c)(e^*-e) + e\theta[e(n+1) - e^*n] + \mu e^*\theta[e^*(n+1) - en]\}}{n(e+e^*)^2 + 2[e^*(n+1) - en]^2} \tag{10}$$

The home country's optimal emission tax for home firm's sales to the home market is independent of the foreign country's emission tax policy. Since the same result holds for the foreign country's optimal emission tax policy, we can state the result as follows:

Lemma 3 *Under FBTA, each country's optimal emission tax policy is independent of each other.*

This result is generated by a property of the reciprocal market model in which markets are segmented due to constant marginal production costs and no arbitragers. The home country's government has an incentive to raise its own industry profits at the expense of foreign firms. At the same time, it has also an incentive to give a more favorable treatment to firms having a lower emission coefficient because they are more efficient in terms of production and cleaner in terms of pollution emissions. However, under the rule of BTAs, it is impossible for the home country to discriminate between home and foreign firms. Thus, in the presence of a gap in emission coefficients, the optimal emission tax policy has a complicated expression. As a simplified case, suppose that countries have identical emission coefficients. Then, under FBTA, the home country's optimal emission tax policy is

$$\tau_x = \frac{(1+\mu)\theta}{2}. \tag{11}$$

For the home country, the optimal emission tax rate for home and foreign firms is a half of the sum of their marginal external costs of emissions.

3.3 Optimal Emission Tax Policy under NBTA

Lastly, we turn to the regime of NBTA. Under NBTA, each country's emission tax rate for its sales to its own market must equal its emission tax rate

for its exports to the other country's market and the pollution-content tariff on imports is exempted. The home country chooses τ_x to maximize the total home welfare under the conditions that $\tau_x = \tau_y$ and $t = 0$,

$$\frac{\partial w}{\partial \tau_x} = (p - c - eh' + n^* y^{*2} p'') \frac{\partial q}{\partial \tau_x} + n^*[c + eh' - (c^* + \mu e^* h' + \tau_y^* e^*) + 2p'y^*] \frac{\partial y^*}{\partial \tau_x}$$
$$+ n[p^* - c - eh' - t^* e + \mu e^* h'] \frac{\partial y}{\partial \tau_x} + (nyp^{*\prime} - \mu h' e^*) \frac{\partial q^*}{\partial \tau_x}.$$

As before, we can derive the best response function of each country's emission pax policy by using the linear model. If countries are identical except for the emission coefficients, then the home country's optimal emission tax policy is

$$\tau_x = \frac{e^*(n^2 - n - 1)}{e[n(2n + 1) + (n + 1)^2]} \tau_x^*$$
$$+ \frac{(2n + 1)\theta[(n + 1)^2 e - (n^2 + 1)\mu e^*] - (n + 1)^2(a - c)}{ne[n(2n + 1) + (n + 1)^2]}. \quad (12)$$

The best response of the home country's emission tax depends on the degree of market concentration. If the number of firms in each country is greater than two, then the sign of the coefficient of τ_x^* is positive. Thus, the home country's optimal emission tax rises in response to an increase in the emission tax in the foreign country. Since a similar result applies to the best response of the foreign country's emission tax, we can state the result as follows:

Proposition 4 *Suppose that countries are symmetric except for the emission coefficients. Then, if the number of each country's firms is larger than two, then, under NBTA, each country lowers its emission tax in response to a reduction in the emission tax of the other country.*

This result is in contrast to that obtained in PBTA. As we have shown in Proposition 1, in the presence of the partial border tax adjustments, the home country *raises* its emission tax for home firm's home sales in response to a reduction of the foreign country's emission tax for foreign firm's export sales to the home market. If border tax adjustments are absent, the pollution-content tariff on imports cannot be used and thus the home country does not have any instrument to counteract the effect of foreign country's export promotion driven by the lower emission tax of the foreign country. Therefore, in the absence of border tax adjustments, the home

country lowers its emission tax so as to expand its exports to the foreign country in response to a fall in the foreign country's emission tax as long as the market concentration is low.

4 Non-cooperative Policy Game

We will examine Nash equilibrium in the non-cooperative policy game. We will consider a situation in which countries choose emission tax policies simultaneously under each of the tax regimes. We will also compare policy game outcomes in the two extreme regimes, full BTA and no BTA, in terms of economic welfare. For the simplification of the analysis, we will consider a case in which the countries have identical preferences and production technologies.

4.1 Nash Equilibrium

First, we will consider a policy game outcome under PBTA. In the case of symmetric countries, the home country's best response of its emission tax for home market sales is derived from (7) as

$$\tau_x = -\frac{\tau_y^*}{2} + \frac{(1+\mu)\theta}{2},$$

(13)

and the home country's best response in its emission tax for home firm's exports is obtained from (9) as

$$\tau_y = \frac{\tau_x^*}{2n(n+1)} - \frac{a - c - (2n+1)[(1-\mu)n + 1]e\theta}{2n(n+1)e}.$$

(14)

The corresponding foreign best response functions have the same forms as (13) and (14) respectively. Suppose that the degree of the cross-border pollution is perfect, i.e. $\mu = 1$. Then, solving (13) and the foreign counterpart of (14) simultaneously, we find

$$\tau_x = \frac{a - c + [2n(2n+1) - 1]e\theta}{(2n+1)^2 e},$$

(15)

$$\tau_y^* = \frac{4(n+1)e\theta - 2(a - c)}{(2n+1)^2 e}.$$

(16)

Since the countries are symmetric, we have $\tau_x^* = \tau_x$ and $\tau_y = \tau_y^*$. In the Nash equilibrium, the volume of exports is guaranteed to be positive under a certain condition[11]. In the equilibrium, each country's emission tax rate for its sales to its own market is positive but its emission tax rate for its exports to the other country's market could be positive or negative.[12] Also, each country's emission tax rate for its sales to its own market is necessarily larger than its emission tax rate for its exports to the other country's market, i.e., $\tau_x - \tau_y > 0$[13]. Under PBTA, each country's government provides a more favorable treatment to its exports to the other country as compared to its sales to its own market.

Proposition 5 *Suppose that countries are identical in preferences and technologies. If the degree of cross-border pollution is perfect, $\mu = 1$, then, in the Nash equilibrium of the policy game under PBTA, each country's emission tax for its sales to its own market is higher than its emission tax for its exports to the other country's market.*

Next, we will consider an equilibrium outcome in FBTA. As we have shown, FBTA is a special case of PBTA in that the emission tax for exports to the other country's market is exempted, $\tau_y = \tau_y^* = 0$. Therefore, each country's optimal emission tax rate is independent of each other. In the case with symmetric countries, the equilibrium outcome of the policy game under the full BTA has been obtained as (11).

Lastly, we turn to NBTA regime. If countries are symmetric, then the Nash equilibrium outcome of the policy game under NBTA is obtained by using (12) with $e = e^*$ and $\tau_x = \tau_x^*$,

$$\tau_x = \frac{\theta(2n+1)}{2n} - \frac{\theta\mu(2n+1)(n^2+1)}{2(n+1)^2 n} - \frac{a-c}{2ne}. \tag{17}$$

There are three components on the RHS. The first term is positive because the emission tax is used to internalize the external costs of emissions by home firms. The second term is negative because the government has an

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[11] We can derive outputs of each firm, the total sales, the market price, the profit of each firm, and the total welfare of each country. See Appendix C

[12] From Appendix C, the volume of exports is positive if $\frac{a-c-\theta e}{e\theta} > \frac{2n+1}{2(n+1)}$. Also we can show that $\tau_y \geq 0$ if and only if $\frac{a-c-\theta e}{e\theta} \leq 2n+1$. Thus, if $\frac{2n+1}{2(n+1)} < \frac{a-c-\theta e}{e\theta} < 2n+1$, then a country's emission tax for its exports to the other country is positive.

[13] We can show that $\tau_x - \tau_y = [3(a-c) + (4n^2 - 2n - 5)e\theta]/[(2n+1)^2 e] > 0$ if and only if $n \geq 1$.

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incentive to provide an export subsidy for home firms. Providing a subsidy for exports and expanding home firm's sales to the foreign market can benefit the home country due to the following two reasons. First, it benefits home firms by shifting profits from foreign firms to home firms. Second, it reduces the foreign firm's sales in the foreign market and resulting reductions in foreign firm's emissions would mitigate the negative effects of cross-border pollution. The last term is also negative. Since firms have market power, sales to the home market are insufficiently lower than the optimal level. Thus, the home government can benefit consumers by providing a subsidy for the home firm's home market sales.

4.2　Welfare Comparison between FBTA and NBTA

In this section, we will compare Nash equilibrium outcomes of the two extreme regimes, FBTA and NBTA, in terms of economic welfare and the environmental quality measured by total emissions. Even in the linear model, analytical results are very complicated. Thus, we will use a numerical example.[14] As in the previous section, we will consider a situation in which countries are symmetric.

Figure 1 shows a relation between each country's total welfare and the degree of cross-border pollution. The higher μ implies the larger degree of cross-border pollution. FBTA achieves the greater total welfare than NBTA if the degree of cross-border pollution is sufficiently high. However, an opposite result holds if the degree of cross-border pollution is sufficiently low. Under FBTA, the pollution-content tariff is used to internalize cross-border pollution while such a direct measure to deal with cross-border pollution does not exist under NBTA. If cross-border pollution does matter, a lack of a direct instrument such as the pollution-content tariff more severely distorts an incentive for each country's government to choose emission tax policy under NBTA than it does under FBTA.

Figure 2 shows the emission tax rate under each tax regime. As the degree of cross-border pollution rises, the emission tax rate increases under FBTA. This is because each country's government has an incentive to raise its pollution-content tariff to internalize cross-border pollution. However, the emission tax rate moves to an opposite direction under NBTA. In NBTA,

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[14]See Appendix C for the details of the numerical example.

an increase in the degree of cross-border pollution induces the government of each country to *reduce* its emission tax rate for the purpose of mitigating the effect of cross-border pollution. By stimulating its domestic production, the lower emission tax leads to a decline of the other country's production, which results in a reduction of emissions generated in the other country.

The effect on the total welfare can be decomposed into the effects on consumer surplus, producer surplus, tax revenue, and environmental quality. If the degree of cross-border pollution is sufficiently large, then the market price in NBTA is lower than that in FBTA, so that consumer welfare is worse off under FBTA (Figure 3). Similarly, NBTA is more beneficial for producers than FBTA if the degree of cross-border pollution is significant (Figure 4). Opposite results are obtained for the tax revenue and the environment. For the high degree of cross-border pollution, the tax revenue in FBTA is larger than that in NBTA and total emissions are lower in FBTA than those in NBTA (Figure 5 and 6). Clearly, these results are caused by a difference in the behavior of the emission tax rate under the two regimes.

The degree of cross-border pollution depends on the nature of an environmental problem. The degree is significantly high and μ equals one for global warming caused by greenhouse gas emissions. Thus, when countries choose emission tax policy for greenhouse gases non-cooperatively, FBTA regime is better than NBTA in terms of both total economic welfare and the environmental quality even though consumers and producers are burdened with the higher emission tax.

Proposition 6 *Suppose that countries choose emission tax policy for greenhouse gases non-cooperatively. Then, full border tax adjustment (FBTA) regime can be better than no border tax adjustment (NBTA) regime in terms of both global economic welfare and global environment.*

5   Concluding Remarks

In this paper, we have examined a strategic interaction among countries that choose emission tax policies non-cooperatively. The border tax adjustment affects each country's optimal policy response to its trade partner's emission tax policy. Under the partial border tax adjustment, the home country's emission tax policy for home firm's home sales becomes more stringent if the foreign country lowers its emission tax for foreign firm's export sales to

the home market. The home country has an incentive to counteract the effect of foreign country's export promotion driven by its lax emission tax policy, rasing its emission tax so as to increase its pollution-content tariff for taking back some of rents from foreign firms to home firms. In the absence of border tax adjustments, this effect does not exist so that the home country's emission tax policy becomes more lax in response to a decline in the foreign country's emission tax.

In the Nash equilibrium of the policy game, each country's emission tax rate can be higher in the presence of the full border tax adjustment as compared with that under no border tax adjustment as long as the degree of cross-border pollution is sufficiently high. This result suggests that border tax adjustments provide an incentive for each country to raise its emission tax. The reason is that the border tax adjustments allow the use of the pollution-content tariff which is an instrument for protecting domestic firms from import competition as well as for internalizing cross-border pollution.

Even though the use of the border tax adjustments has protectionism motives in addition to environmental objectives, its use does not necessarily mean inefficiency in an intra-industry resource allocation. In the presence of the sufficiently high degree of cross-border pollution, the total welfare in each country can be higher in the full border tax adjustment as compared with that in no border tax adjustment. This holds because the benefits of lower emissions and higher tax revenue outweigh the losses of greater tax burdens for consumers and firms.

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Appendix A: Changes in the Total Welfare

Taking the total derivatives of w, we have

$$
\begin{aligned}
dw &= pdq - ncdx + n[p^* - t^*e - c]dy + nyp^{*\prime}dq^* + n^*y^{*2}p^{\prime\prime}dq \\
&\quad + [2n^*p^\prime y^* - n^*(c^* + \tau_y^*e^*)]dy^* - dh \\
&= (p - c + n^*y^{*2}p^{\prime\prime})dq + n^*[c - (c^* + \tau_y^*e^*) + 2p^\prime y^*]dy^* \\
&\quad + n[p^* - c - t^*e]dy + nyp^{*\prime}dq^* - dh
\end{aligned}
\tag{18}
$$

and

$$
dh = h^\prime[edq + \mu e^*dq^* + n^*(\mu e^* - e)dy^* + n(e - \mu e^*)dy].
\tag{19}
$$

Using (18) and (19), we find (5).

Appendix B: Linear Model

We shall consider a case in which demand and damage functions are linear. For the home country, the inverse demand function is

$$p(q) = a - bq,$$

where $a, b > 0$, $a > c$, and $a > c^*$. Similarly, for the foreign country,

$$p^*(q^*) = a^* - b^* q^*,$$

where $a^*, b^* > 0$, $a^* > c^*$, and $a^* > c$. Then, the Cournot equilibrium conditions for the home market are

$$a - b(n + 1)x - bn^* y^* = c + \tau_x e, \tag{20}$$

$$a - bnx - b(n^* + 1)y^* = c^* + (\tau_y^* + t)e^*. \tag{21}$$

For the foreign market,

$$a^* - b^*(n^* + 1)x^* - b^* ny = c^* + \tau_x^* e^*, \tag{22}$$

$$a^* - b^* n^* x^* - b^*(n + 1)y = c + (\tau_y + t^*)e. \tag{23}$$

Solving (20) and (21) simultaneously, we have equilibrium outputs for the home market,

$$x = \frac{1}{b(n + n^* + 1)} \left\{ (a - c - \tau_x e)(n^* + 1) - [a - c^* - (\tau_y^* + t)e^*]n^* \right\}, \tag{24}$$

$$y^* = \frac{1}{b(n + n^* + 1)} \left\{ [a - c^* - (\tau_y^* + t)e^*](n + 1) - (a - c - \tau_x e)n \right\}. \tag{25}$$

Similarly, for the foreign market,

$$x^* = \frac{1}{b^*(n + n^* + 1)} \left\{ (a^* - c^* - \tau_x^* e^*)(n + 1) - [a^* - c - (\tau_y + t^*)e]n \right\}, \tag{26}$$

$$y = \frac{1}{b^*(n + n^* + 1)} \left\{ [a^* - c - (\tau_y + t^*)e](n^* + 1) - (a^* - c^* - \tau_x^* e^*)n^* \right\}. \tag{27}$$

The total sales in the home and foreign markets are respectively given by

$$q = \frac{1}{b(n + n^* + 1)} \left\{ (a - c - \tau_x e)n + [a - c^* - (\tau_y^* + t)e^*]n^* \right\}, \quad (28)$$

$$q^* = \frac{1}{b^*(n + n^* + 1)} \left\{ (a^* - c^* - \tau_x^* e^*)n^* + [a^* - c - (\tau_y + t^*)e]n \right\}. \quad (29)$$

The prices in the home and foreign markets are

$$p = \frac{1}{(n + n^* + 1)} \left\{ a + (c + \tau_x e)n + [c^* + (\tau_y^* + t)e^*]n^* \right\}, \quad (30)$$

$$p^* = \frac{1}{(n + n^* + 1)} \left\{ a^* + (c^* + \tau_x^* e^*)n^* + [c + (\tau_y + t^*)e]n \right\}. \quad (31)$$

The profits of each home firm and each foreign firm are

$$\pi = bx^2 + b^* y^2 - f, \quad (32)$$

$$\pi^* = b^* x^{*2} + b y^{*2} - f^*. \quad (33)$$

Also, we assume that damage functions of the home and foreign countries are respectively given by,

$$h(E + \mu E^*) = \theta(E + \mu E^*), \quad (34)$$

$$h^*(E^* + \mu^* E) = \theta^*(E^* + \mu^* E), \quad (35)$$

where $\theta, \theta^* > 0$. The total home country welfare and the total foreign country welfare are

$$w = \frac{bq^2}{2} + n\pi + \tau_x nex + tn^* e^* y^* + \tau_y ney - \theta[ne(x + y) + \mu n^* e^*(x^* + y^*)], \quad (36)$$

$$w^* = \frac{b^* q^{*2}}{2} + n^* \pi^* + \tau_x^* n^* e^* x^* + t^* ney + \tau_y^* n^* e^* y^*$$
$$- \theta^*[n^* e^*(x^* + y^*) + \mu^* ne(x + y)]. \quad (37)$$

Appendix C: Nash Equilibrium

We will consider a situation in which countries are symmetric.

Equilibrium Outcomes in PBTA

Plugging (15) and (16) into (24) and (27) with the condition $\tau_x = t$, we can derive outputs of each home firm,

$$x = \frac{2n(a-c) + e\theta}{b(2n+1)^2}, \tag{38}$$

$$y = \frac{2(n+1)(a-c) - (4n+3)e\theta}{b(2n+1)^2}. \tag{39}$$

Note that the export of each home firm is positive if $(a - c - \theta e)/\theta e > (2n+1)/[2(n+1)]$. We assume that this condition is satisfied. Also, plugging (15) and (16) into (28) and (30), we find the total sales and the market price in the home market,

$$q = \frac{2n(a - c - e\theta)}{b(2n+1)}, \tag{40}$$

$$p = \frac{a + 2nc + 2ne\theta}{2n+1}. \tag{41}$$

With (32) and (36), the profit of each home firm and the total home country welfare are written as

$$\pi = b(x^2 + y^2) - f, \tag{42}$$

$$w = \frac{bq^2}{2} + n\pi + \tau_x ne(x + y) + \tau_y ney + 2\theta ne(x + y). \tag{43}$$

The symmetry of the countries implies that $x^* = x$, $y^* = y$, $q^* = q$, $p^* = p$, $\pi^* = \pi$, and $w^* = w$.

Equilibrium Outcomes in FBTA and NBTA

In FBTA, optimal emission tax policy satisfies the following conditions, $\tau_x = t = \tau_x^* = t^*$ and $\tau_y = \tau_y^* = 0$. It is convenient to rewrite the equilibrium emission tax rate (11) is

$$\overline{\tau}_x = \frac{(1+\mu)\theta}{2}.$$

Under NBTA, optimal emission tax policy satisfies the following conditions, $\tau_x = \tau_x^* = \tau_y = \tau_y^*$ and $t = t^* = 0$. And it is also convenient to rewrite the

equilibrium tax rate (17) as

$$\widetilde{\tau}_x = \frac{\theta(2n+1)}{2n} - \frac{\theta\mu(2n+1)(n^2+1)}{2(n+1)^2 n} - \frac{a-c}{2ne}.$$

Let τ denote the emission tax rate and $\tau = \overline{\tau}_x$ in FBTA and $\tau = \widetilde{\tau}_x$ in NBTA. It is easy to see that equilibrium outcomes under FBTA have the same functional forms of the emission tax τ as those under NBTA. With the use of (24), (25), (26),and (27), we can derive the outputs for each country's market as

$$x = x^* = y = y^* = \frac{(a-c-\tau e)}{b(2n+1)}. \tag{44}$$

Similarly, using (28), (29), (30), and (31), we can derive the total sales and the market price for each country's market as

$$q = q^* = \frac{2n(a-c-\tau e)}{b(2n+1)}, \tag{45}$$

$$p = p^* = \frac{a + 2n(c+\tau e)}{2n+1}. \tag{46}$$

With the use of (32) and (33), the profit of each country's firm can be derived as

$$\pi = \pi^* = 2bx^2 - f. \tag{47}$$

Using (34) and (35), we have each country's damage function as

$$h = h^* = 2\theta nex(1+\mu). \tag{48}$$

Each country's tax revenue is

$$2\tau nex. \tag{49}$$

Using (36) and (37) with (44)-(49), we can obtain the total welfare of each country as

$$w = w^* = 2bn(n+1)x^2 + 2nex[\tau - \theta(1+\mu)] - nf. \tag{50}$$

In the numerical example, we use the following parameters.

$$a = a^* = 100, \ b = b^* = 1, \ c = c^* = 2, \ \theta = \theta^* = 4$$
$$e = e^* = 6, \ n = n^* = 15, \ f = f^* = 0.$$
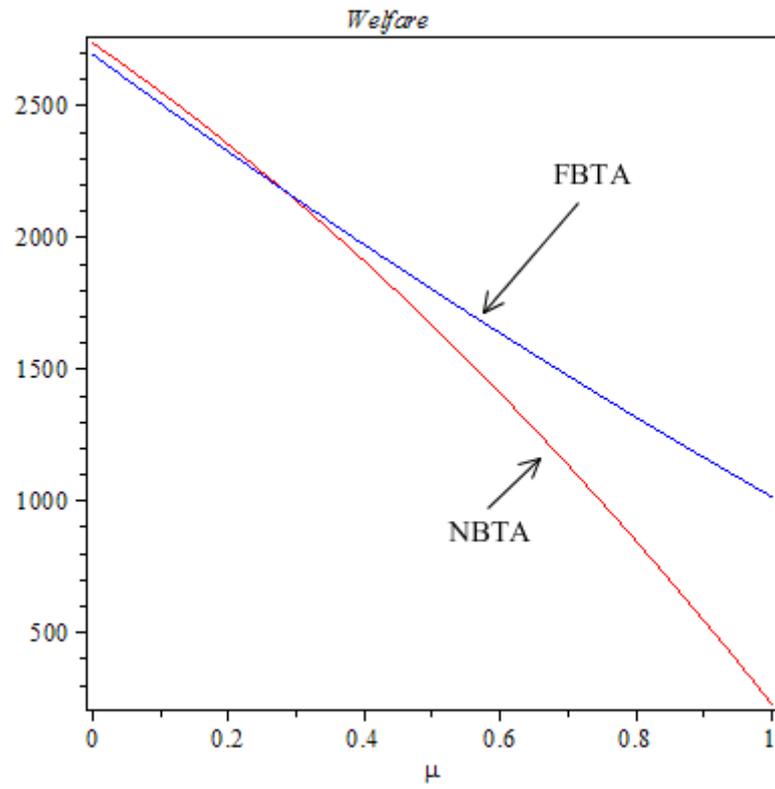
Figure 1: Total welfare
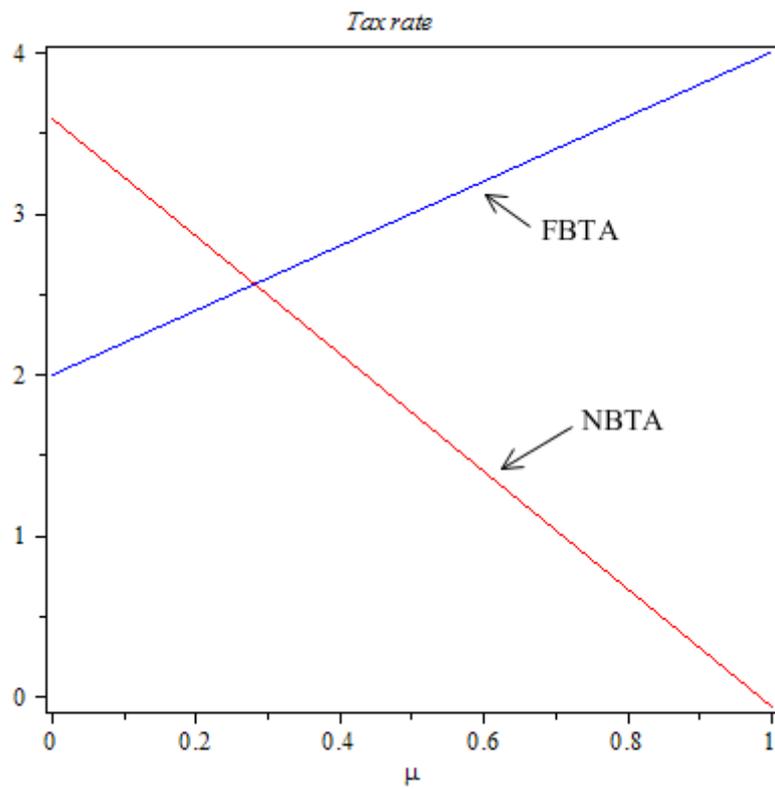
Figure 2: Emission tax rate
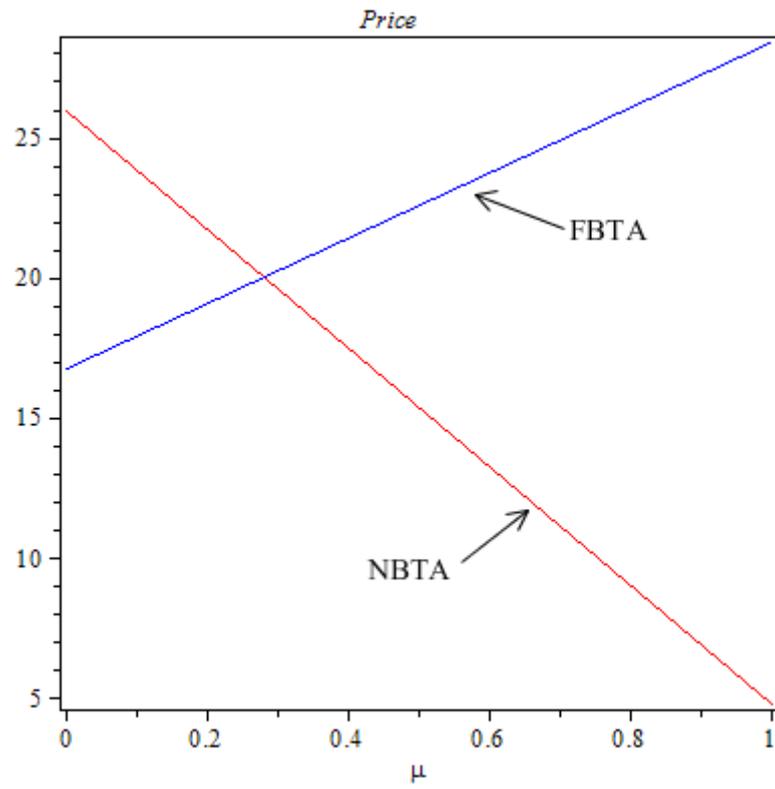
Figure 3: Market price
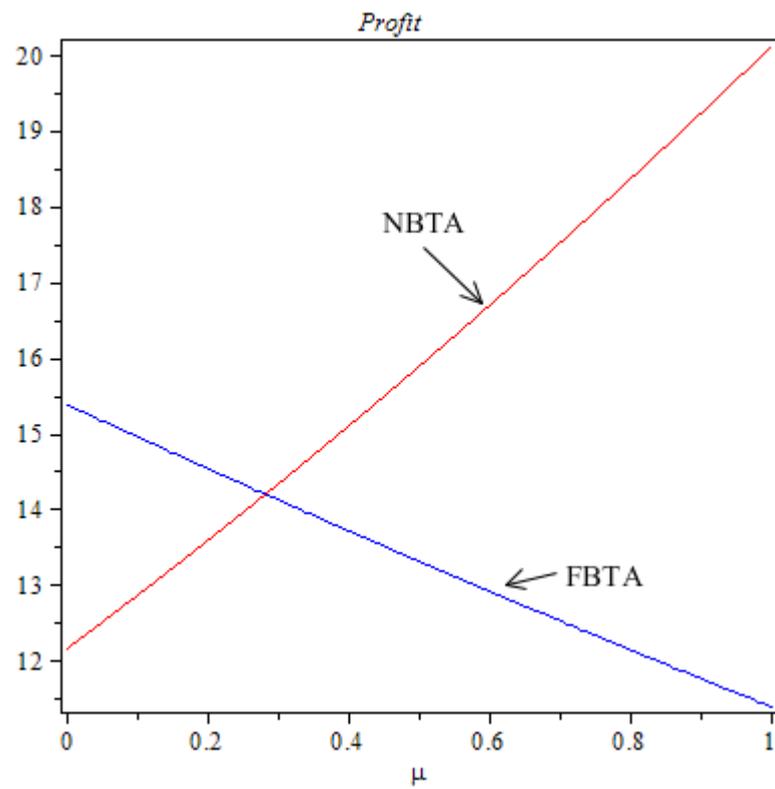
Figure 4: Firm's profit
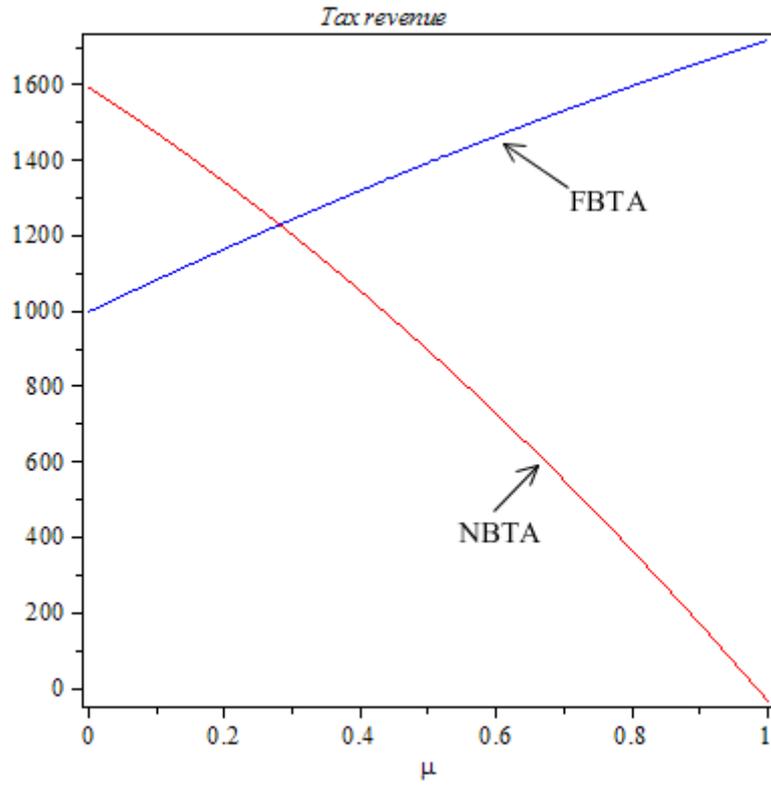
Figure 5: Tax Revenue

Figure 6: Emissions