Environmental Regulations on International Transportation*

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Abstract

This paper incorporates pollution emissions from international transportation into the standard model of strategic trade and environmental policies, and investigates the effect of trade liberalization and some form of environmental agreement on national welfare and environment. Our model explicitly includes the imperfectly competitive market for international transportation, as well as the imperfectly competitive market for final products. We find that a trade liberalization may reduce each country's welfare unless some level of environmental regulation on international transportation is in place. In addition, when trade is fairly liberalized, a mutual increase in the common emission tax rates may improve each country's welfare. However, when trade is not fairly liberalized, imposing emission tax on international transportation may reduce welfare.

Keywords International transportation; Emission tax; Tariff;

JEL Code F18; Q53; Q54; Q56

1 Introduction

As globalization continues, the amount of international and cross-national transportation for goods has been growing significantly. Since 1990, CO2 emissions from international aviation have increased by around 76 percent, and they will grow even more with the development of trade liberalization (IEA 2010).[1] Currently, the total emissions from international transportation are much larger than the sum of emissions from all sources in UK and France.[2] In addition, Hummels (2009) indicates that if world trade is fully liberalized, then CO2 emissions associated with international transportation would rise by as much as 10 percent, while production related emissions see no growth as a result of trade liberalization. By using an applied general equilibrium model, Olsthoorn (2001) shows that CO2 emission from international aviation may increase between 1995 and 2050 in several scenarios. Cristea et al. (2011) find that international trade will increase between countries which are not connected by land transportation by trade liberalization. Therefore, to reduce CO2 emissions from international aviation, we need some economic regulations.

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*Do not quote this paper since it is very preliminary. Comments are welcome.

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[1]CO2 emissions from international marine bunkers also have increased by around 63 percent since 1990 (IEA 2010).

[2]In 2008, CO2 emissions from international marine are 578.20 million tonnes and those from international aviation are 454.85 million tonnes, while CO2 emissions from all sources in UK are 510.6 million tonnes and those in France 368.2 million tonnes (IEA 2010).

However, regulating emissions from international transportation are especially challenging, because they are produced along routes where no single nation has regulatory authority and do not occur within a countries political jurisdiction. In fact, in the Kyoto protocol, emissions from international aviation and shipping cannot be attributed to any particular national economy.[3] Furthermore, regulations on emissions from international transportations would raise costs for moving goods, and thus they might pose an impediment to free trade. The IATA is suggesting four main strategies stopping growing CO2 emission; (1) technology, (2) operations, (3) infrastructure and (4) economic measures.[4] In terms of economic mesures, EU is trying to regulate an emission trading system for aviation. Germany is imposing an emission taxes for airpassengers fee.

In this paper, we investigate the effects of various types of regulation policy for reducing emissions from international transportation in a two-country model of strategic environmental policymaking. We consider a situation where domestic and foreign final-goods firms compete in each country a lá Cournot. The imports and exports are shipped by transportation firms with emitting some pollutants like GHG emissions. The market for international transportation is also considered to be imperfectly competitive. Within this framework, we consider the three regulation regimes: (1) each government imposes emission tax on its domestic transportation or logistics firms based on their amount of fuel uses or transportation (we call it as regime TX); (2) each government imposes tariff on imports from foreign country (we call it as regime TR). We assume that transportation firms need fees both departure and arrival. We investigate the strategic incentives for policymaking of governments under each policy regime and try to answer the question of how trade liberalization and environmental agreement affect the quality of environment and national welfare under several policy regimes.

We find the following results. First, a trade liberalization may reduce each country's welfare unless some level of environmental regulation on international transportation is in place. Second, when trade is fairly liberalized, a mutual increase in the common emission tax rates may improve each country's welfare. However, when trade is not fairly liberalized, imposing emission tax on international transportation may reduce welfare.

This paper may contribute to the literature on trade and environment in three ways. First, we focus on the problem of emissions from international transportation and explicitly incorporate an imperfectly competitive transportation sector into the framework of strategic environmental and trade policies. The existing basic literature on strategic environmental policy (such as Conrad (1993), Barrett (1994), Kennedy (1994), and Ulph (1996)) has not accounted for the problem and regulations of emissions from international transportation. Second, our results have important policy implications for current discussions of the regulations of emissions from international transportation. Our theoretical results provide a clue as to what kind of regulation is preferred for producers, logistics firms, environment, and national welfare. Finally, our simple framework provides a benchmark for the future study of regulatory design on emissions from international transportation under some asymmetric situations, e.g., with developing and developed countries or with net exporter and importer countries.

This paper is organized as follows. Section 2 presents the basic structure of the model, and the second-best optimal policy combinations of tariff and emission tax is characterized. Section 3 investigates non-cooperative tariff regime. Section 4 investigates non-cooperative emission tax

[3] Emissions from domestic aviation are observed to be included within the Kyoto targets agreed by countries. This has led to some national policies such as fuel and emission taxes for domestic air travel in the Netherlands and Norway respectively. Although some countries tax the fuel used by domestic aviation, there is no duty on kerosene used on international flights (See http://www.aef.org.uk/downloads/Factsheetclimate.pdf).

[4] See following URL for IATA's approach to reduce emission from aviation:
http://www.iata.org/SiteCollectionDocuments/Documents/Global_Approach_Reducing_Emissions_251109web.pdf

regime. Finally, Section 5 concludes the paper.

2 The model

Consider two countries labeled by i $(i = 1, 2)$. In each country, there is one representative final-good firm producing a final product, one representative carrier (logistics) firm transporting the final products between two countries. Each final-good firm i that produces homogenous product and provides q_{ii} for domestic (country i's) market and exports q_{ij} for foreign (country j's) market. Pollution emissions are generated in the process of transportation (not production) between countries and deteriorate the quality of the global environment.

The inverse demand function for final product in country i is given by:

$$p_i = \alpha - \beta\left(q_{ii} + q_{ji}\right), \tag{1}$$

for $i = 1, 2$, and $i \neq j$. In the above equation, p_i represents the price of the final product in country i, the parameter α the market size of both countries, and the parameter β the slope of the inverse demand.

The profits of (final-good) firm i is given by:

$$\pi_i = p_i q_{ii} + \left(p_j - p_T - k_j\right) q_{ij}, \tag{2}$$

where p_T is the price of carrier (transportation) services between the two countries and k_j is a tariff rate imposed by government j. We assume for simplicity that marginal production costs are zero. The final-good firms i and j compete in a Cournot fashion in each market, given the inverse demand function (1).

The profits of carrier i is given by:

$$\Pi_i = p_T y_i - \tau_i y_i, \tag{3}$$

where y_i is the amount of final goods transported across national borders by carrier i and τ_i is the emission tax imposed by government i on carrier i based on its transportation amount. We assume that one unit of emissions is generated by one unit of transportation.

The national welfare in country i is defined by:

$$W_i = CS_i + \pi_i + \Pi_i + R_i - D(E), \tag{4}$$

where $R_i \equiv \tau_i y_i + k_i q_{ji}$ is the revenue of government i, E is the total amount of international transportation ($E \equiv q_{12} + q_{21}$), and $D(\cdot)$ is the environmental damage function from emissions resulted from international transportations. We assume that one unit of transportation generates one unit of emission and the emissions are public bads for both countries. The damage function is assumed to be quadratic as $D\left(E\right) = \delta E^2/2$, where δ represents the slope of marginal environmental damage curve. The consumer surplus in country i is given by:

$$CS_i = \int_0^{Q_i} \left(\alpha - \beta z\right) dz - p_i \cdot Q_i, \tag{5}$$

where $Q_i \equiv q_{ii} + q_{ji}$ is the total consumption of final-good in country i.

The model has two stages. In the first stage, each government non-cooperatively or cooperatively chooses its policy level (emission tax, tariff, or both). In the second stage, two final-good firms compete in a market in each country, and two carriers compete in international transportation market.

Table 1: The effect of policy changes: comparative static results

	p_i^*	p_j^*	q_{ii}^*	q_{ij}^*	q_{ji}^*	q_{jj}^*	Q_i^*	Q_j^*	p_T^*	y_i^*	y_j^*	E^*
k_i	+	−	+	+	−	−	−	+	−	−	−	−
τ_i	+	+	+	−	−	+	−	−	+	−	+	−

The model is solved backwards. From the profit maximization of firm i, we have:

$$q_{ii} = \frac{\alpha + p_T + k_i}{3\beta}, \quad q_{ij} = \frac{\alpha - 2\left(p_T + k_j\right)}{3\beta}. \tag{6}$$

The above equations imply that the consumption of domestic products (imports) is increasing (decreasing) in the price of international carrier services and tariff rates. From (6), the total demand of international carrier services (E) is given by:

$$E = q_{12} + q_{21} = \frac{2\left(\alpha - 2p_t - k_1 - k_2\right)}{3\beta}.$$

Transforming the above equation yields the following inverse demand for carrier services:

$$p_T = \frac{2\alpha - 2\left(k_1 + k_2\right) - 3\beta\left(y_1 + y_2\right)}{4}. \tag{7}$$

Each carrier i maximizes its profits (3) given the market price for international carrier services (7). Thus, we have y_i, E, and p_T in the second-stage Nash equilibrium as:

$$y_i^*(k_i, k_j, \tau_i, \tau_j) = \frac{2\left(\alpha - \sum k_i - 4\tau_i + 2\tau_j\right)}{9\beta}, \tag{8}$$

$$E^*(k_i, k_j, \tau_i, \tau_j) = \frac{4\left(\alpha - \sum k_i - \sum \tau_i\right)}{9\beta}, \tag{9}$$

$$p_T^*(k_i, k_j, \tau_i, \tau_j) = \frac{\alpha - \sum k_i + 2\sum \tau_i}{6}, \tag{10}$$

for $i = 1, 2$ and $i \neq j$.

By substituting (10) into (6), we have the following prices and quantities for final products:

$$p_i^*(k_i, k_j, \tau_i, \tau_j) = \frac{7\alpha + 5k_i - k_j + 2\sum \tau_i}{18}, \tag{11}$$

$$q_{ii}^*(k_i, k_j, \tau_i, \tau_j) = \frac{7\alpha + 5k_i - k_j + 2\sum \tau_i}{18\beta}, \tag{12}$$

$$q_{ij}^*(k_i, k_j, \tau_i, \tau_j) = \frac{2\alpha + k_i - 5k_j - 2\sum \tau_i}{9\beta}, \tag{13}$$

$$Q_i^*(k_i, k_j, \tau_i, \tau_j) = \frac{11\alpha - 5k_i + k_j - 2\sum \tau_i}{18\beta}. \tag{14}$$

Table 1 presents the comparative static results for the changes in k_i and τ_i. We see from the table that an increase in a tariff rate in country i lowers the price of international transportation, whereas an increase in an emission tax rate in country i raises the price. It has a different impact on country j's market, p_j^* and Q_j^*. An increase in k_i reduces the demand for carrier services (through a decrease in q_{ji}) and thus lowers the price for carrier services as shown in (10). The fall in the carriage price lowers firm i's costs for exports, and thus it makes country j's market more competitive. On the other hand, an increase in τ_i decreases international trade by increasing the price for carrier services. Therefore, an increase in tariff rate in country i increases (decreases) firm i's (j's) market share in both countries i and j, whereas an increase in an emission tax rate in country i increases (decreases) the market share of home products (imports) in both countries. Notice that an increase in a tariff as well as en emission tax rate in country i total amount of transportation and emissions, so the policies may work as environmental regulations.

Substituting the variable in the second stage equilibrium into (2), (3), (4), and (5), we have the profits of final-good firm i, those of carrier i, social welfare, and consumer surplus in the second stage equilibrium denoted as $\pi_i^*(k_i, k_j, \tau_i, \tau_j)$, $\Pi_i^*(k_i, k_j, \tau_i, \tau_j)$, $W_i^*(k_i, k_j, \tau_i, \tau_j)$, and $CS_i^*(k_i, k_j, \tau_i, \tau_j)$, respectively.

2.1 Second-best Optimum

Here, we derive the second-best policies in the case where both countries can cooperatively decide their policy combinations (k_i and τ_i) so as to maximize the sum of their national welfare.[5] Because two countries are symmetric in our model, we only consider the uniform level of regulation for both countries ($k_1 = k_2 = k$ and $\tau_1 = \tau_2 = \tau$) that maximizes the joint welfare. The joint welfare $\sum_i W_i^*$ is given by:

$$W_1^*(k,\tau) + W_2^*(k,\tau) = \frac{8\,(k+\tau)\left[\alpha\,(32\delta - 7\beta) - 2\,(16\delta + \beta)\,(k+\tau)\right] + \alpha^2\,(275\beta - 64\delta)}{324\beta^2}.$$

Notice that the above joint welfare is only a function of $(k + \tau)$.

Proposition 1
Consider the case where two countries cooperatively design their policy combination.

(a) *The optimal policy combination is characterized by:*

$$\Lambda \equiv k^{OP} + \tau^{OP} = \frac{\alpha\,(32\delta - 7\beta)}{4\,(\beta + 16\delta)}. \tag{15}$$

(b) *The optimal policy should be set such that the sum of emission tax and tariff rates is negative (positive) when $\delta/\beta < (>)\ 7/32$.*

Since in the cooperative policy setting, either policy, emission tax or tariff, will charge on the total amount of transportation, the difference between tax and tariff only affects the distribution of tax revenues between the two countries. Therefore, the optimal policy makes tax and tariff indifferent as assertion (a) of Proposition 1. The intuition behind the assertion (b) is also simple. Due to the imperfect competition in transportation market, the transportation prices are inefficiently high and the amount of trade is inefficiently small, which strengthen the market power of the domestic firm in each market. Therefore, when the damages from emissions are small, the optimal policy should encourage the trade and/or transportation in order to make the final-good market more competitive. On the other hand, when the damages from emissions are large, the amount of emissions from international transportation is inefficiently large, so the optimal policy should impose emission tax and/or tariffs on imports to internalize the negative externalities. Proposition 1-(b) also indicates that when δ/β is small (large), either emission tax or tariff rates should be negative (positive) in order to achieve the second-best optimum.

[5] The first-best allocation is characterized by no-trade condition ($q_{12} = q_{21} = 0$) and efficiency pricing ($p_1 = p_2 = 0$ and $q_{11} = q_{22} = \alpha/\beta$) as long as $\delta > 0$ because of the assumption of homogenous goods between home products and imports.

3 Non-cooperative Tariff Regime

We then derive the Nash equilibrium under a non-cooperative tariff regime. In this section, we treat τ_i as an exogenous parameter and the same between countries (i.e., $\tau_1 = \tau_2 = T$).

Before deriving the equilibrium of the tariff game, it is helpful to show the marginal effects of tariff changes on consumer and producers' surplus and the total emission under laissez-faire. Differentiating CS_1^*, CS_2^*, Π_1^*, Π_2^*, π_1^*, π_2^*, E^*, and W_i^* in k_1 and evaluating them at $k_1 = k_2 = 0$ and $T = 0$, we have :

$$\frac{\partial CS_i^*}{\partial k_i} = -\frac{55\alpha}{324\beta} < 0, \quad \frac{\partial CS_j^*}{\partial k_i} = \frac{11\alpha}{324\beta} > 0,$$
$$\frac{\partial \pi_i^*}{\partial k_i} = \frac{43\alpha}{162\beta} > 0, \quad \frac{\partial \pi_j^*}{\partial k_i} = -\frac{47\alpha}{162\beta} < 0,$$
$$\frac{\partial \Pi_i^*}{\partial k_i} = \frac{\partial \Pi_j^*}{\partial k_i} = -\frac{2\alpha}{27\beta} < 0, \quad \frac{\partial E^*}{\partial k_i} = -\frac{4}{9\beta} < 0,$$
$$\frac{\partial W_i^*}{\partial k_i} = \frac{\alpha(79\beta + 64\delta)}{324\beta^2} > 0, \quad \frac{\partial W_j^*}{\partial k_i} = -\frac{\alpha(107\beta - 64\delta)}{324\beta^2} \gtreqless 0.$$

As might be expected, country i's unilateral increase in its tariff rate from laissez-faire situation increases the profits of firm i but decreases that of firm j. It also decreases the demand for international transportation, so it reduces the profits of both carriers. However, from (10) and (13), a small increase in k_i lowers the price of transportation and thus raises the exports of firm i to country j's market. Therefore, it makes the market in country j more competitive, which is beneficial to consumers in country j. Finally, the welfare of country i is improved by a small increase in tariff k_i because of the improvement of the environment and the increases in π_i that dominate the sum of decreases in CS_i and Π_i. On the other hand, the effect of a small increase in k_i on the welfare of country j depends on the magnitude of δ/β. When δ/β is large, the increase in k_i improves W_j by the improvement of the environment.

In what follows, we derive the equilibrium of the non-cooperative tariff game. From the First-Order Condition (FOC) of welfare maximization of government i under tariff regime, we obtain the following reaction function of government i:

$$k_i = R_i(k_j) \equiv \frac{\alpha\,(79\beta + 64\delta) - 4\,(35\beta + 32\delta)\,T}{253\beta + 64\delta} + \frac{5\beta - 64\delta}{253\beta + 64\delta} k_j. \tag{16}$$

Lemma 1 $R_i'(k_j) \gtreqless 0$ *when* $\delta/\beta \lesseqgtr 5/64$.

The lemma implies that the non-cooperative tariff rates are strategic substitutes (complements) when environmental damages are large (small).

Solving (16) for $i = 1, 2$, the Nash equilibrium rate of tariff can be characterized as:

$$k^{TR}(T) = \frac{\alpha\,(79\beta + 64\delta) - 4\,(35\beta + 32\delta)\,T}{8\,(31\beta + 16\delta)}, \tag{17}$$

where superscript TR refers to the equilibrium variables in the non-cooperative tariff game.

Lemma 2 $-1 < dk^{TR}/dT < 0$.

This lemma shows that the non-cooperative tariff rates are decreased by an in crease in common emission tax rates. Consider the situation where both countries are mutually obliged to introduce the common rate of emission taxes by, for example, some environmental agreements.

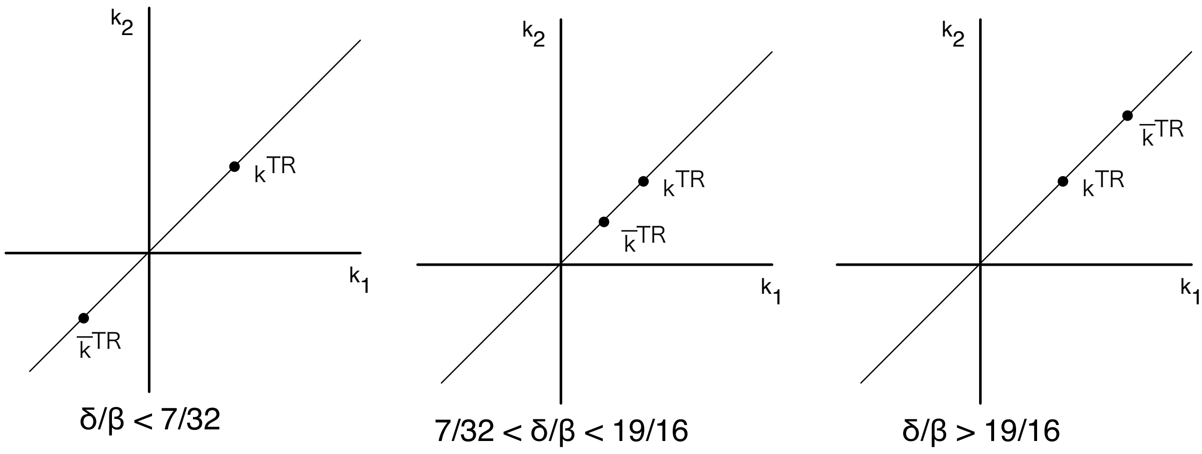

Figure 1: Optimal and Non-cooperative Tariffs: the case of $T = 0$.

The lemma implies that, in this case, each country reacts by lowering its tariff rate. In other words, such environmental agreements may induce each government to voluntarily promote trade liberalization.

We then compare the non-cooperative tariff rate with the second-best one. When $T = \tau^{OP} = \bar{T}$, it holds that $k^{OP} = \Lambda - \bar{T}$. We have:

$$k^{TR}(\bar{T}) - \left(\Lambda - \bar{T}\right) = \frac{27\alpha\beta(19\beta - 16\delta)}{8(\beta + 16\delta)(31\beta + 16\delta)} + \frac{27\beta}{2(31\beta + 16\delta)}\bar{T}. \tag{18}$$

Thus, we have the following proposition.

Proposition 2
Under the non-cooperative tariff regime,

(a) if $\bar{T} = 0$, the non-cooperative tariff rates are positive for all δ/β,

(b) if $\bar{T} = 0$, the non-cooperative tariff rates are higher (lower) than the second-best tariff rates when δ/β is smaller (larger) than 19/16, and

(c) as $\bar{T}$ becomes greater, the non-cooperative tariff rates are more likely to be higher than the optimal one.

Proof. Immediately from (17) and (18).

There are mainly two inefficiencies that each government should address: the inefficiency from the imperfect competition of the domestic and international carrier markets and that from the public good (bad) nature of global environment quality (total emissions). Setting higher (lower) tariff rates contributes to solution of the latter (former) issue, but, at the same time, it aggravates the former (latter) issue. Proposition 2-(b) implies that when the environmental damages are serious (not so serious), the tariff rates strategically chosen by each government are inefficiently lower (higher) than the optimal tariff rates. In other words, when the environmental damages from international transportation are small, a mutual trade liberalization improves both countries' welfare. However, when they are serious, the trade liberalization harms both countries.

Figure 1 illustrates the comparison between the non-cooperative and second-best tariff rates for various values of δ/β. When $\delta/\beta < 7/32$, k^{OP} is negative (from Proposition 1) while k^{TR} is positive, which is illustrated by orange. In this case, any free trade agreement that lowers and abolish both countries' tariff rates necessarily improves their welfare. However, when $\delta/\beta \in [7/32, 19/16]$, which is illustrated by blue, free trade agreement that lowers both tariff rates is beneficial for the countries, but one that abolish them may reduce their welfare. Abolition of tariffs surely alleviates the inefficiency from the imperfect competition in each country, but it increases the emission from international transportation. Finally, when $\delta/\beta > 19/16$, which is illustrated by red, any attempt that lowers their tariff rates reduces their welfare because $k^{OP} > k^{TR}$ holds.

Furthermore, Proposition 2-(c) may have an important policy implication as follows. When $\delta/\beta > 19/16$, the sign of the first term on the right-hand side of (18) is negative, so an increase in $\bar{T}$ will reduce the gap between k^{TR} and k^{OP}. Therefore, in this case, a mutual increase in emission tax will improve both countries' welfare. On the other hand, when $\delta/\beta < 19/16$, the sign of the first term on the right-hand side of (18) is positive, so an increase in $\bar{T}$ will widen the gap between k^{TR} and k^{OP}. Therefore, in this case, a mutual increase in emission tax will reduce both countries' welfare.

Finally, Proposition 2 also implies that if the emission regulation is absent ($\bar{T} = 0$) and the damages from emissions are serious, trade liberalization (mutual tariff reduction) reduces both countries' welfare. However, if imposing the common emission tax to both countries is available, such trade liberalization may improve both countries' welfare.

4 Non-cooperative Emission Tax Regime

In this section, we derive the Nash equilibrium under a non-cooperative emission tax regime. As before, we treat k_i as an exogenous parameter and the same between countries (i.e., $k_1 = k_2 = K$).

Before deriving the equilibrium of the non-cooperative emission tax game, it is helpful to show the marginal effects of tax changes on consumer and producers' surplus and the total emission under laissez-faire. Differentiating CS_1^*, CS_2^*, Π_1^*, Π_2^*, π_1^*, π_2^*, and E^* in τ_1 and evaluating them at $K = 0$, and $\tau_1 = \tau_2 = 0$, we have:

$$\frac{\partial CS_i^*}{\partial \tau_i} = \frac{\partial CS_j^*}{\partial \tau_i} = -\frac{11\alpha}{162\beta} < 0, \quad \frac{\partial \pi_i^*}{\partial \tau_i} = \frac{\partial \pi_j^*}{\partial \tau_i} = -\frac{\alpha}{81\beta} < 0,$$
$$\frac{\partial \Pi_i^*}{\partial \tau_i} = -\frac{8\alpha}{27\beta} < 0, \quad \frac{\partial \Pi_j^*}{\partial \tau_i} = \frac{4\alpha}{27\beta} > 0, \quad \frac{\partial E^*}{\partial \tau_i} = -\frac{4}{9\beta} < 0,$$
$$\frac{\partial W_i^*}{\partial \tau_i} = -\frac{\alpha\,(25\beta - 32\delta)}{162\beta^2} \gtreqless 0, \quad \frac{\partial W_j^*}{\partial \tau_i} = \frac{\alpha\,(11\beta + 32\delta)}{162\beta^2} > 0.$$

We find that country i's unilateral increase in its emission tax rate from laissez-faire situation is good for the environment and carrier j, but reduces consumer surplus and the profits of final-good firms in both countries as well as the profits of carrier i. Notice that the effect of the unilateral tax increase on consumer surplus and the profits of final-good firms are respectively the same between two countries because the emission tax raises the price of carrier services, which makes final-good firms in both countries bear the expenses equally. In addition, a small increase in τ_i improves (reduces) welfare of country i when δ/β is larger (smaller) than $25/32$, while it always improves the welfare of country j.

Comparing the marginal welfare effect of emission taxes with that of tariffs, we find the following two points. First, the two policies have different impact on the welfare of each country, but they have same impact on the joint welfare:

$$\frac{d\left(W_1^*+W_2^*\right)}{dk_i}=\frac{d\left(W_1^*+W_2^*\right)}{d\tau_i}=\frac{\alpha\left(-7\beta+32\delta\right)}{81\beta^2}.$$

Second, the conditions for improving both countries' welfare are different between a small increase in tariffs and emission taxes. In particular, $\delta/\beta > 107/64$ is required for a small increase in one country's tariffs to improve both countries' welfare, while $\delta/\beta > 25/32$ for emission taxes: the emission tax is more likely to improve both countries' welfare.

Now we proceed to derive the subgame-perfect equilibrium of this emission tax game. From the FOC of welfare maximization of government i under tax regime, we obtain the following reaction function of government i:

$$\tau_i=S_i\left(\tau_j\right)\equiv\frac{\alpha\left(32\delta-25\beta\right)+32\left(\beta-2\delta\right)K}{74\beta+32\delta}-\frac{\beta+16\delta}{37\beta+16\delta}\tau_j. \tag{19}$$

Lemma 3 $S_i'(\tau_j)<0$.

The lemma implies that the emission tax rates on international transportation are necessarily strategic substitutes.

Solving (19) for $i=1,2$, the Nash equilibrium rate of tax can be characterized as:

$$\tau^{TX}(K)=\frac{\alpha\left(32\delta-25\beta\right)+32\left(\beta-2\delta\right)K}{4\left(19\beta+16\delta\right)}, \tag{20}$$

where superscript TX refers to the equilibrium variables in the non-cooperative emission tax game.

Lemma 4 (i) $d\tau^{TX}/dK \gtreqless 0$ *for* $\delta/\beta \lesseqgtr 1/2$; (ii) $d\tau^{TX}/dK > -1$.

Unlike the non-cooperative tariff game, the non-cooperative emission tax rates are increasing in the common tariff rates when δ/β is small. The intuition is as follows. The non-cooperative emission tax rates are negative when δ/β is small. In other words, each government has an incentive to subsidize its domestic carrier to grab the market share from the foreign carrier. In this case, an increase in the common tariff rates lessens the incentive, so it increases (decreases) its emission tax (subsidy) rates. This implies that free trade agreement that lowers the common tariff rates leads to increase each country's subsidies for its own carrier firm when $\delta/\beta < 1/2$, which increases total emissions even more.

We then compare the non-cooperative emission tax rate with the optimal one. When $K = k^{OP} = \bar{K}$, it holds that $\tau^{OP} = \Lambda - \bar{K}$. Then we have:

$$\tau^{TX}(\bar{K})-(\Lambda-\bar{K})=\frac{27\alpha\beta(\beta-8\delta)}{(\beta+16\delta)(19\beta+16\delta)}+\frac{27\beta}{19\beta+16\delta}\bar{K}. \tag{21}$$

Proposition 3
Under the non-cooperative emission tax regime,

(a) *if $\bar{K}=0$, the non-cooperative emission tax rates are positive (negative) when δ/β is larger (smaller) than 25/32.*

(b) *if $\bar{K}=0$, the non-cooperative emission tax rates are higher (lower) than the second-best optimal emission tax rates when δ/β is smaller (larger) than 1/8, and* *(c) as $\bar{K}$ becomes greater, the non-cooperative emission tax rates are more likely to higher than the optimal one.*

Proof. Immediately from (20) and (21).

Unlike the non-cooperative tariff, each government may strategically set the negative rate of emission tax on its domestic carrier firm to enhance competitiveness of the carrier in international transportation market. However, as Proposition 3-(b) shows, when δ/β is less than 1/8, the non-cooperative emission subsidy is insufficient compared to the optimal rate. This is because an increase in subsidy in country i necessarily increases the profits of firm j and consumer surplus in country j through the decrease in the equilibrium price of international transportation, but each government ignore the positive external effect.[6] However, when δ/β is greater than 1/8, the non-cooperative emission tax (or subsidy) is insufficient (excessive) compared to the optimal rate. This comes from the fact that the total emissions are public bads, and thus each government has an incentive to free-ride on other country's efforts.

Proposition 3-(b) also implies that any decrease in the common tariff rate in both countries necessarily improves both countries welfare under non-cooperative emission tax regime as long as $\delta/\beta < 1/8$. Proposition 3-(c) implies that when $\delta/\beta > 1/8$, an exogenous free trade agreement that lowers both countries tariff rates widens the gap between the optimal and non-cooperative emission tax (or subsidy) rates. Especially when $\delta/\beta < 1/2$, we know, from Lemma 5, that the mutual tariff reduction lowers the non-cooperative emission tax rate, whereas it should raise the optimal emission tax rate by exactly the same rate. Therefore, such mutual tariff reduction may aggravate the inefficiency from the welfare point of view.

5 Concluding remarks

References

Antweiler, W., Copeland, B.R., Taylor, M.S. (2001) 'Is free trade good for the environment?', *American Economic Review* **91**: 877-908.

Barrett, S. (1994) 'Strategic environmental policy and international trade', *Journal of Public Economics* **54**: 325-338.

Burguet, R., Sempere, J. (2003) 'Trade liberalization, environmental policy, and welfare', *Journal of Environmental Economics and Management* **46**: 25-37.

Conrad, K. (1993) 'Taxes and subsidies for pollution-intensive industries as trade policy', *Journal of Environmental Economics and Managemant* **25**: 121-135.

Cristea, A., Hummels, D., Puzzello L., Avetisyan M. (2011) 'Trade and the Greenhouse Gas Emissions from International Freight Transport', *NBER working paper*No. 17117.

Hummels, D. (2009) 'How Further Trade Liberalization would Change Greenhouse Gas Emissions from International Freight Transport', OECD.

International Energy Agency (2010) *CO2 emissions from fuel combustion highlights,* OECD.

Kennedy, P.W. (1994) 'Equilibrium pollution taxes in open economies with imperfect competition', *Journal of Environmental Economics and Management* **27**: 49-63.

[6] Actually, the equilibrium price of international transportation becomes zero (negative) when $\delta/\beta = (<)\ 1/8$. This might be possible when equilibrium emission tax rates are negative in both countries: each carrier pays money to transport products to final-good firms because it gets the greater subsidies per transportation amount from the government.

McCollum, D., Gregory, G., David, G. (2009) Greenhouse Gas Emissions from Aviation and Marine Transportation: Mitigation Potential and Policies. Pew Center on Global Climate Change, The Pew Center, 2009.

Olsthoorn, X., (2001) 'Carbon dioxide emissions from international aviation: 1950-2050', *Journal of Ari Transport Management* **7**: 87-93.

Rauscher, M. (1997) *International Trade, Factor Movements, and the Environment.* Oxford: Clarendon Press.

Ulph, A. (1996) 'Environmental policy and international trade when governments and producers act strategically', *Journal of Environmental Economics and Management* **30**: 265-281.