Environmental Regulations on International Transportation∗

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Abstract

We examine the effects of an environmental regulation on emissions from international transportation in this paper. We construct two-country model with one transport firm in each country. The transportation costs are endogenous in the model. International transportation emits pollutions and gives negative externalities on welfare. Final-goods which are produced in each country are traded in the international market under duopolistic competition.

We consider three regimes: (1) each government imposes environmental taxes on its transportation firm (TRSP), (2) each government imposes import tariff (TRFF), (3) each government imposes airport usage fee (AUF). We will show that the amount of international transportation under TRSP is larger than other regimes. The ranking between TRFF and AUF depends on the substitutability between final-goods and the degree of environmental damages from emissions. The welfare rankings among three regimes can change, also depending on the degree of these parameters. We extend to policy coordination between two countries. The cooperative transportation tax rate is exactly same as the cooperative tariff rate and is exactly twice as the cooperative airport usage fee.

We also investigate how trade liberalization affects cooperative and non-cooperative policies for taxing international transportation. We find that when environmental damages are prominent, trade liberalization reduces the distortion associated with non-cooperative regulation. On the other hand, when environmental damages are not prominent enough, trade liberalization aggravates the distortion.

Keywords: International transportation; Emission tax; tariff; Airport usage fee
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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). Currently, the total emissions from international transportation are much larger than the sum of emissions from all sources in UK and France. 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. Therefore, to reduce CO2 emissions from international aviation, we need some economic regulations.

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 country's political jurisdiction. In fact, in the Kyoto protocol, emissions from international aviation and shipping cannot be attributed to any particular national economy. 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. In terms of economic measures, EU is trying to regulate an emission trading system for aviation. Germany is also considering an emission taxation for aviation.

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 à la 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 tax on its domestic transportation or logistics firms based on their amount of fuel uses or transportation (we call it as regime TRSP); (2) each government imposes tariff on imports from foreign country (we call it as regime TRFF); (3) each government imposes charges airport usage fee on both domestic and foreign transportation firms (we call it as regime AUF). We assume that transportation firms need fees both departure and arrival. We investigate the strategic incentives for policymaking of governments under each

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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).
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:
policy regime and try to answer the question which policy regime is better for environment, consumers, and social welfare in each country.

We firstly show that the amount of international transportation and emissions under regime TRSP is necessarily larger than that under other two regimes, while its ranking between regimes TRFF and AUF depends on both the degree of homogeneity between domestic and foreign products and the degree of environmental damages from emissions. We also show that the welfare rankings among three regimes can change, depending on the two degrees. When the slope of the marginal environmental damages is large, the welfare under regime AUF is larger than other two regimes. When it is intermediate, the welfare under regime TRFF is larger than other two regimes. When it is small, the welfare under regime TRSP is larger than other two regimes. There results are consequences of the strategic interactions between two governments.

Furthermore, we examine policy coordination between governments under each policy regime. The cooperative transportation tax rate is exactly same as the cooperative tariff rate and is exactly twice as the cooperative airport usage fee. When environmental damages are small, the (second-best) cooperative taxes and tariffs become negative. This is due to an imperfectly competitive market structure in both final-goods and transportation sectors. By comparing a non-cooperative regulation with a cooperative one under each regime, we find that (1) when environmental damages are large, the governments strategically set inefficiently smaller rate of tax or tariff under both regimes TRSP and TRFF. However, when they are small, they strategically set inefficiently larger rate of tax or tariff. (2) Under regime AUF, they necessarily set inefficiently larger rate of tax.

Finally, we investigate how trade liberalization affects cooperative and non-cooperative policies for taxing international transportation. We find that when environmental damages are prominent, trade liberalization reduces the distortion associated with non-cooperative regulation. On the other hand, when environmental damages are not prominent enough, trade liberalization aggravates the distortion.

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 literature on strategic environmental policy 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.

The remainder of the paper is organized as follows. In the next section, we describe the basic structure of our model and derive the equilibrium for final-goods and international transportation markets. Section 3 investigates and compares three regulatory regimes. Section 4 analyze the effect of policy cooperation under each policy regime, and Section 5 the effect of trade liberalizations.
2 The Model

Consider two countries labeled by \( i \) (\( i = 1, 2 \)). In each country, there is one representative firm producing a final good, one representative logistics firm transporting the final good between two countries, and one representative consumer. Each final-good firm \( i \) produces output \( q_{ii} \) for domestic (country \( i \)’s) market and exports \( q_{ij} \) for foreign (country \( j \)’s) market. Pollutant emissions are generated in the process of transportation between countries and deteriorate the quality of the environment in both countries.

The utility of the representative consumer in country \( i \) is:

\[
U_i = \alpha(q_{ii} + q_{ji}) - \frac{1}{2} [(q_{ii})^2 + 2\gamma q_{ii}q_{ji} + (q_{ji})^2] + m, \tag{1}
\]

where \( \alpha \) represents the market size of both countries, \( \gamma \) the degree of substitutability between the domestic and imported goods, and \( m \) the consumption of the numeraire (or other composite) goods. The case of asymmetric market size between two countries is considered later. The budget constraint of consumer \( i \) is \( p_{ii}q_{ii} + p_{ji}q_{ji} + m = y \), where \( p_{ii} \) (\( p_{ji} \)) is the price of domestic (foreign) goods in country \( i \) and \( y \) is exogenously given incomes. From the utility maximization of each consumer, we have the following inverse demand functions of both domestic and foreign products for \( i = 1, 2 \) and \( i \neq j \):

\[
p_{ii} = \alpha - q_{ii} - \gamma q_{ji}, \quad p_{ji} = \alpha - q_{ji} - \gamma q_{ii}, \tag{2}
\]

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

\[
\pi_i = p_{ii}q_{ii} + (p_{ij} - p_T - k_j)q_{ij}, \tag{3}
\]

where \( p_T \) is the price of 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 and domestic transportation costs are zero for both firms. We assume that final-good firms \( i \) and \( j \) compete in a Cournot fashion in each market, given the inverse demand functions (2).

The profits of logistics firm \( i \) is given by

\[
\Pi_i = p_T y_i - \tau_i y_i - (\lambda_i + \lambda_j) y_i, \tag{4}
\]

where \( y_i \) is the amount of final goods transported across national borders by logistics firm \( i \), \( \tau_i \) is the tax imposed by government \( i \) on logistics firm \( i \) based on its transportation amount, and \( \lambda_i \) (\( \lambda_j \)) is the tax imposed by government \( i \) (\( j \)) on logistics firm \( i \) based on the use of country \( i \)’s (\( j \)’s) airport or harbor.

The welfare in country \( i \) is defined by

\[
W_i = CS_i + \pi_i + \Pi_i + R_i - D(Q), \tag{5}
\]

where \( CS_i \) is consumer surplus in country \( i \) (\( CS_i \equiv U_i - (p_{ii}q_{ii} + p_{ji}q_{ji}) \)), \( R_i \) is the revenue of government \( i \), \( Q \) is the total amount of international transportation (\( Q \equiv q_{12} + q_{21} \)), and \( D(\cdot) \) is the damage function from emissions resulted from international transportation. We assume that one unit of emissions is generated by one unit of transportation and that the damage function to be quadratic as

\[
D(Q) = \frac{\delta}{2} Q^2,
\]
where $\delta$ represents the slope of marginal environmental damage curve.

The government revenue $R_i$ is defined by

$$R_i = \begin{cases} 
  t_i y_i & \text{under regime TRSP} \\
  k_i q_{ji} & \text{under regime TRFF} \\
  \lambda_i (y_i + y_j) & \text{under regime AUF}
\end{cases}$$

(6)

The model has two stages. In the first stage, two governments choose their policy level. We consider three policy regimes: (1) each government chooses a transportation tax rate (regime TRSP); (2) each government chooses a tariff rate (regime TRFF); (3) each government chooses an airport usage fee (regime AUF). In the second stage, two final-good firms compete in a final-good market in each country, and two logistics firms compete in international transportation market.

The model is solved backwards. From the profit maximization of final-good firm $i$, we have

$$q_{ii} = \frac{\alpha(2 - \gamma) + \gamma (p_T + k_i)}{4 - \gamma^2}, \quad q_{ij} = \frac{\alpha(2 - \gamma) - 2 (p_T + k_j)}{4 - \gamma^2}. \quad (7)$$

The above equations imply that the consumption of domestic (foreign) products is increasing (decreasing) in the price of international transportation.

From (7), we obtain the total demand of international transportation ($Q$) as follows:

$$Q = q_{12} + q_{21} = \frac{2\alpha(2 - \gamma) - 2(k_1 + k_2) - 4p_T}{4 - \gamma^2},$$

which yields the inverse demand function:

$$p_T = \frac{2\alpha(2 - \gamma) - 2(k_1 + k_2) - (4 - \gamma^2)Q}{4}. \quad (8)$$

Each logistics firm $i$ maximizes its profits (4) given the market price for international transportation (8). Thus, we have $y_i$, $Q$, and $p_T$ in Nash equilibrium as:

$$y_i^* = \frac{2\alpha(2 - \gamma) - 2(k_1 + k_2) - 4(2\tau_i - \tau_j) - 4(\lambda_1 + \lambda_2)}{3(4 - \gamma^2)},$$

(9)

$$Q^* = \frac{4[\alpha(2 - \gamma) - (k_1 + k_2) - (\tau_1 + \tau_2) - 2(\lambda_1 + \lambda_2)]}{3(4 - \gamma^2)}, \quad (10)$$

$$p_T^* = \frac{\alpha(2 - \gamma) + 2(\tau_1 + \tau_2) + 4(\lambda_1 + \lambda_2) - (k_1 + k_2)}{6}. \quad (11)$$

for $i = 1, 2$ and $i \neq j$. Note that raising the transportation tax in either countries decreases the total amount of transportation and increases the transportation prices, while raising the tariff rate in either countries decreases both the total amount of transportation and transportation prices. Substituting (9) and (11) into (4), we have the profits of logistics firm $i$ in second stage equilibrium as $\Pi_i^*$. 

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By substituting (11) into (7), we have

\[ q_{ii}^* = \frac{\alpha(12 - 4\gamma - \gamma^2) + \gamma(5k_i - k_j) + 2\gamma(\tau_1 + \tau_2) + 4\gamma(\lambda_1 + \lambda_2)}{6(4 - \gamma^2)}, \]  

\[ q_{ij}^* = \frac{2\alpha(2 - \gamma) - (5k_j - k_i) - 2(\tau_1 + \tau_2) - 4(\lambda_1 + \lambda_2)}{3(4 - \gamma^2)}, \]  

\[ p_{ii}^* = \frac{\alpha(12 - 4\gamma - \gamma^2) + \gamma(5k_i - k_j) + 2\gamma(\tau_1 + \tau_2) + 4\gamma(\lambda_1 + \lambda_2)}{6(4 - \gamma^2)}, \]  

\[ p_{ij}^* = \frac{\alpha(2 - \gamma)(8 - \gamma^2) + (2 - \gamma^2)[2(\tau_1 + \tau_2) + 4(\lambda_1 + \lambda_2) + (5k_j - k_i)]}{6(4 - \gamma^2)}. \]  

for \( i = 1, 2 \) and \( i \neq j \). Thus, we have the following lemma.

**Lemma 1**

A raise in \( \tau_1 \) increases \( q_{11}, q_{22}, p_{11}, p_{22}, p_{12}, \) and \( p_{21} \), but decreases \( q_{12} \) and \( q_{21} \).

A raise in \( k_1 \) increases \( q_{11}, q_{12}, p_{11} \) and \( p_{21} \), but decreases \( q_{22}, q_{21}, p_{12} \) and \( p_{22} \).

A raise in \( \lambda_1 \) increases \( q_{11}, q_{22}, p_{11}, p_{22}, p_{12} \) and \( p_{21} \), but decreases \( q_{12} \) and \( q_{21} \).

Raising transportation tax rate increases all prices, while raising tariff rate in one country increases the prices in the country but reduces the prices in another country.

Substituting (12)~(15) into (3), we obtain the profits of final-good firm \( i \) in second stage equilibrium as \( \pi_i^* \).

# 3 Equilibrium under Various Regulation Regimes

## 3.1 Transportation Tax Regime

In this section, we derive the equilibrium under regime TRSP. In the first stage, each government \( i \) non-cooperatively chooses the tax rate on its domestic logistics firm \( (\tau_i) \) so as to maximize the social welfare. The both countries’ tariff rates and airport usage fees are fixed at zero (i.e., \( k_1 = k_2 = 0 \) and \( \lambda_1 = \lambda_2 = 0 \)). Before examining the optimal policy for each government, it is helpful to show the marginal effects of tax changes on consumer’s and producers’ surplus and the quality of environment.

Differentiating \( CS_1^*, CS_2^*, \Pi_1^*, \Pi_2^*, \pi_1^*, \pi_2^* \), and \( Q^* \) with \( \tau_1 \) and evaluating them at \( \tau_1 = \tau_2 = 0 \),
we have

\[
\frac{\partial CS_i^*}{\partial \tau_i} \bigg|_{\tau_1=\tau_2=0} = -\frac{\alpha(8 + 6\gamma - 3\gamma^2)}{18(2 - \gamma)(2 + \gamma)^2} < 0, \tag{16}
\]

\[
\frac{\partial CS_j^*}{\partial \tau_1} \bigg|_{\tau_1=\tau_2=0} = -\frac{\alpha(8 + 6\gamma - 3\gamma^2)}{18(2 - \gamma)(2 + \gamma)^2} < 0, \tag{17}
\]

\[
\frac{\partial \Pi_i^*}{\partial \tau_i} \bigg|_{\tau_1=\tau_2=0} = -\frac{8\alpha}{9(2 + \gamma)} < 0, \tag{18}
\]

\[
\frac{\partial \Pi_j^*}{\partial \tau_1} \bigg|_{\tau_1=\tau_2=0} = \frac{4\alpha}{9(2 + \gamma)} > 0, \tag{19}
\]

\[
\frac{\partial \pi_i^*}{\partial \tau_1} \bigg|_{\tau_1=\tau_2=0} = -\frac{\alpha(8 - 6\gamma - \gamma^2)}{9(2 - \gamma)(2 + \gamma)^2} < 0, \tag{20}
\]

\[
\frac{\partial \pi_j^*}{\partial \tau_1} \bigg|_{\tau_1=\tau_2=0} = -\frac{\alpha(8 - 6\gamma - \gamma^2)}{9(2 - \gamma)(2 + \gamma)^2} < 0, \tag{21}
\]

\[
\frac{\partial Q_j^*}{\partial \tau_i} \bigg|_{\tau_1=\tau_2=0} = -\frac{4}{3(4 - \gamma^2)} < 0. \tag{22}
\]

Thus, we have the following lemma.

**Lemma 2**

A small increase in \(\tau_i\) reduces \(CS_i^*, CS_j^*, \Pi_i^*, \pi_i^*, \pi_j^*, Q_j^*\) and increases \(\Pi_j^*\).

The effect of a small increase in \(\tau_i\) reduces consumer surplus and profits of final-good firm in both countries (shown in (16)) because the tax raises transportation prices, which in turn raises the price of both domestic and imported final-goods in both countries (Lemma 1). The effects of a small increase in \(\tau_i\) on \(\Pi_i^*\) and \(\Pi_j^*\) are straightforward: the tax imposed on domestic logistics firm reduces (increases) domestic (foreign) logistics firm. Therefore, the amount of transportation and emissions are decreased by the tax increases.

Now we proceed to derive the equilibrium of policy-setting stage. From the FOC of welfare maximization of government \(i\) under regime TRSP, we obtain the following reaction function of government \(i\):

\[
\tau_i = R_i^r(\tau_j) \equiv \Delta_\tau - \frac{4 - 3\gamma^2 + 16\delta}{52 - 15\gamma^2 + 16\delta} \tau_j, \tag{23}
\]

where

\[
\Delta_\tau \equiv \frac{\alpha(2 - \gamma)(32\delta + 6\gamma + 9\gamma^2 - 40)}{104 - 30\gamma^2 + 32\delta} \wedge 0.
\]

From (23), we have the following lemma.\(^5\)

\[^5\]The SOC is derived as

\[
\frac{\partial^2 W_i}{\partial \tau_i^2} = -\frac{52 - 15\gamma^2 + 16\delta}{9(4 - \gamma^2)^2} < 0.
\]

In addition,

\[
\frac{\partial^2 W_i}{\partial \tau_i^2} \cdot \frac{\partial^2 W_j}{\partial \tau_i^2} - \frac{\partial^2 W_i}{\partial \tau_i^2} \cdot \frac{\partial^2 W_j}{\partial \tau_i^2} = \frac{8(28 - 9\gamma^2 + 16\delta)}{27(4 - \gamma^2)^3} > 0.
\]
Lemma 3
The tax rates on international transportation are strategic substitutes (i.e., \( R_i^i' < 0 \)).

Solving (23) for \( i = 1, 2 \), Nash equilibrium rate of tax can be characterized as

\[
\tau_i^N = \frac{\alpha(2 - \gamma)(32\delta + 6\gamma + 9\gamma^2 - 40)}{4(28 - 9\gamma^2 + 16\delta)} \quad i = 1, 2. \tag{24}
\]

In order to assure the equilibrium amount of international transportation to be positive, we need \( \delta < \alpha(16 - 9\gamma)/8 \), which is satisfied under Assumption 1.

From (24), we find that the equilibrium tax rate is positive (negative) when

\[
\delta > (<) \frac{40 - 6\gamma - 9\gamma^2}{32}.
\]

We also find that the critical value of \( \delta \) is a decreasing function of \( \gamma \). Thus, we have the following proposition.

Lemma 4
If \( \delta > (<) \delta \), then the equilibrium policy is positive (negative) tax. The greater competition in the final-good market, the more likely the equilibrium tax rate to be positive.

Substituting (24) and \( k_1 = k_2 = 0 \) into (9) through (15), we characterize the Subgame-Perfect Nash Equilibrium (SPNE) of regime TRSP. The amount of international transportation under regime TRSP, \( Q^{TRSP} \) can be obtained as

\[
Q^{TRSP} = \frac{2\alpha(16 - 9\gamma)}{28 - 9\gamma^2 + 16\delta} > 0. \tag{25}
\]

The equilibrium amount of international transportation is necessarily positive for all \( \gamma \in [0, 1] \) and \( \delta > 0 \).

\[
W_i^{TRSP} = \frac{\alpha^2 \left( 1228 - 888\gamma - 177\gamma^2 + 162\gamma^3 + 160\delta 
+ 480\gamma\delta - 324\gamma^2\delta + 192\delta^2 \right)}{2(28 - 9\gamma^2 + 16\delta)^2} + y, \tag{26}
\]

3.2 Tariff Regime

In this section, we derive the equilibrium under regime TRFF. In the first stage, each government \( i \) non-cooperatively chooses a tariff rate \( (k_i) \) on imports so as to maximize the social welfare. The both countries’ transportation taxes and airport usage fees are fixed at zero (i.e., \( \tau_1 = \tau_2 = 0 \) and \( \lambda_1 = \lambda_2 = 0 \)). Before examining the optimal policy for each government, it is helpful to show the marginal effects of tax changes on consumer’s and producers’ surplus and the quality of environment.

Differentiating \( CS_1^*, CS_2^*, \Pi_1^*, \Pi_2^*, \pi_1^*, \pi_2^*, \) and \( Q^* \) with \( \tau_1 \) and evaluating them at \( k_1 = k_2 = 0 \),
we have

\[
\frac{\partial CS_1^*}{\partial k_1}
\bigg|_{k_1=k_2=0} = \frac{-5\alpha(8+6\gamma-3\gamma^2)}{36(2-\gamma)(2+\gamma)^2} < 0,
\]

(27)

\[
\frac{\partial CS_2^*}{\partial k_1}
\bigg|_{k_1=k_2=0} = \frac{\alpha(8+6\gamma-3\gamma^2)}{36(2-\gamma)(2+\gamma)^2} > 0,
\]

(28)

\[
\frac{\partial \Pi_1^*}{\partial k_i}
\bigg|_{k_1=k_2=0} = -\frac{2\alpha}{9(2+\gamma)} < 0,
\]

(29)

\[
\frac{\partial \Pi_2^*}{\partial k_1}
\bigg|_{k_1=k_2=0} = -\frac{2\alpha}{9(2+\gamma)} < 0,
\]

(30)

\[
\frac{\partial \pi_1^*}{\partial k_1}
\bigg|_{k_1=k_2=0} = \frac{\alpha(8+30\gamma+5\gamma^2)}{18(2-\gamma)(2+\gamma)^2} > 0,
\]

(31)

\[
\frac{\partial \pi_2^*}{\partial k_1}
\bigg|_{k_1=k_2=0} = -\frac{\alpha(40+6\gamma+\gamma^2)}{18(2-\gamma)(2+\gamma)^2} < 0,
\]

(32)

\[
\frac{\partial Q^*}{\partial k_i}
\bigg|_{k_1=k_2=0} = -\frac{4}{3(4-\gamma^2)} < 0.
\]

(33)

Thus, we have the following lemma.

**Lemma 5**

A small increase in \(k_i\) reduces \(CS_i^*, \Pi_i^*, \Pi_j^*, \pi_j^*\) and \(Q^*\) and increases \(CS_j^*, \pi_i^*\).

Raising the tariff rate drives the foreign competitor out of the domestic market and increases the profits of the domestic final-good firm, at the expense of the domestic consumers. Interestingly, the foreign consumers are better off when the domestic government imposes tariff on imports because the prices in the foreign market are reduced.

From the FOC of welfare maximization of government \(i\) under regime TRFF, we obtain the following reaction function of government \(i\):

\[
k_i = R_i^i \equiv \Delta_k = \frac{20 - 15\gamma^2 - 64\delta}{340 - 87\gamma^2 + 64\delta} k_j,
\]

(34)

where

\[
\Delta_k \equiv \frac{\alpha(2-\gamma)(64\delta + 30\gamma + 9\gamma^2 + 40)}{340 - 87\gamma^2 + 64\delta} > 0.
\]

**Lemma 6**

The tariff rates are strategic complements (substitutes) if the slope of marginal environmental damages are relatively small (large). Formally,

\[
R_k^i \equiv 0 \Leftrightarrow \delta \leq \frac{20 - 15\gamma^2}{64}.
\]

In contrast to transportation tax rates as in Lemma 3, the strategic relationship of tariff rates crucially depends on the magnitude of \(\delta\).
Solving (34), we obtain the Nash equilibrium tariff rate in imposed by government $i$:

$$
k_i^N = \frac{\alpha(2 - \gamma)(64\delta + 30\gamma + 9\gamma^2 + 40)}{8(40 - 9\gamma^2 + 16\delta)} > 0, \quad \text{for } i = 1, 2. \quad (35)$$

Substituting (35) and $k_1 = k_2 = 0$ into (9) through (15), we characterize the Subgame-Perfect Nash Equilibrium (SPNE) of regime TRFF. The amount of international transportation under regime TRSP, $Q^{TRFF}$ can be obtained as

$$
Q^{TRFF} = \frac{5\alpha(4 - 3\gamma)}{40 - 9\gamma^2 + 16\delta} > 0. \quad (36)
$$

$$
W_i^{TRFF} = \frac{\alpha^2 \left( 30400 - 16800\gamma - 4020\gamma^2 + 2520\gamma^3 + 27\gamma^4 \right)}{32(40 - 9\gamma^2 + 16\delta)^2} + y. \quad (37)
$$

### 3.3 Airport Usage Fee Regime

Suppose that each country can charge usage fees on both the arrival and the departure from its domestic airport or harbor. In the first stage, each government $i$ non-cooperatively chooses airport usage fee, $\lambda_i$, so as to maximize the social welfare. The both countries’ transportation tax and tariff rates are fixed at zero (i.e., $\tau_1 = \tau_2 = 0$ and $k_1 = k_2 = 0$). Before examining the optimal policy for each government, it is helpful to show the marginal effects of tax changes on consumer’s and producers’ surplus and the quality of environment.

Differentiating $CS_1^*, CS_2^*, \Pi_1^*, \Pi_2^*, \pi_1^*, \pi_2^*$, and $Q^*$ with $\lambda_1$ and evaluating them at $\lambda_1 = \lambda_2 = 0$, we have

$$
\frac{\partial CS_1^*}{\partial \lambda_1} \bigg|_{\lambda_1 = \lambda_2 = 0} = -\frac{\alpha(8 + 6\gamma - 3\gamma^2)}{9(2 - \gamma)(2 + \gamma)^2} < 0, \quad (38)
$$

$$
\frac{\partial CS_2^*}{\partial \lambda_1} \bigg|_{\lambda_1 = \lambda_2 = 0} = -\frac{\alpha(8 + 6\gamma - 3\gamma^2)}{9(2 - \gamma)(2 + \gamma)^2} < 0, \quad (39)
$$

$$
\frac{\partial \Pi_1^*}{\partial \lambda_1} \bigg|_{\lambda_1 = \lambda_2 = 0} = -\frac{4\alpha}{9(2 + \gamma)} < 0, \quad (40)
$$

$$
\frac{\partial \Pi_2^*}{\partial \lambda_1} \bigg|_{\lambda_1 = \lambda_2 = 0} = -\frac{4\alpha}{9(2 + \gamma)} < 0, \quad (41)
$$

$$
\frac{\partial \pi_1^*}{\partial \lambda_1} \bigg|_{\lambda_1 = \lambda_2 = 0} = -\frac{2\alpha(8 - 6\gamma - \gamma^2)}{9(2 - \gamma)(2 + \gamma)^2} < 0, \quad (42)
$$

$$
\frac{\partial \pi_2^*}{\partial \lambda_1} \bigg|_{\lambda_1 = \lambda_2 = 0} = -\frac{2\alpha(8 - 6\gamma - \gamma^2)}{9(2 - \gamma)(2 + \gamma)^2} < 0, \quad (43)
$$

$$
\frac{\partial Q^*}{\partial \lambda_1} \bigg|_{\lambda_1 = \lambda_2 = 0} = -\frac{8}{3(4 - \gamma^2)} < 0. \quad (44)
$$

Thus, we have the following lemma.
Lemma 7
A small increase in $\lambda_i$ reduces $CS_i^*, CS_j^*, \Pi_i^i, \Pi_i^j, \pi_i^*, \pi_j^*$ and $Q^*$. 

From the FOC of welfare maximization of government $i$ under regime AUF, we obtain the following reaction function of government $i$:

$$\lambda_i = R_i^\Delta \equiv \Delta_k - \frac{4 - 3\gamma^2 + 16\delta}{28 - 9\gamma^2 + 16\delta} \lambda_j,$$

where

$$\Delta_k = \frac{\alpha(2 - \gamma)(32\delta + 6\gamma - 3\gamma^2 + 8)}{4(28 - 9\gamma^2 + 16\delta)} > 0.$$ 

Lemma 8
The airport usage fees are strategic substitutes (i.e., $R_i^i < 0$).

Solving (45), we obtain the Nash equilibrium airport usage fee imposed by government $i$:

$$\lambda_i^N = \frac{\alpha(2 - \gamma)(32\delta + 6\gamma - 3\gamma^2 + 8)}{16(8 - 3\gamma^2 + 8\delta)} > 0, \text{ for } i = 1, 2.$$ 

Thus, we have the following lemma.

Lemma 9
The equilibrium airport usage fees are necessarily positive.

The equilibrium amount of international transportation is

$$Q^{AUF} = \frac{\alpha(4 - 3\gamma)}{8 - 3\gamma^2 + 8\delta} > 0.$$ 

Thus, we have the following proposition.

Proposition 1
When $\delta > \gamma^2/4$, $Q^{TRSP} > Q^{TRFF} > Q^{AUF}$ holds. When $\delta < \gamma^2/4$, $Q^{TRSP} > Q^{AUF} > Q^{TRFF}$ holds.
The ranking of the amount of international transportation under different regimes also represents the ranking of total emissions.

In the following, we compare the equilibrium welfare under different regimes. From (26) and (37), we have

$$W_{i}^{TRSP} - W_{i}^{TRFF} = \frac{9\alpha^2 [240 - 100\gamma - 36\gamma^2 + 9\gamma^3 + 16\delta(4 - \gamma)]}{32(28 - 9\gamma^2 + 16\delta)^2(40 - 9\gamma^2 + 16\delta)^2} \Psi_1, \quad (49)$$

where

$$\Psi_1 = 3520 - 2960\gamma - 800\gamma^2 + 912\gamma^3 - 36\gamma^4 - 27\gamma^5 - \left(5120 - 2431\gamma - 1792\gamma^2 + 960\gamma^3\right)\delta - \left(3072 - 1792\gamma\right)\delta^2.$$ 

Thus, $\Psi_1 > 0$ when

$$\delta < \delta_1 = \frac{-160 + 76\gamma + 56\gamma^2 - 30\gamma^3 + \sqrt{67840 - 84480\gamma - 1024\gamma^2 + 34656\gamma^3 - 8240\gamma^4 - 3432\gamma^5 + 1089\gamma^6}}{16(12 - 7\gamma)},$$

and $\Psi_1 < 0$ when $\delta > \delta_1$.

From (26) and (48), we have

$$W_{i}^{TRSP} - W_{i}^{AUF} = \frac{9\alpha^2 (2 - \gamma)^2 [24 + 32\delta + \gamma(2 - 9\gamma)]}{32(28 - 9\gamma^2 + 16\delta)^2(8 - 3\gamma^2 + 8\delta)^2} \Psi_2,$$

where

$$\Psi_2 = 352 - 120\gamma - 204\gamma^2 + 42\gamma^3 + 27\gamma^4 - (256 + 96\gamma - 144\gamma^2)\delta - 512\delta^2.$$ 

Thus, $\Psi_2 > 0$ when

$$\delta < \delta_2 = \frac{-16 - 6\gamma + 9\gamma^2 + \sqrt{3(2 + \gamma)^2(256 - 320\gamma + 99\gamma^2)}}{64},$$

and $\Psi_2 < 0$ when $\delta > \delta_2$.

From (37) and (48), we have

$$W_{i}^{TRFF} - W_{i}^{AUF} = \frac{9\alpha^2 (4 - 3\gamma)^2}{4(40 - 9\gamma^2 + 16\delta)^2(8 - 3\gamma^2 + 8\delta)^2} \Psi_3,$$

where

$$\Psi_3 = (4\delta - \gamma^2) \left[80 - 36\gamma^2 + 3\gamma^4 + 6(4 + \gamma^2)\delta - 32\delta^2\right].$$ 

Thus, $\Psi_3 > 0$ when

$$\gamma^2 < \delta < \delta_3 = \frac{3(4 + \gamma^2) + \sqrt{2704 - 1080\gamma^2 + 105\gamma^4}}{32},$$

and $\Psi_3 < 0$ when $\delta < \delta_3$ or $\delta > \delta_4$.

We obtain the order of the critical value of $\delta$ as $\delta_3 < \delta_1 < \delta_2 < \delta_4$. Thus, we have the following proposition.
**Proposition 2**

(i) If $\delta > \delta_4$, then $W^{AUF} > W^{TRFF} > W^{TRSP}$.

(ii) If $\delta_2 < \delta < \delta_4$, then $W^{TRFF} > W^{AUF} > W^{TRSP}$.

(iii) If $\delta_1 < \delta < \delta_2$, then $W^{TRFF} > W^{TRSP} > W^{AUF}$.

(iv) If $\delta_3 < \delta < \delta_1$, then $W^{TRSP} > W^{TRFF} > W^{AUF}$.

(v) If $\delta < \delta_3$, then $W^{TRSP} > W^{AUF} > W^{TRFF}$.

Figure 1 illustrates the results in $\gamma - \delta$ plane. The assertions (i)~(v) are depicted by regions (A)~(E) in the figure.

### 4 Policy Cooperation

In this section, we consider a case of policy cooperation between two governments. The principle is that both government will decide the level of regulations ($\tau_1 = \tau_2 = \tau$, $k_1 = k_2 = k$, or $\lambda_1 = \lambda_2 = \lambda$) to maximize the sum of both countries’ welfare ($\hat{W} = W_1 + W_2$). We compare the equilibrium with policy cooperation and that with non-cooperative policy derived in the previous section.

From the FOC of joint welfare maximization under regime TRSP, we have

$$\tau^C = \frac{\alpha(2 - \gamma)(32\delta + 6\gamma + 3\gamma^2 - 16)}{4(4 - 3\gamma^2 + 16\delta)},$$

where $\tau^C$ represents the cooperative tax rate.

Thus, we have the following proposition.
Proposition 3
A cooperative tax rate on international transportation is higher (lower) than a non-cooperative tax rate when the environmental damages are (not) severe. Formally, if $\delta > (<) \frac{2-\gamma}{8}$, then $\tau^C > (<) \tau^N_i$ holds.

Proof.
From (24) and (50), we have
\[
\tau^C - \tau^N_i = \frac{9\alpha(2-\gamma)^2(2+\gamma)[8\delta - (2-\gamma)]}{(4-3\gamma^2 + 16\delta)(28 - 9\gamma^2 + 16\delta)} > 0 \iff \delta \leq \frac{2-\gamma}{8},
\]
where the denominator is always positive for $\gamma \in [0, 1]$. □

Raising tax imposed on domestic logistics firm by the domestic government has two opposite effects on foreign country’s payoff. On the one hand, raising the tax reduces emissions because it reduces the amount of international transportation as shown in (22). The emission reductions are also beneficial to the foreign country. Thus, raising the tax in one country has positive external effect on other country’s welfare. On the other hand, raising the tax also increases the price of international transportation, and thus raises the costs for final-good firms in both countries. The increase in cost reduces not only the profits of the final-good firm but also consumers surplus in both countries. This is because it shrinks the production of both final-good firms, which exacerbates the problem of under-provision of products associated with an oligopoly market in both countries. Thus, raising the tax in one country has negative (pecuniary) external effect on other country’s welfare. When environmental damages are significant in both countries (i.e., $\delta$ is large), the former external effect is dominant. Thus, the non-cooperative tax rate is smaller than cooperative one because the cooperative policy setting can internalize it. When environmental damages are not significant, the latter external effect is dominant, so the non-cooperative tax rate is larger than the cooperative one.

From the FOC of joint welfare maximization under regime TRFF, we have
\[
k^C = \frac{\alpha(2-\gamma)(32\delta + 6\gamma + 3\gamma^2 - 16)}{4(4-3\gamma^2 + 16\delta)} = \tau^C. \tag{51}
\]
Then, we have
\[
k^C - k^N_i = \frac{9\alpha(16 - 12\gamma - 4\gamma^2 + 3\gamma^3)}{8(4-3\gamma^2 + 16\delta)(40 - 9\gamma^2 + 16\delta)} \left[16\delta + \gamma^2 - 20\right] \gtrless 0 \iff \delta \gtrless \frac{20 - \gamma^2}{16}.
\]

Proposition 4
A cooperative tariff rate is higher (lower) than a non-cooperative tariff rate when the environmental damages are (not) severe. Formally, if $\delta > (<) \frac{20-\gamma^2}{16}$, then $k^C > (<) k^N_i$ holds.

From the FOC of joint welfare maximization under regime AUF, we have
\[
\lambda^C = \frac{\alpha(2-\gamma)(32\delta + 6\gamma + 3\gamma^2 - 16)}{8(4-3\gamma^2 + 16\delta)} = \frac{1}{2} \tau^C = \frac{1}{2} k^C. \tag{52}
\]
Then, we have
\[
\lambda^C - \lambda^N_i = -\frac{9\alpha(4 - 3\gamma)(4 - \gamma^2)^2}{16(4-3\gamma^2 + 16\delta)(8 - 3\gamma^2 + 8\delta)} < 0.
\]
Proposition 5
A cooperative airport usage fee on international transportation is necessarily lower than a non-cooperative rate (i.e., $\lambda_C < \lambda_i^N$).

5 The Effect of Trade Liberalization

In this section, we investigate the effects of trade liberalization on the equilibrium non-cooperative and cooperative regulation policies. Consider a situation where the exogenously given tariff rate $\bar{k} > 0$ is imposed in both countries. Under such situation, each government non-cooperatively sets its transportation tax rate $\tau_i$ to maximize social welfare. The profits of final-good firm $i$ (3) are replaced by $\pi_i = p_{ii}q_{ii} - (p_{ij} - p_T - k)q_{ij}$, where $\bar{k}$ is the tariff rate on imports.

In a similar way with the previous section, we can derive the non-cooperative equilibrium tax rates on international transportation as

$$\tau_i^N = \tau_i^N + \frac{8(1 - 2\delta)}{28 - 9\gamma^2 + 16\delta} \bar{k}, \quad \text{for } i = 1, 2,$$  \hspace{1cm} (53)

where $\tau_i^N$ is the non-cooperative tax rate in the case where both countries impose tariff on imports and $\tau_i^N$ is that in free trade case shown in (24). Thus, we have the following lemma.

Lemma 10
The non-cooperative rate of transportation tax with positive tariffs is greater (smaller) than that under free trade when $\delta < (>) 1/2$.

On the other hand, the cooperative tax rates, $\bar{\tau}^C$ are derived by

$$\bar{\tau}^C = \tau^C - k.$$  \hspace{1cm} (54)

Lemma 11
The cooperative rate of transportation tax with positive tariffs is necessarily smaller than that under free trade by exactly the tariff rate.

Unlike the non-cooperative tax rate (53), cooperative tax rate under tariff regime is smaller than that under free trade regime, and the differences are exactly the tariff rate imposed in both countries ($\bar{k}$). The intuition is as follows. An increase in the tariff rate raises transportation prices by the same amount that an increase in the transportation tax rate does. On the other hand, imposing tariffs on imports can transfer the profits from foreign to domestic, but imposing transportation tax on domestic logistics firm can transfer the profits from domestic to foreign. Unlike the case of non-cooperative policy setting, the difference of the distributions of the profits does not matter, so the cooperative transportation tax is exactly reduced by the tariff rate.

From (53) and (54), we have

$$\bar{\tau}^C - \tau_i^N = (\tau^C - \tau_i^N) + \frac{9(4 - \gamma^2)}{28 - 9\gamma^2 + 16\delta} \bar{k},$$

which yields the following proposition.

Proposition 6
If the environmental damages are prominent such that $\tau^C > \tau^N$, trade liberalization reduces the difference between $\bar{\tau}^C$ and $\tau^N$ and thus reduces the distortion of non-cooperative regulation.
On the other hand, if the environmental damages are not prominent such that $\tau^C < \tau^N$, trade liberalization enlarges their differences and thus aggravates the distortion.

References


<http://www.iata.org/SiteCollectionDocuments/Documents/

