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International Trade and Global Warming

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Abstract

In a non-cooperative strategic environmental regulation, unilateral regulation may yield the so-called "carbon-leakage" and the government choice over the emission taxes and quotas play an important role. Furthermore, the trade and industrial structure of a country critically hinges on the government's policy tools. The paper shows that emission taxes makes the competitive production equilibrium unstable, while emission standards work as "hidden production subsidy" towards emission-intensive industries.

Keywords: global warming, strategic environmental regulation, emission quota, emission tax, carbon leakage, emission standards, .
JEL Classification Number: F18

1 Introduction

Global warming, that is caused by increasing the level of green-house gases (GHGs) such as carbon dioxide, is expected to seriously affect economic activities through climate changes. The reduction of GHGs has been discussed in a number of international conventions. In particular, the third Conference of Parties to the United Nations Framework Convention on Climate Change (COP3) held in Kyoto at the end of 1997 was notable in the sense that a legally binding protocol, so called, the Kyoto Protocol was adopted.[1]

The protocol includes two important agreements. First, the targets of reduction in GHGs in 38 developed countries were explicitly set. Annex I countries (which consists of OECD countries and countries in the former USSR and eastern Europe) as a whole reduce emission 5.2 percent below 1990 levels between 2008 and 2012. For this, each country was committed

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[1] About ten thousand people including government officials from 161 countries, NGO members, and the press attended COP3.

to a specific target level.[2] An important question faced by these countries is, however, how these targets should be implemented. It seems that this question has not fully been explored in the existing literature.

Second, emission trading, joint implementation (JI) and clean development mechanism (CDM) were accepted.[3] These mechanisms give Annex I countries some degree of flexibilities to implement the targets.[4] It is actually expected that some countries such as US and Japan cannot achieve their targets without these mechanisms, especially, emission trading.

It is no doubt that the Kyoto Protocol is a significant step for the reduction of GHG emission, but developing countries have no obligation to the reduction.[5] With only partial participation by countries to the framework of GHG emission reduction, a concern is carbon leakage. That is, even if the level of GHG emission falls in Annex I countries, it may rises in the other counties. As a result, the worldwide level may rise. Moreover, the partial participation may affect international trade in goods and foreign direct investment.

The purpose of this paper is to theoretically examine GHG emission regulations in the framework of open economy. We examine emission quota, emission tax, and emission standard and compare them. In particular, we explicitly consider the effect of the introduction of those regulations on the economy and international trade, which has not been analyzed in the previous literature.

Although global warming has been attracting a considerable attention, there are not many rigorous studies that tackle the issue in the context of international trade theory. Early studies relating to global warming are those that deal with international externalities (particularly, cross-border pollution).[6] There are two types of external diseconomies: one makes consumers worse off and the other lowers some productivity.

Markusen (1975a) seems to be the first that explicitly analyzes international negative externalities in the context of international trade theory. He derives necessary conditions that characterize an optimal tax structure when one of the countries unilaterally imposes taxes or provides subsidies. Markusen (1975b,1976) extends the above analysis by taking account of the

[2]For example, the targets of EU, US, Japan, Russia and Australia are, respectively, -8%, -7%, -6%, 0% and+8%.

[3]JI is a joint project to decrease GHG emission among Annex I countries, while CDM is one between Annex I countries and non Annex I countries. The amount of reduction obtained by a project is distributed as credit among participating countries.

[4]These three mechanisms were named “Kyoto mechanism” in COP4 held in Buenos Aires in 1998.

[5]There was an agreement in COP1 that developing countries should not be under any new obligation to the reduction.

[6]In international trade theory, a number of researches conducted with international externalities is very small relative to that with local externalities. Studies of trade and environment under local externalities include Copeland and Taylor (1994,1999).

dependence and interaction between two countries when a bilateral externality exists. While the level of pollution enters in the social welfare function in Markusen (1975a,b), the stock of a common property resource affects production in Markusen (1976).[7]

Although their frameworks are somewhat restrictive, Ludema and Wooton (1994) and Copeland (1996) deal with interesting issues in the presence of cross-border negative externalities. They pont out that strategic aspects could arise when there exist pollution regulations.[8]

Copeland and Taylor (1995, 1999) use Heckscher-Ohlin frameworks to analyze trade and environment. In their models, two factors are labor and emission.[9] For production, thus, firms have to purchase an emission permit, the price of which is equal to the marginal product of emission. Since countries share the common technologies, it is crucial in their analyses whether the factor price equalization holds. Their utility functions, in which the total level of emission enters, are key to their results, because the linkage between the income level and the sensitivity to environment is explicitly introduced.

Copeland and Taylor (1995) analyze the effects of international trade (between North and South) and environmental policy on trade follows, pollution levels and welfare in the presence of transboundary pollution. Copeland and Taylor (1999) explicitly focuses on the relationship between global warming and international trade. They show that trade in permits may either be redundant or make participants to trade in goods and permits worse off and that unilateral emission reduction by North may decrease emission by South due to income effect.

As briefly reviewed so far, the previous literature does not directly inquire into how each country's choice of environment regulatory policies affects either the world abatement performance or the own country's trade structure. As the present paper will show, a country's strategic choice of emission controls greatly affects not only the volume of the world total green-house gas (GHG) emission volume through the so-called "carbon leakage" effect but also each country's welfare. By applying the tariff-quota equivalence theorem in international trade, we will find that in strategic environment policy

[7]Because of international production externalities, Markusen (1976) is also related to another trade and environment issue, i.e., the analysis of trade and renewable resources, for which dynamic frameworks is often used. See Chichilnisky (1993), López (1994), and Brander and Taylor (1998), for example.

[8]Using a partial equilibrium framework, Ludema and Wooton (1994) examine the nations' strategic policy choices when pollution abatement technology exists and trade tax and/or externality tax are available. Copeland (1996) analyses the optimal policy of the importing country and points out that pollution regulations (such as pollution quota and tax and process standard) taken by the exporting country may create rent-shifting opportunities for the importing country.

[9]Chichilnisky (1994) also uses a Heckscher-Ohlin framework where one of two factors is environmental resources and both factors are endogenously supplied. In her analysis, North-South trade and the overuse of environmental resources arise because of the difference in property rights between North and South.

games the equivalence between emission quotas and emission taxes breaks down, though it holds in a closed economy. Choice of emission quota is likely to be more effective to restrain the world GHG emission.

Furthermore, if international commodity trade is free, then a country's choice of emission controls over emission quotas, emission taxes and emission standards critically affects stability of the resulting trade and production structure. Two important results are as follows. First, when a government tries to replicate the production equilibrium in free trade under the emission quota with the equivalent emission taxes, then the equilibrium becomes unstable. The country may completely specialize either in the emission-intensive industry or in the emission non-intensive one. Either specialization pattern will turn out to be possible and stable. Second, when a government enforces the equivalent emission standards achieving the emission per unit of output at the emission-quota equilibrium, then only completely specialization in the emission-intensive industry is possible at the resulting equilibrium insofar as the emission intensities differ between the industries and there is no emission intensity reversals.

The rest of the paper is organized as follows. In section 2, we discuss the first issue stated above, i.e., the effect of a country's choice between emission quotas and emission taxes over the world GHG emission performance by using a simple three country model where a single final good is produced by fossil fuels and its production emits GHG over the world. We will then explore into the resulting effect of the so-called "carbon leakage" and the welfare of each country from the view-point of strategic environment policy games by applying the tariff-quota equivalence theorem.

In section 3, we further look into the effects of those emission controls over each country's trade and production structure. We will first show that when the abatement activity is formulated as further inputs of labor, the economy can be modeled as a standard Heckscher-Ohlin two-by-two model where the two factors are labor and environment resource. The economic effects of emission controls in the form of emission quotas are then clarified to further explore into the effects of policy switches from emission quotas to other equivalent policies such as emission taxes and emission standards.

The last section concludes the paper with some discussion on the implications of the results for managing international emissions trading in the Kyoto mechanism.

2 Emission Controls, Carbon Leakage, and Strategic Environment Regulations

2.1 Basic Structure of the Model

Consider a world consisting of three countries, 1, 2 and 3. The first two countries uses fossil fuels for production and emits green-house gases (GHG). Neither of them can produce fossil fuels for themselves, and both must depend on their imports from abroad. And this supply of fossil fuels is made by the last third country. Country 3 produces fossil fuels but does not emit any GHG.

Let us give a further structure to country 3's economy. Its welfare consists only of the profits from selling its fossil fuels to the rest of the world. Let X denote the total amount of fossil fuels produced, $C(X)$ the associated total cost function and p the world price of the fossil fuel. Then the welfare of country 3 is assumed to be expressed by

$$u_3 = pX - C(X) \tag{1}$$

For simplicity of exposition, we assume that country 3 is a price taker in the world fossil fuel market. Thus it determines its fossil fuel supply so as to equate the world price p with the marginal cost $C'(X)$, which is assumed to be increasing in the output. Thus its supply price of fossil fuel is given by its marginal cost, which we express by

$$p = P_s(X) \left(= C'(X)\right) \tag{2}$$

Since the marginal cost of producing fossil fuel is increasing, country 3's supply curve becomes upward sloping with respect to the fuel price.

Let us depict the structures of the two fuel consuming countries, countries 1 and 2. When we assume away the effects of abatement activities, there must be a one-to-one technological relationship between country i's amount of fuel consumption x_i and its amount of GHG emission z_i. We call this relationship the emission technology and express by

$$z_i = G_i(x_i) \text{ for } i = 1, 2 \tag{3}$$

By consuming fossil fuels, each fuel-consuming country can produce various goods and services, the value of which we express by the GDP function $f_i(x_i)$. Since the fuels must be imported from abroad with a unit price p, its net benefit is equal to $f_i(x_i) - px_i$.

However this is not an end of the story. Since each fuel-consuming country emits GHG as much as z_i, the world total GHG emission becomes $Z = z_1 + z_2$. This GHG emission damages the global environment as much as measured by the global warming damage function $D(Z)$. We assume that the marginal global warming damage $D'(Z)$ is increasing in the total GHG emission. And country i perceives its $100 \times \gamma_i$ % as its own damage[10].

To sum up, country i's welfare is given by

$$u_i = f_i(x_i) - px_i - \gamma_i D\left(\sum_j G_j(x_j)\right) \tag{4}$$

Put (2) into (4). Then one can express each fuel-consuming country's national welfare as a function of the fuel consumption profile (x_1, x_2) as below:

$$u^i(x_i, x_j) = f_i(x_i) - P_s(x_i + x_j)x_i - \gamma_i D\left(\sum_k G_k(x_k)\right) \tag{5}$$

2.2 Free Emission Equilibrium

At first, let us see what equilibrium emerges when no fuel-consuming country's governments imposes any GHG emission controls and they allow their private sector to seek for the own profit maximization. The resulting fuel consumption level should equate the marginal value product of fossil fuel $f'(x_i)$ with its world price p.

$$f_i'(x_i) = p \tag{6}$$

Assume that the marginal value product of fossil fuels is decreasing. Then an increase in the world price of the fossil fuel decreases each country's fuel consumption, leading to a reduction in GHG emission.

What is important is that each country's GHG emission is not independent of the other's. As is shown by (**??**), when one country increases its GHG emission, the other country has an incentive to reduce its GHG emission through an increase in the world price of fossil fuel. In this sense, the equation (6) with the fuel price being replaced with the fuel supply price function $P(X)$,

$$f_i'(x_i) = P_s(x_i + x_j) \tag{7}$$

gives country i's private reaction function, showing its optimal fuel consumption given the other's.

The private reaction curve associated with the private reaction function of country i is depicted by curve R_i^p in Figure 1. The intersection of the two private reaction curves represents the free emission equilibrium E_{pp} where the private sectors can freely and competitively choose their fuel consumption levels without being subject to the governments' GHG controls.

[10] Note that we do not impose a condition $\sum_i \beta_i = 1$. This is because there may be damages from global warming on the areas with no human beings or there may be externalities in damage perception, i.e., there may be some countries which value the well-being of other countries.

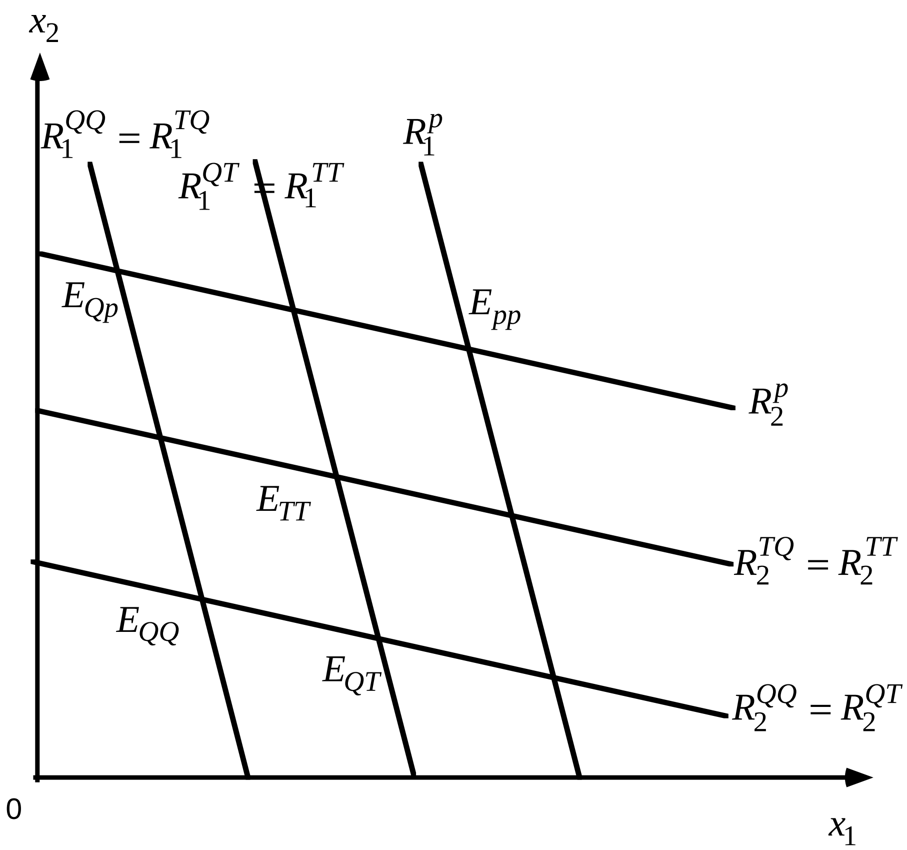

Figure 1: Strategic Choices of Emission Controls

2.3 GHG Emission Control by Direct Regulations

What if each country's government begins to regulate its own GHG emission level? Let us first consider the case when the government employs emission quotas over the country's total GHG emission volume[11].

2.3.1 Emission Quota Equilibrium

A country, if it is a small country in the world fuel market, worsens her welfare by intervening in free private trade. But this is not true for large countries. A large country importing fuels may have a strategic incentive to restrain her import, lower the world fuel price and thus to improve her terms of trade. When global warming matters, she may find further gains from strategic fuel import control, for the resulting change in the fuel price affects other countries' fuel consumption and thus their GHG emission volumes. She can indirectly alter the damages from global warming. To clarify these strategic effects, we assume hereafter that the two fuel-consuming countries are large in the world fuel market.

Assume that each fuel-consuming country's government regulates the country's total GHG emission and thus indirectly intervenes in fuel trade. We need each government's reaction curve for delineating the resulting equilibria. We call country i's government government i, and let $R_i^{QQ}(x_j)$ government i's reaction function. When country i's fuel consumption x_i is equal to $R_i^{QQ}(x_j)$, it should maximize country i's welfare given by (5) given country j's fuel consumption x_j. Thus it should satisfy the following first-order condition for welfare maximization[12]:

$$0 = f_i'(x_i) - P_s(X_i + x_j) - P_s'(x_i + x_j)x_i - \gamma_i D'(Z)G_i'(x_i) \tag{8}$$

The first first term on the RHS represents the marginal value product of fossil fuel, the second term the world fuel price (the marginal fuel consumption costs for a small country), the third term the marginal loss from terms-of-trade (TOT) deterioration due to an increase in the own fuel consumption, and the last term the marginal global warming effect, i.e., the marginal damage from aggravation in global warming. Assuming that the payoff function is strictly concave in the own fuel consumption, country i's best response fuel consumption depends on country j's through the TOT

[11]There are two major policy tools to achieve the present total emission control of GHG. One is to cast a cap over the total emission volume with emission quota to the private sector. Another is to control the total emission volume at a specified target level by suitably choosing carbon tax rates. Note that the carbon tax policy here differs from the one discussed later. The carbon tax policy as total emission control allows the carbon tax rates so as to keep the total emission level equal to the target level, while the ordinary carbon tax policy requires the government to commit to a specified tax rate.

[12]A function with superscript j represents the function partially differentiated to country j's fuel consumption.

effect and the marginal global warming effect. The reaction curve associated with $x_i = R_i^{QQ}(x_j)$ is shown by curve R_i^{QQ} in Figure 1. The intersection of the two reaction curves, E_{QQ} represents an equilibrium where both fuel-consuming country's governments directly control their total GHG emission volumes.

The reaction curves in Figure 1 are described as downward sloping curves. This is the case in which each country's fuel consumption is a strategic substitute to the other's. In general, it may not be the case. The reaction curve of a country's government may be upward sloping, i.e., a country's fuel consumption may become a strategic complement to the other's. A factor giving the dividing line between strategic substitutes and complements is a size of the change in the TOT effect due to an increase in the other country's fuel consumption. In fact, an increase in the other country's fuel consumption raises the world fuel price and the marginal global warming effect, both of which increases the country's marginal fuel consumption costs. However the direction and the size of the changes in the TOT effects are generally ambiguous, which makes it difficult for us to predict whether the reaction curves are downward or upward sloping.

However, fortunately, the succeeding analysis does not depend on the assumptions on strategic substitutes and complements, as will be shown below. What is necessary for inquiry is the so-called equilibrium stability condition, i.e., the absolute value of the slope of each reaction curve is strictly smaller than unity.

$$\left| R_i^{QQ\prime}(x_j) \right| < 1 \text{ for } i, j = 1, 2 (j \neq i) \tag{9}$$

We impose this stability condition for each possible reaction curve of both countries including the private reaction ones.

2.3.2 Free Emission Equilibrium vs. Direct Total Emission Control Equilibrium

Before comparing the two equilibria, E_{pp} and E_{QQ}, let us first discuss the effects of direct total emission control by a single country, say country 1, when the other country 2 maintains laissez-faire in GHG emission. As shown in Figure 1, the reaction function of country 1's government R_1^{QQ} is located left to the private counterpart R_1^p. There are two factors causing this inward shift.

First, the government takes into account the TOT deterioration effect which is neglected in the private decision over fuel consumption. Second, the government also cares an increase in the marginal global warming effect, which is also neglected by the private sector. These two factors makes the government restrain its national fuel consumption compared with the private decision.

When country 1's reaction curve shifts inward from R_1^p to R_1^{QQ} by the government's starting to restrain the country's GHG emission, an equilibrium changes from the initial free emission equilibrium E_{pp} to E_{QP}. Insofar as the absolute value of the slope of each reaction curve is than unity (equilibrium stability condition), there must be a decrease in the world total fuel consumption, leading to a drop in the world fuel price. This result has the following implications.

First, the decrease in the world fuel price lets country 2 without emission control have an incentive to expand its fuel consumption, leading to an increase in its GHG emission. This is what is called the "carbon leakage" effect.

Second, and more importantly, a country's emission control does not necessarily lead to a decrease in the world total GHG emission. Since country 1's emission volume decreases with the total emission volume control but country 2's increases by virtue of the carbon leakage effect, it is generally ambiguous whether the world total GHG emission decrease or not. More specifically, when country 2's energy efficiency is sufficiently lower than country 1's in the sense of more GHG emission per input of fuel, the result is an increase in the world total GHG emission.[13]

Proposition 1 *When only country 1 controls the own GHG emission volume, it has the following three effects.*

1. *The world fuel price decreases.*
2. *Country 2 without GHG emission quotas expands its fuel consumption as well as its GHG emission.*
3. *The world total GHG emission volume increases if country 2's energy efficiency is sufficiently lower than country 1's.*

As has been made clear, GHG emission quotas by the countries with higher energy efficiently cannot effectively restrain the world total GHG emission without the cooperation from those with lower energy efficiency.

[13]In the present paper, we assume away the income effects on the demand for higher environmental quality. If those effects set in and the higher income strengthens demand for the more improved global environment, then a sufficiently great decrease in the world fuel price may give country 2 an incentive to regulate its GHG emission volume. This is because the drop in the world fuel price increases country 2's real income. This is what Copeland and Taylor (1999) discussed. However their argument seems to lack reality. First, the size of real income increase to trigger emission control may be too large to realize, particularly for developing countries. Second, there may be many countries, like oil-producing ones, which suffer from a decrease in the real income due to the drop in the world fuel price. If those countries initially employs any GHG emission quotas but become less environment-minded after the real income loss , then the world total GHG emission may increase even if there are some countries starting to control the emissions.

When both countries, 1 and 2, i.e., all the fuel-consuming countries undertakes emission quotas, there would be a decrease in the world total GHG emission. This state is depicted by point E_{QQ} in Figure 1.

2.3.3 Choices between emission taxes and emission quotas

As an policy instrument to control GHG emission, a country can also employ emission taxes other than emission quotas. Their difference is that the country's total GHG emission volume is kept at at the target level regardless of the world fuel price, while in the case of emission taxes the emission volume changes along with the world fuel price level through a change in the fuel consumption. Then what if either of the two countries employs emission taxes as a means to control the national GHG emission.

Assume that initially country 2 as well as country 1 employs direct emission control, and consider country 1's choice between emission taxes and emission quotas. We note that given country 2's fuel consumption, the choice does not matter for country 1 insofar as the two policies achieve the best-response fuel consumption against country 2's. What does this mean?

When country 1 employs emission taxes and country emission quotas, their reaction curves should be depicted over the plane of country 1's emission tax rate and country 2's fuel consumption volume. However when we transform them into the plane of fuel consumption volumes, then country 1's reaction curve should be the same as when it employs direct control. That is, country 1's transformed reaction curve with emission taxes, expressed by R_1^{TQ}, is just equal to R_1^{QQ}[14].

Similarly, when country 2 initially employs emission taxes, insofar as country 2's policy level is given, it is indifferent for country 1 between emission taxes and emission quotas. This establishes $R_1^{QT} = R_1^{TT}$ where R_1^{QT} represents country 1's transformed reaction curve when it employs emission quotas and country 2 employs emission taxes, and etc. And one should note that each country's transformed reaction curve in Regime (T, T) , expressed by R_i^{TT}, should be located left to the private reaction curve R_i^p, for the government has an incentive to restrain fuel consumption for the reasons stated earlier[15].

Proposition 2 *Given the other country's policy tool, the choice between emission taxes and emission quotas does not matter for a country's government.*

The last task is the relation between R_1^{QQ} and R_1^{QT}. That is, what effects arise to country 1's incentive for GHG emission when country 2 switches

[14]The superscripts, for example TQ, represent the sate in which country 1 employs emission taxes (T) and country 2 direct control (Q).

[15]The result below is an extension of the tariff-quota equivalence theorem in trade to the choices over the environmental policies in the international setting.

from emission quotas to emission taxes? In fact, this has a very important effect.

As discussed earlier, country 1's optimal fuel consumption should equate the marginal value product of fuel, $f_i'(x_i)$ with the sum of the the following three marginal cost of fuel consumption:

1. direct purchase cost of fuel, p
2. TOT deterioration effect
3. marginal global warming effect

When country 2 commits to a certain specified emission level, then the second and third marginal costs arise only from country 1's own increase in fuel consumption. However when country 2 employs emission taxes, then the increase in the world fuel price due to country 1's consumption expansion gives country 2 an incentive to reduce its fuel consumption[16]. This decrease in country 2's fuel consumption eases the second and third marginal cost effects, which lets country 1 expand further its fuel consumption than before. Thus we have established

Proposition 3 *Given the rival country's fuel consumption volume, a country's best response fuel-consumption volume is greater when the rival employs emission taxes than when it employs emission quotas.*

The results obtained so far are summarized in Figure 1.

What implications are obtained from the above discussion? First, when either country controls the own GHG emission, the world total fuel consumption decreases as well as the fuel price as is shown by a shift of an equilibrium from E_p to E_{Qp}. We have already discussed the resulting effect regarding the carbon leakage effect.

[16]More specifically, country 1's best response fuel consumption given country 2's emission tax rate is obtained as follows. First, let t_2 denote country 2's specific emission tax. Then given the world fuel price p, its fuel consumption should satisfy

$$f_2'(x_2) = P_s(x_1 + x_2) + t_2 G_2'(x_2),$$

where one should note that $G_2'(x_2)$ represents the marginal GHG emission of fuel in country 2. As is expressed in (**??**) country 2's fuel consumption depends on its own emission tax rate t_2 and country 1's x_1, the relation of which we express by $x_2 = x_2^{QT}(x_1, t_2)$.

And this fuel demand function of country 2 satisfies

$$-\frac{\partial x_2^{QT}}{\partial x_1} = \frac{P_s'}{P_s' - f_2''} \in (0,1)$$
$$-\frac{\partial x_2^{QT}}{\partial t_2} = \frac{1}{P_s' - f_2''} > 0$$

As the first equation shows, given the initial fuel-consumption pair, if country 2 commits to a specified rate of emission tax, then an increase in country 1's fuel consumption decreases country 2's fuel consumption as discussed in the text.

Second, the world total fuel consumption volume tends to be the smallest when both countries regulate the own GHG emission by emission quotas. Thus the world total GHG emission volume would be the smallest at equilibrium E_{QQ}.

Third, for a country committing to emission quotas, it is often more beneficial that the other country employs emission taxes rather than emission quotas. This is because the country with emission quotas can strategically expand the own fuel consumption at the expense of the other country through a price hike in the world fuel market.

Let us inquire into this strategic gains of country 1 more in detail by using Figures 2 and 3. And for this inquiry, one may resort to the use of iso-welfare contours. They take the same shapes as the iso-profit curves in homogeneous Cournot duopoly, for an increase in the other country's fuel consumption aggravate the own TOT as well as global warming.

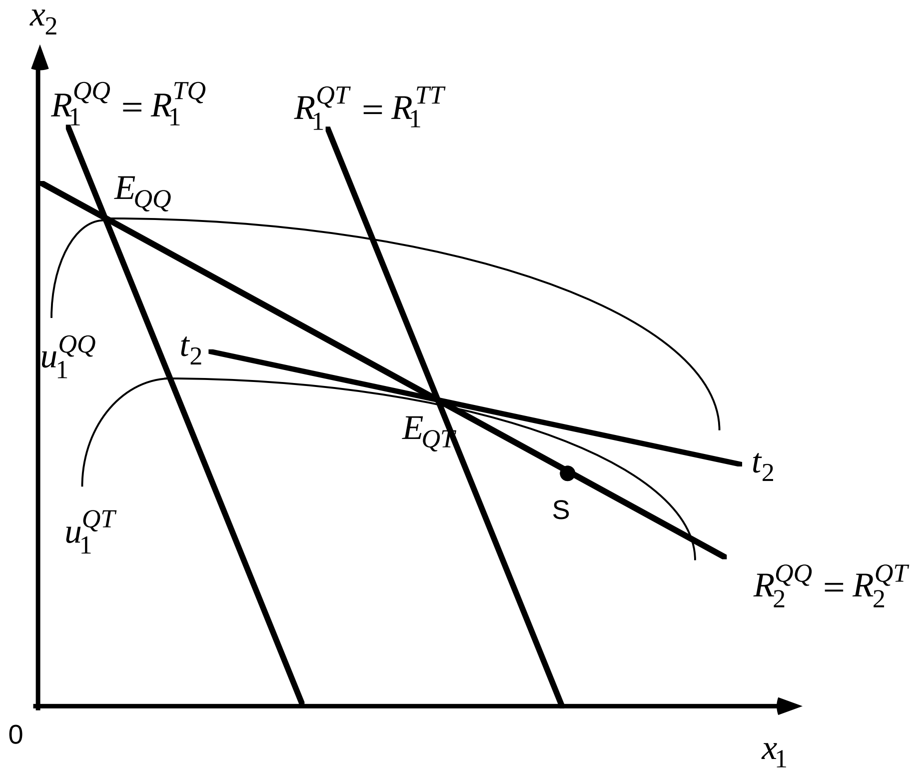

Figure 2: Country 1's Gains from Commitment to Emission Quota

The curves u_1^{QQ} and u_1^{QT} show two iso-welfare curves of country 1, where the former is associated with equilibrium E_{QQ} and the latter with E_{QT}. Since in Figure 2 country 2's fuel consumption is a strategic substitute to country 1's and an increase in country 2's fuel consumption hurts country

1, the best fuel consumption profile for country 1 along country 2's reaction curve is the one such as point S requiring an increase in country 1's consumption and a decrease in country 2's compared with a non-cooperative equilibrium for emission quotas E_{QQ}. It is a point achieved when country 1 acts as Stackelberg leader against country 2.

Since E_{QT} is an equilibrium when country 1 chooses quotas and country 2 taxes, country 1's iso-welfare contour u_1^{QT} should touch its feasibility locus $t_2 t_2$ which shows a locus of feasible fuel consumption profiles given country 2's equilibrium emission tax rate and we call the iso-emission tax rate curve. Then if the situation is the one in Figure 2, that is if the equilibrium is located left to country 1's Stackelberg equilibrium S, country 1 should definitely enhances its welfare compared with when country 2 chooses emission quotas, i.e., E_{QQ}.

However this is not the only possibility. As shown in Figure 3, country 1's welfare may become worse at E_{QT} than at E_{QQ}. The critical difference between the two figures is whether the iso-emission tax rate curve of country 2 is flatter in the absolute value than its reaction curve. If the iso-emission tax rate curve of country 2 is sloper in the absolute value than its reaction curve, then country 1 tend to overconsume fuel compared with its Stackelberg leader equilibrium S. If this overconsumption effect is sufficiently strong, country 1 may ultimately lose from country 2's policy switch.

These results can be extended to the case where each country's fuel consumption is a strategic complement to the other"s as shown in Figure 4. Since each country's reaction curve is now upward sloping, country 2's iso-emission tax rate curve, which is always downward sloping, has the smaller slope than country 2's reaction curve. Thus it is straightforward to see that

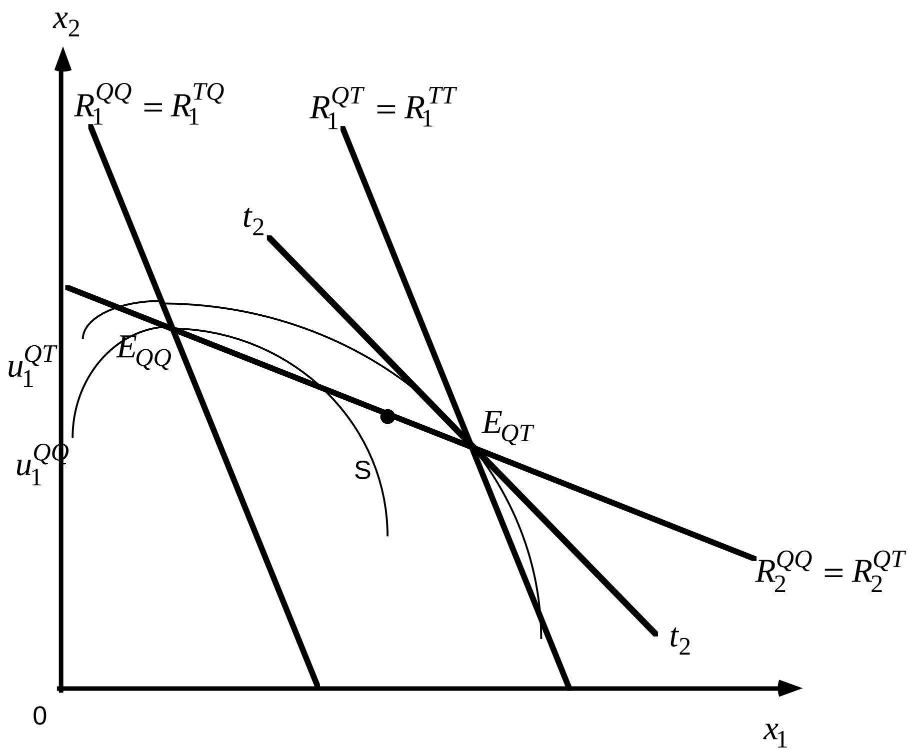

Figure 3: Country 1's Losses from Commitment to Emission Quota

country 1 is hurt by country 2's switch from quotas to taxes[17][18].

Proposition 4 *Country 2's policy switch from emission quota to emission tax benefits country 1 employing emission quota only if country 2's fuel consumption is a strategic substitute to country 1's and country 2's iso-emission tax rate curve has the larger slope than its own reaction curve at the equilibrium when country 1 chooses quotas and country 2 taxes. Otherwise, it tends to hurt country 1 .*

Note that the conditions using the slopes of the iso-emission tax rate curves and the reaction curves can be used to rank the welfare levels of each country among other possible equilibria. But the essence of the argument is the same, so that we skip such welfare comparison.

One of the most important conclusions from the present discussion is that a country's choice of emission quotas significantly affects global warming as well as each country's national welfare. However choice of environmental policies does also affect each country's trade and production structure in free commodity trade. Let us discuss this issue in the next section.

3 Trade Structure and Emission Controls

Let us build a trade model of a small country facing free commodity trade. There are two goods (good 1 and good 2) that are produced using a single factor (labor) with a CRS technology in competitive markets. The labor coefficient of good i $(i = 1, 2)$ is given by a_i. The endowment of labor is given by L.

[17]By using the results in footnote 16, we may prove the result a little more rigorously. To prove the result in the text, it suffices to prove that country 1's welfare is still increasing along country 2's reaction curve $R_2^{QQ} = R_2^{QT}$ at equilibrium E_{QT}. This can be computed as below

$$\left.\frac{du_1^{QQ}(x_1, R_2^{QQ}(x_1))}{dx_1}\right|_{x_1=x_1^{QT}} = f_1' - P_s - x_i P_s' \left(1 + R_2^{QQ\prime}\right) - \gamma_1 D' \left(G_1' + G_2' R_2^{QQ\prime}\right)$$
$$= \left(x_1 P_s' + \gamma_1 D' G_2'\right) \left(\frac{\partial x_2^{QT}}{\partial x_1} - R_2^{QQ\prime}\right),$$

where use was made of country 1's equilibrium condition at E_{QT}, i.e.,

$$0 = \frac{\partial u_1^{QT}}{\partial x_1} = f_1' - P_s - x_1 P_s' \left(1 + \frac{\partial x_2^{QT}}{\partial x_1}\right) - \gamma_1 D' \left(G_1' + G_2' \frac{\partial x_2^{QT}}{\partial x_1}\right).$$

Thus, we obtain

$$\left.\frac{du_1^{QQ}(x_1, R_2^{QQ}(x_1))}{dx_1}\right|_{x_1=x_1^{QT}} > 0 \iff \frac{\partial x_2^{QT}}{\partial x_1} > R_2^{QQ\prime}$$

[18]Similar results hold even when we allow international emissions trading designed in the Kyoto mechanism as discussed in Kiyono (2000).

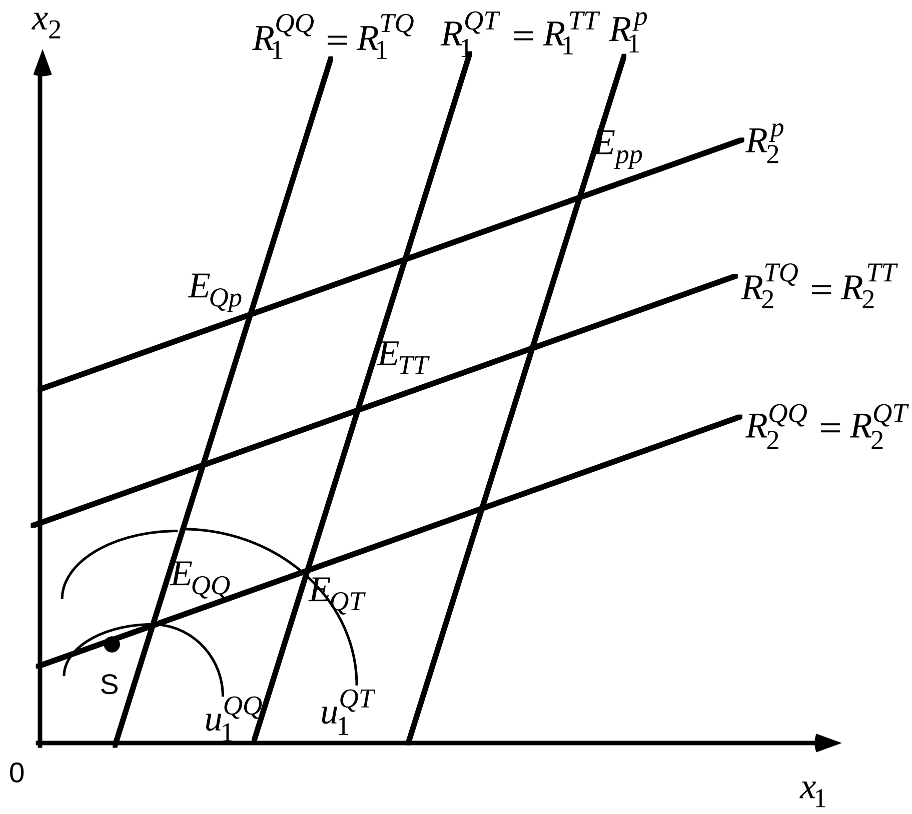

Figure 4: Case of Strategic Complements

Production of one unit of good i $(i = 1, 2)$ emits e_i units of GHG. GHG reduces economic welfare, but does not generate production externalities. While GHG is a joint output, it is convenient to describe the output of good i $(i = 1, 2)$ as a function of labor input, L_i, and the amount of GHG emitted during production, Z_i:

$$X_i = F^i(L_i, Z_i), \quad i = 1, 2, \tag{10}$$

where F^i is concave, continuously differentiable, and linearly homogeneous. One should note that labor includes here inputs for emission abatement behind technical substitution between labor and emission expressed by (10). Thus although a firm can reduce labor input by increasing GHG emission, this substitution has a limit which is given by $(\bar{a}_i, \bar{e}_i)$. That is, $\bar{a}_i$ is the minimum amount of labor input while $\bar{e}_i$ is the maximum amount of GHG emission for one unit of good i production.

This can be illustrated using a unit isoquant (see Figure 5). The smooth substitution between labor input and GHG emission is possible only in the region above $\bar{a}_i$. It is obvious that firms will use$\bar{a}_i$ units of labor to produce one unit of good i without any emission regulation.

We let good 2 be numeraire and assume that the world relative price of good 1, $p^w (\equiv p_1^w / p_2^w)$, is exogenously given. Without any emission regulation, the production structure is that of Ricardian model. Thus, the economy specializes in good i under free trade if

$$\frac{a_1}{a_2} > p^w. \tag{11}$$

In the following, we assume (11) and examine various kinds of emission regulations.

3.1 Emission Quota

As a benchmark of emission regulation, we first consider emission quotas. The government sets an aggregate level of domestic emission of GHG which is denoted by Z. To implement the emission level, the government issues Z units of marketable emission permits. The permits can be traded freely within the economy and the price of permit is denoted by r.

Once the permits have been issued, the economy behaves like a Heckscher-Ohlin (HO) model which is described by the following:

$$c^i(r, w) \geq p_i^w, \quad i = 1, 2, \tag{12}$$

$$\sum_i a_i(r, w) X_i = L, \tag{13}$$

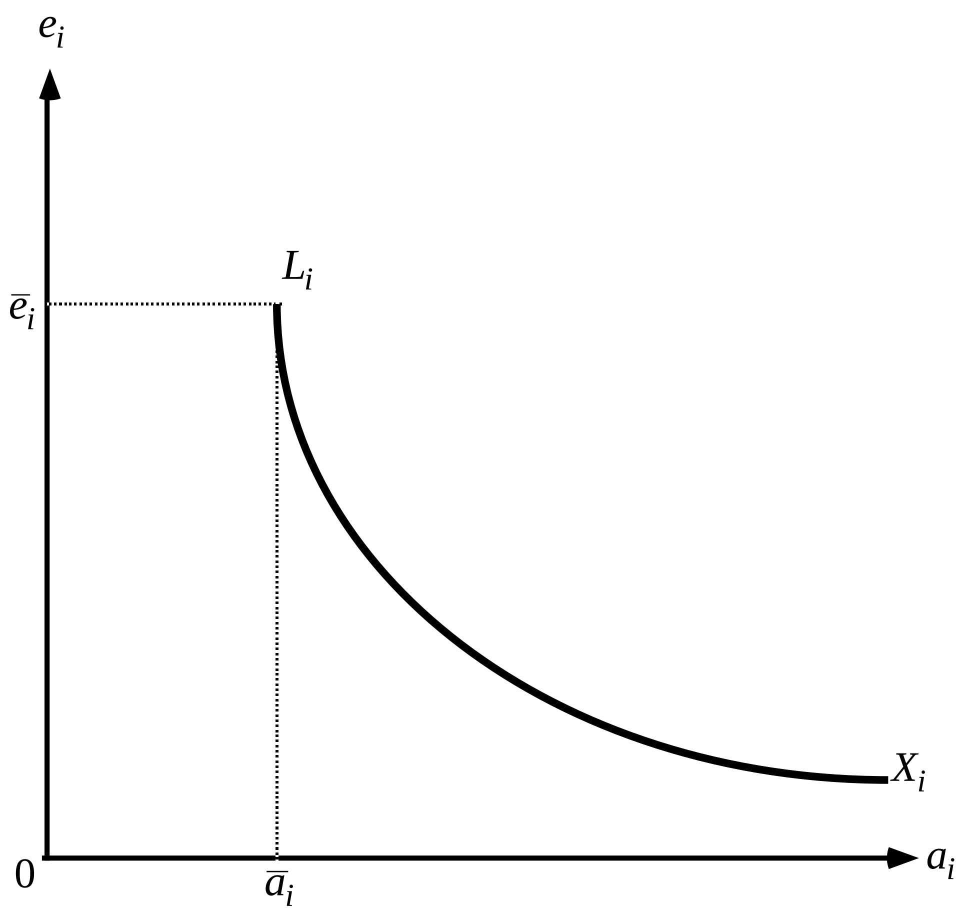

Figure 5: Technical Substitution between Emission and Labor

$$\sum_i e_i(r,w)X_i \le Z, \tag{14}$$

where $c^i(.)$ is the unit cost function of good i. If $c^i(.) > p_i^w$ $(i = 1, 2)$, then the economy completely specializes in the other good, i.e., good j $(j = 1, 2; i \neq j)$. (13) shows the full employment of labor. In the HO model, both factors are assumed to be fully employed, but inequality could hold in (14). If this is the case, the permit price becomes zero.

The unit cost curve of good i is illustrated in Figure 6. Since the substitution between labor input and GHG emission is not always possible as is shown in Figure 5, the unit cost curve has a segment portion, L_iL_i'. The slope of L_iL_i' is equal to $\bar{e}_i/\bar{a}_i$. For the following analysis, we define emission intensity which is given by

$$z_i(r,w) \equiv \frac{e_i(r,w)}{a_i(r,w)} = \frac{Z_i(r,w)}{L_i(r,w)} \tag{15}$$

and assume that good 1 is always more emission-intensive relative to good 2. That is, $z_1(r,w) > z_2(r,w)$ holds for any (r,w). Using Shepherd's lemma, the slope of the unit cost curve equals $z_i(r,w)$.

We now examine free trade equilibria both with and without emission quota with the aid of Figure 7. Without any emission regulation, the production possibility frontier (PPF) is given by $L_1^0L_2^0$, the slope of which is a_1/a_2. With (11), the economy completely specializes in good 1 and its output is $L/\bar{a}_1$. The production and consumption points are, respectively, given by L_1^0 and Cwhich is located on the world-relative-price line $p'L_1^0$ going through L_1^0.

When emission quota is introduced, the PPF becomes F_1F_2. Since the production structure is just like a HO model in the presence of emission quota, F_1F_2 is (strictly) concave to the origin. The production point shifts from L_1^0 to Q where the world-relative-price line, pp, is tangent to F_1F_2. This shift can be decomposed into the following two effects.

The first is the introduction of emission quota without substitution between labor input and GHG emission. We call this effect the impact effect. Without the substitution, the PPF is $Z_1^0Q'L_2^0$ which is defined by (13) (i.e.,$L_1^0L_2^0$) and (14) (i.e., $Z_1^0Z_2^0$).[19] Thus, the impact effect corresponds to the shift from L_1^0 to Q' where the world-relative price line is tangent to $Z_1^0Q'L_2^0$ at point Q'[20].

The second is the substitution effect. The emission quota affects both permit price and wage and hence the substitution between labor input and emission arises. With the substitution, even when the emission quota is the same at the initial level, the emission quota constraint becomes less binding. That is, decreases in the emission coefficients in both sectors shifts

[19]Because of (15), $Z_1^0Z_2^0$ cuts both F_1F_2 and $L_1^0L_2^0$ from above.

[20]Full employment of labor implies that $a_1/a_2 < p^w < e_1/e_2$.

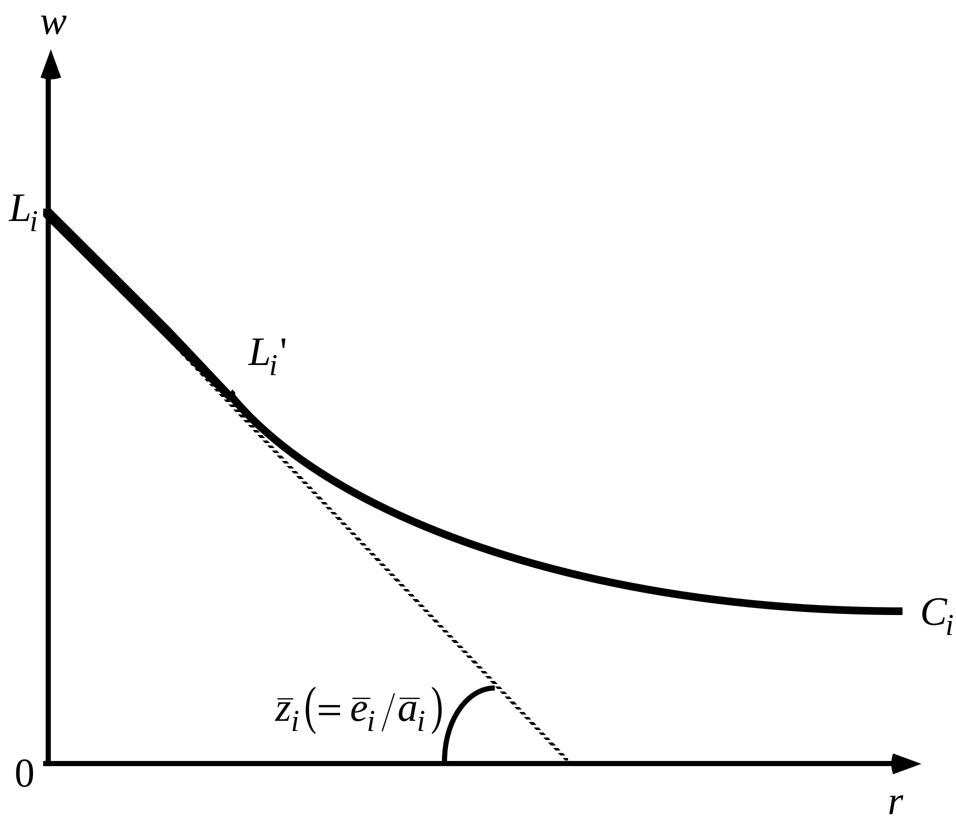

Figure 6: Factor Price Frontiers between Wage and Emission Permit Price

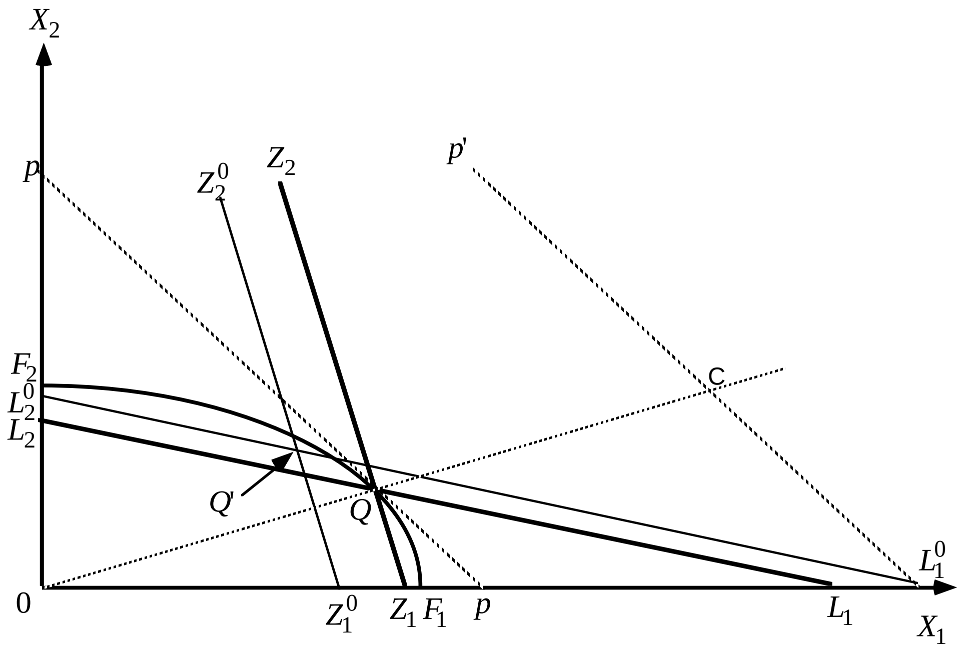

Figure 7: Trade and Production Structure under Emission Controls

the emission quota constraint from the initial curve $Z_1^0 Z_2^0$ outward to the new one $Z_1 Z_2$. On the other hand, substitution between labor and emission through abatement activities increases the labor coefficients, which leads to the inward shift of the labor endowment constraint from $L_1^0 L_2^0$ to $L_1 L_2$. The new equilibrium given the emission quota is represented by point Q along the new PPF shown by $F_1 F_2$. The substitution effect corresponds to the shift from Q' to Q. Here one notes that point Q' located within the PPF shows production inefficiency, for production at Q' does not allow substitution between labor and emission, which is in fact feasible.

With the aid of Figure 8, we examine the effects of emission quota on the permit price, wage, GDP, and specialization patterns . In the figure, $L_i C_i$ $(i = 1, 2)$ is the unit cost curve of good i (i.e., (12)). Since $z_1(r, w) > z_2(r, w)$ for any (r, w), the unit cost curve of good 1 cuts that of good 2 from above.

Without any emission regulation, $r = 0$. Thus, the equilibrium is given by L_1. The wage of industry 1 which is indicated by L_1 is higher than that of industry 2 which is indicated by L_2 and hence the economy completely specializes in good 1. The impact effect of emission quota is the shift from $L_1$to Q' where $L_1 Z_1$ and $L_2 Z_2$ intersect to each other.[21] The substitution effect is given by the shift from Q' to Q if the economy is diversified and from Q' to a point on the factor price frontier formed by $L_1 C_1$ and $L_2 C_2$, i.e.,$L_1 Q C_2$. The economy is diversified if $z_2(r_Q, w_Q) < Z/L < z_1(r_Q, w_Q)$.

[21]Without the substitution, the FPF is $L_1 Q' Z_2$.

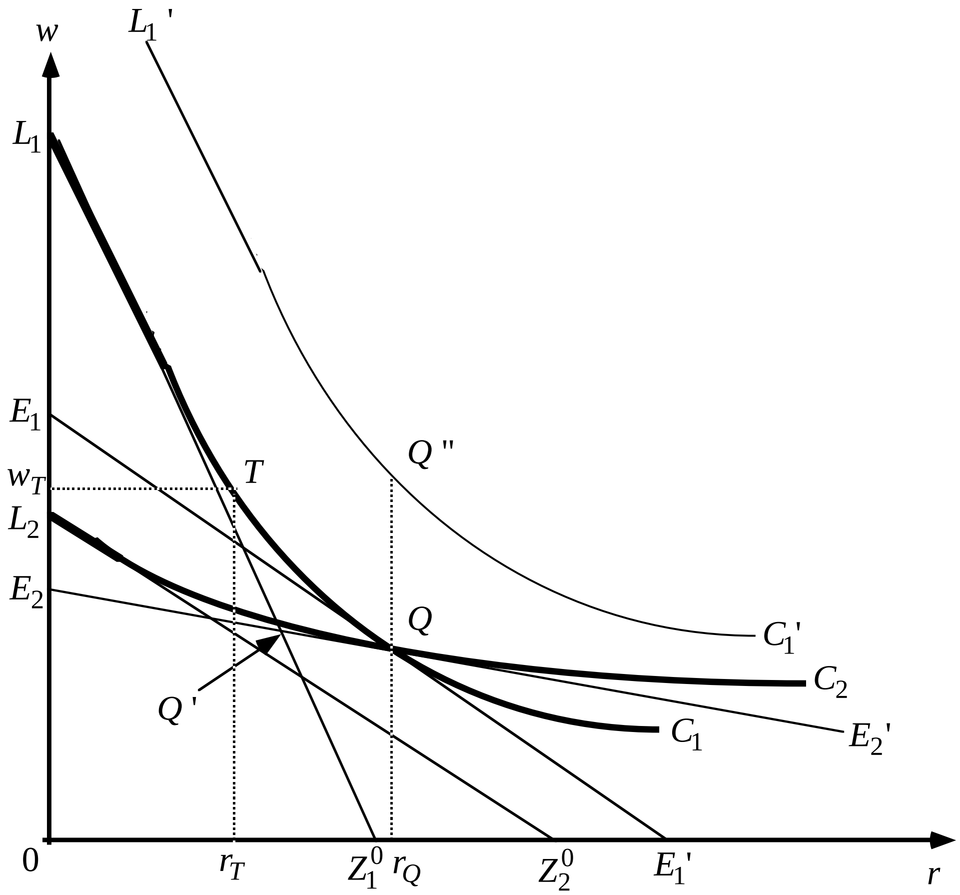

Figure 8: Emission Quotas, Emission Taxes and Emission Standards

The economy completely specializes in good 1 if $Z/L \geq z_1(r_Q, w_Q)$ and good 2 if $Z/L \leq z_2(r_Q, w_Q)$. When the economy completely specializes, the equilibrium is given by a point on L_1QC_2 where its slope is equal to Z/L.

GDP per capita which is given by

$$y = w + \frac{Z}{L}r \tag{16}$$

can be measured by the intercept of the line that has the slope Z/L and goes through the equilibrium point. It can easily be verified that as the level of emission quota lowers, the equilibrium point shifts down along the factor price frontier, L_1QC_2. In Figure 7, the shift of production point induced by decreasing the quota level is shown by $L_1F_1'QF_2'O$. In Figure 7, Q happens to be located on OC. If the social utility function is homothetic, then Q is also the consumption point. If the level of emission quota becomes tighter, thus, the trade pattern is reversed.

The above analysis is summarized in the following proposition.

Proposition 5 *Suppose that emission quota is introduced under free trade. The economy remains to completely specialize in good 1 if the level of quota is high. If the level is low, however, the economy is diversified or completely specializes in good 2. With the homothetic social utility function, as the quota level falls, the exports of good 1 decrease and the trade pattern is eventually reversed. The lower the quota level is, the lower the GDP.*

3.2 Quota-Equivalent Emission Tax

We next examine emission tax, i.e., the tax per unit of GHG emission. The government sets the level of emission tax r to reduce GHG emission. This effect can be seen with the aid of Figure 7. Once the tax is determined, the wage is also determined by the factor price frontier. If $r = r_T$, for example, then the wage is determined at T (i.e., $w = w_T$) and specializes in good 1. The GHG emission per capita is give by the slope of the factor price frontier at T. The economy completely specializes in good 1 if $0 < r < r_Q$ and good 2 if $r > r_Q$.

It is obvious that the complete specialization equilibrium under emission quota can be attained by setting the permit price equal to the emission tax. And we call this rate of (specific) emission tax the quota-equivalent emission tax.

However, the quota-equivalent emission tax alone cannot lead to the incomplete specialization equilibrium under emission quota, which is shown by Q in Figure 8. When the government sets $r = r_Q$, the wage becomes identical. However, GHG emission may be different between emission tax and quota. This is because emission tax alone cannot uniquely determine the outputs of goods 1 and 2 under free trade and hence the amount of GHG emission.

Proposition 6 *If the economy specializes completely under emission quota, the equilibrium can be attained with emission tax by setting the permit price equal to the emission tax, i.e., the quota-equivalent emission tax. If the economy is diversified under emission quota, however, the equilibrium cannot be attained by the quota-equivalent emission tax alone.*

Furthermore, with respect to the incomplete specialization equilibrium under emission tax, we obtain the following proposition:

Proposition 7 *A diversified equilibrium under the quota-equivalent emission tax is unstable, and the economy may specialize in either sector.*

Let us confirm this result by using Figure 8. Suppose that the economy is initially diversified at Q and then the world relative price of good 1 rises. The unit cost curve of good 1 shifts outward (from L_1C_1 to $L_1'C_1'$). Given $r = r_Q$, the good-1 sector is now willing to pay the higher wage than the good-2 sector. This drives the economy to complete specialization in good 1 with a rise in the per-capita GHG emission. This is shown in Figure 7 by the movement from the initial quota-equilibrium Q to point L_1. Note that once the economy specializes in the good-1 sector, the production equilibrium is now locally stable against small changes in the world prices.

If the world relative price of good 1 falls, on the other hand, the economy completely specializes in good 2 and the GHG emission per capita falls. The production point in Figure 7 is located at L_2. Thus, even if the quota-equivalent emission tax can support the the incomplete specialization equilibrium emission quota, a small change in the world price may lead to drastic changes in GHG emission as well as the production and trade structures when emission tax is used.

3.3 Quota-Equivalent Emission Standard

We investigate emission standard under which the government sets the level of e_i ($i = 1, 2$). This is actually equivalent to set the level of z_i, i.e., the emission intensity, or, to choose a specific technology. Once z_i is determined, thus, the substitution between labor input and GHG emission becomes essentially impossible. This is because once the government replaces emission quotas with the quota-equivalent emission standards, the industries do not have to pay emission permit prices, i.e., the costs for GHG emission, and thus they try to minimize the abatement activities as much as possible. The result is that each industry just meets the government emission standard requirement.

Although there are many possible emission standard levels to choose, we focus our attention on the emission standards which can replicate the emission-quota equilibrium in the sense of achieving the same volume of

GHG per output in each sector. We call such emission standard the quota-equivalent emission standard[22].

Now consider the effects of replacing the emission quota with the quota-equivalent emission standards by using Figure 8. Noting that z_i is equal to the slope of the unit cost curve of good i, the factor price frontier with the quota-equivalent emission standards is formed by the tangent lines to the unit cost curves. As a result the FPF with emission standard is given by E_iQE_i' for the good-i industry. Since the emission permit is useless with the quota-equivalent emission standards, the permit price becomes zero. Thus, the equilibrium is located on the vertical wage axis. Since the good-1 sector with the higher emission intensity can save the expenses for emission permits more, it is willing to pay the higher wage $0E_1$ than the maximum wage $0E_2$ that the good-2 sector is willing to pay. That is, the quota-equivalent emission standards work as hidden production subsidies to the emission-intensive industry. Thus the economy is driven to complete specialization in the emission-intensive good-1 sector. In Figure 7, the production equilibrium is now given by point L_1 again with the larger GHG emission than at the emission quota equilibrium[23].

Although the incomplete specialization equilibrium with emission quota cannot be attained by emission standard, any complete specialization equilibrium can be attained. If the equilibrium is at T under emission quota in Figure 8, for instance, it can be attained by setting $z_1 = z_1(r_T, w_T)$ and $z_2 \leq z_1(r_T, w_T)$.

Proposition 8 *If the economy specializes completely under emission quota, the equilibrium can be attained by the quota-equivalent emission standard. But if the economy is diversified under emission quota, however, the only production equilibrium under the quota-equivalent emission standard is complete specialization in the emission-intensive industry with the larger GHG emission.*

[22]Note that the quota-equivalent emission standard requires different rates of allowable emission rates per unit of output between the sectors. In this sense, this standard must be distinguished in general from the simple uniform emission standard which requires each and every industry to emit the same volume of GHG emission per unit of, say, fossil fuel input.

[23]Similar results hold for the model developed in the previous section when one considers the quota-equivalent emission standards. Each country with the quota-equivalent emission standard has an incentive to overconsume fuel, so that at the resulting equilibrium the emission standard level chosen by the government tends to be more stringent than at the emission-quota equilibrium. See Kiyono and Okuno-Fujiwara (2000).

4 Concluding Remarks – Some Implications for the Kyoto Mechanism

What we have attempted to clarify is potential effects of choices over the domestic GHG emission controls. Although the world is now going towards international cooperation against the global warming by proposing the Kyoto mechanism, the mechanism lacks (i) really global cooperation, only covering most advanced countries, and (ii) international enforceability of the cooperative measures. The proposed solutions calls for self-discipline of each member participating the Kyoto mechanism, particularly with respect to what domestic environmental policies are allowed to achieve the aim of the group as a whole. In this respect, we believe that our results sheds some light for discussing the need to further promote international cooperation against the deem of the global warming.

Among the major results in the present paper, those in section 3 sounds harsh, particularly for those promoting free international emissions trading, the most important scheme in the Kyoto mechanism. Replace the role of the emission tax in the previous section with the emission permit price in the world emissions trading market. Our results still hold. This implies that creation of international emissions trading market may make the world trade and industrial structure very volatile against change in the world economic environment. For further inquiry into this problem, one may have to resort to possible implications from trade theories with free factor mobility. International emissions trading allows the assigned units of emissions moves around the world and affects the production structure of each country participating in the Kyoto mechanism.

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