Is Emission Trading Beneficial?

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Abstract

We examine the effect of international trade in emission permits on the national welfare of trading countries. There is a technology gap between the countries: a developed country uses more emission-intensive technology than a developing country. We consider a situation in which the countries introduce emission quotas and start trading permits after commodity-trade liberalization. We show that commodity trade provides double gains: standard gains from trade and extra benefits from an improvement in the global environment. However, emission trading after the commodity-trade liberalization may cause double losses for the developing country: worsening of the terms of trade and deterioration of the global environment. We also examine a distributional question of emission quotas among the countries.

Keywords: global warming, international trade in emission-permits,
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1 Introduction

The Kyoto Protocol is the multilateral framework to address the emission of Greenhouse Gases (GHG). One shortcoming in the Kyoto framework is that the fastest-growing emitters such as China have not signed up. Policy makers have started discussions on a post-Kyoto framework, and have tried to draw developing countries such as Chian and India into a commitment to reduce emissions.[1]

So, the post-Kyoto framework should meet two requirements: First, it has to get developing countries to join a list of countries making commitments to quantitative targets. Second, it needs to have a system that makes those countries to implement targets for cuts in GHG emissions. The European commission states that market-based carbon trading is an instrument for countries to reach their targets at least cost. However, developing countries such as China have resisted mandatory reductions in emissions.[2]

In this paper, we develop a general equilibrium model of international trade in goods and emission-permits. And we ask the following question. If a developing country starts trading emission permits with a developed country, would it have economic and environmental benefits for them? Following an idea of Meade (1952), we regard GHG emissions as an input of environmental resources for production. We focus on a technology gap between developed and developing countries, i.e., a developed country has less emission-intensive technology than a developing country.

We show that emission trading after commodity-trade liberalization induces the developing country to expand production of a dirty good by importing emission permits, increasing the global emissions of GHG and deteriorating the global environment. Also, the developing country may suffer double losses from emission trading: the worsening in the terms of trade and the deterioration in global environment. This result holds regardless of which

[1] The Bush administration proposed that 15 countries producing the most GHG emissions should establish their own targets.

[2] Frankel (2007) proposes a formula for setting emission targets, which can entice developing as well as developed countries to join a post-Kyoto system of emission trading with targets.

country is given the more generous emission quota.

Our model is built on Ishikawa and Kiyono (2004) that develop a model having both Ricardian and Heckscher-Ohlin features and use the model to compare different measures of emission regulations in an open economy. We modify their framework in that one country has more emission-intensive technology as compared to the other. This modification enables us to examine economic and environmental effects of emission trading between developed and developing countries.

Copeland and Taylor (2003) develop a general equilibrium model of international trade and examine the welfare effects of emission trading. Our approach is similar to Copeland and Taylor's in that they regard emissions as a factor of production, but unlike theirs we introduce a technology gap between countries. More importantly, Copeland and Taylor consider a three-country version of their model, i.e., West, East, and South, and show that East-West trade in emission permits may cause carbon leakage due to a shift in production of the dirty good to unconstrained South. We consider emission trading between developing and developed countries and show that the emission trading may cause an increase in global emissions of GHG.

Lastly, our work is related to the literature on trade theory with capital mobility including Mundell (1957), Jones (1980), Brecher and Choudri (1982), Markusen (1983), Grossman (1983), Jones (2000), and Yomogida (2006) among others. We regard GHG emissions as an input for production, which enables us to treat trade in emission permits like trade in inputs such as capital. Nonetheless, unlike capital, the emission of GHG is a global public bad. So, we evaluate the welfare effect of emission trading in terms of the global environment quality in addition to the standard effects of capital mobility.

The rest of this paper is organized as follows: In Section 2, we develop a basic model and examine equilibrium in a small open economy. In Section 3, we extend the basic model to a setting with two countries and examine the economic and environmental effect of commodity trading. We first consider a symmetric technology case and extend the analysis to a setting with a technology gap between countries. In Section 4, we analyze the welfare effect of emission trading after commodity-trade liberalization, and compare the welfare effects under different assignments of emission quotas between countries. In Section 5, we close this paper with conclusion.

2 The Basic Model: A Small Open Economy

Two goods (goods X and Y) are initially produced using a single factor (labor) with a constant returns to scale technology and consumed by the household. Although good-Y production is clean (i.e., it does not damage the environment), good-X production is not. It emits greenhouse gases (GHG) and deteriorates the global environment quality leading to damages on the household. Let us first describe the production technology of each good.

2.1 Production Technology

Production of good X emits greenhouse gases (GHG), while production of good Y does not. Following the idea of Meade (1952), we may regard GHG emission as the input of the environmental resource for producing good X. This environmental resource is an unpaid factor of production and socially overused without any regulations. The environmental regulation is thus a policy to internalize the social opportunity cost of the environmental resource into the private evaluation of costs and benefits. Hereafter we may refer to the environmental resource as the emission for simplicity of exposition. And we specifically assume that the government enforces the total emission quota in the form of the domestic tradeable emission permit markets. Thus the emission price below is also the emission permit price.

Normalize the unit of good Y so that one unit of good Y is produced by one unit of labor. Good X requires both labor and environmental resources, i.e., the output of good X is a function of labor input, L_X, and the amount of emissions of GHG emitted during production, Z_X,

$$X = F(L_X, Z_Z),$$

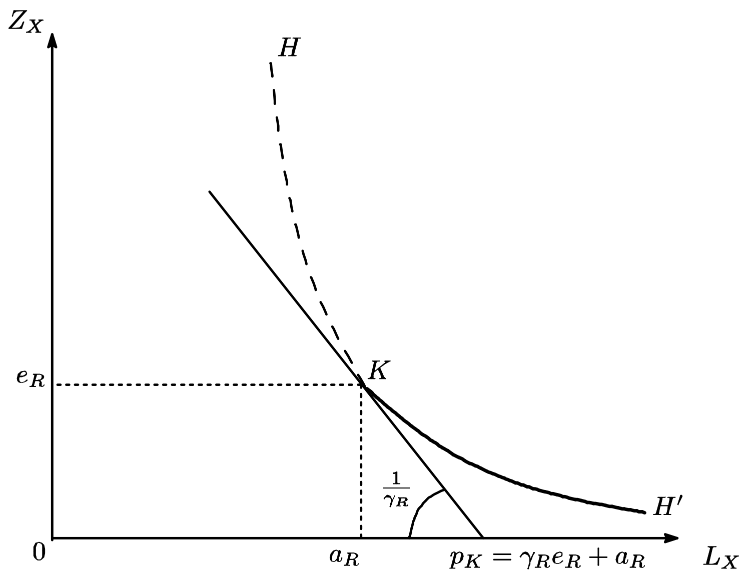

Figure 1: Technical substitution between labor and emission

where F is concave, continuously differentiable, and linearly homogeneous. Note that here labor includes inputs for emission abatement. Thus, a firm can substitute GHG emissions (environmental resources) for labor inputs but this substitution has the limit given by (a_R, e_R), where a_R is the minimum amount of labor input while e_R is the maximum amount of GHG emissions for one unit of good X production. A unit isoquant of good X can be illustrated in Figure 1. The substitution between labor inputs and emissions are possible only in the region above a_R. Obviously, if there is no environmental regulation, firms would choose a_R units of labor to produce one unit of good X.

Let us denote by w the wage and by r the price of the environmental resource. Then the unit cost function of good X is expressed by $c(r, w)$. Shepherd's lemma indicates that $\frac{\partial c(r,w)}{\partial r}$ is the *emission coefficient*, denoted by $e(r/w)$, and $\frac{\partial c(r,w)}{\partial w}$ is the labor coefficient, denoted by $a(r/w)$, so that there holds

$$c(r, w) = re(r/w) + wa(r/w).$$

We often let $\gamma := r/w$, the relative emission price. γ_R is the critical rela-

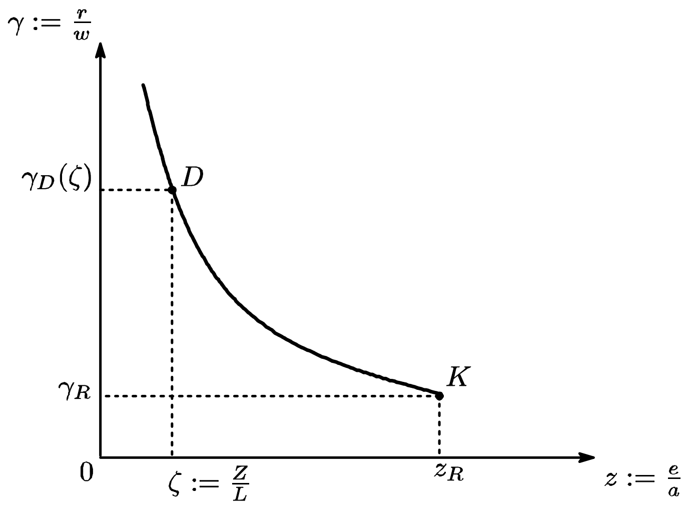

Figure 2: Substitution between labor and emission

tive emission price above which the emission price regulation is effective and promotes abatement in production of good X (see Figure 1). We also let $z(\gamma) := e(\gamma)/a(\gamma)$ and call it the *emission intensity* of good-X production. The critical emission intensity for γ_R is denoted by z_R $(:= e_R/a_R)$. The relation between γ and z can be visualized by the downward-sloping curve shown in Figure 2.

In Figure 2, $\zeta := \frac{Z}{L}$ denotes the per-capita emission quota where L represents the labor endowment and Z the total emission quota imposed by the government. For the emission regulation to be effective, the following assumption must be satisfied:

Assumption 1 *The government imposes the per-capita emission quota* $\zeta < z_R$.

When the emission intensity of good X is equal to this per-capita emission quota given the full employment of the resources, then there is no labor left for good-Y production, so that the country completely specializes in good X. The associated relative emission price, represented by γ_D, depends on the per-capita emission quota. We express this relation with the function $\gamma_D(\zeta)$ as shown in Figure 2.

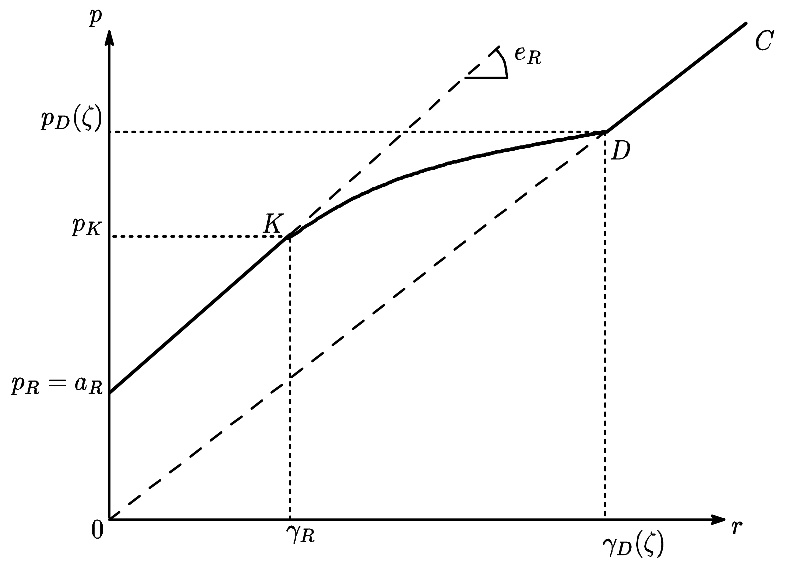

Figure 3: The unit cost curve

When the relative emission price is less than $\gamma_D(\zeta)$ but higher than γ_R, there works substitution between labor and emission along the segment DK. But once the relative emission price is less than γ_R, the substitution ceases and the emission intensity becomes constant at the critical value z_R.

2.2 Supply-side Equilibrium

2.2.1 Unit Cost Curve

Given the good-X price p, the competitive conditions for goods X and Y are represented by

$$c(w, r) \geq p,$$
$$w \geq 1.$$

The unit cost curve for good X is illustrated in Figure 3. As shown in Figure 1, for $r \leq \gamma_R$, the substitution between labor and emission does not arise, so that the unit cost of good X is equal to $re_R + a_R$. The resulting relation between the unit cost and the emission price is shown by the line segment Kp_R, where $p_R = a_R$.

For $r \in (\gamma_R, \gamma_D(\zeta))$, the substitution between labor and emission arises as shown by the curve DK, so that Shepherd's lemma tells us that the slope of the tangent to the unit cost curve is equal to the emission coefficient $e(r)$. The higher emission price promotes substitution of emission with labor, and thus the slope of the tangent becomes flatter as shown by the curve DK.

For $r \geq \gamma_D(\zeta)$, the substitution between labor and emission is not possible because the economy's emission intensity cannot be less than the per-capita emission quota ζ (see Figure 2). We also find that the country completely specializes in good X, which implies that the wage exceeds unity and $\gamma_D(\zeta) = r/w$. Since there holds $\zeta = z(\gamma_D(\zeta))$, the the unit cost is equal to

$$\begin{aligned} re(\gamma_D(\zeta)) + \frac{r}{\gamma_D(\zeta)} a(\gamma_D(\zeta)) &= r\left\{e(\gamma_D(\zeta)) + \frac{a(\gamma_D(\zeta))}{\gamma_D(\zeta)}\right\} \\ &= ra(\gamma_D(\zeta))\left\{\zeta + \frac{1}{\gamma_D(\zeta)}\right\}, \end{aligned} \tag{1}$$

where use was made of $\zeta = z(\gamma_D(\zeta))$.

2.2.2 Production Possibility Frontier

Factor constraints are represented by

$$\begin{aligned} a(w,r)X + Y &\leq L, \\ e(w,r)X &\leq Z. \end{aligned}$$

Given the total emission quota Z, the production possibility frontier can be illustrated in Figure 4. Under Assumption 1, the total emission quota constrains the capacity of producing good X.

When the good X price is less than $p_K := \gamma_R e_R + a_R$, the permit price becomes also less than γ_R, making the emission intensity constant at z_R. Until the permit price becomes equal to zero, the outputs stay constant. This is because the economy is at the kinky point K along the production possibility frontier. Once the permits become free, the economy is just Ricardian, so

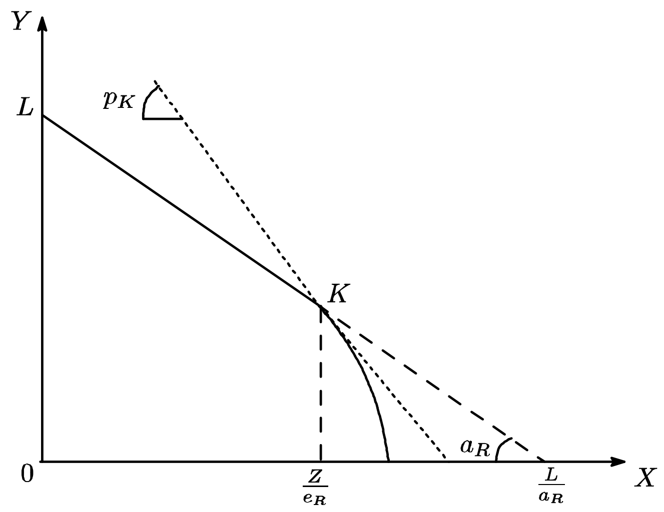

Figure 4: The production possibility frontier

that the resulting relative price would stay at $p_R := a_R$. When the good X price is less than p_R, the economy specializes in good Y and does not emit GHG at all.

If the good X price is greater than p_K, the emission regulation is effective and emission as well as labor constraint holds with equality. An increase in the price of good X raises the output of good X relative to good Y along the production possibility frontier. At the same time, the emission price rises since an expansion of the production of good X leads to the greater demand for emission permits (see Figure 3). If the good X price reaches $p_D(\zeta)$, the country would completely specialize in producing good X.

2.2.3 Relative Supply Curve

The relative supply curve is illustrated in the first quadrant of Figure 5. When the good X price is equal to or less than p_R, the emission constraint does not bind and thus the relative supply curve is similar to that of the Ricardian case. For $p \in (p_R, p_K)$, the supply of good X relative to good Y is fixed because production takes place at the kinky point K on the production possibility frontier. With the factor constraints, we can derive the relative

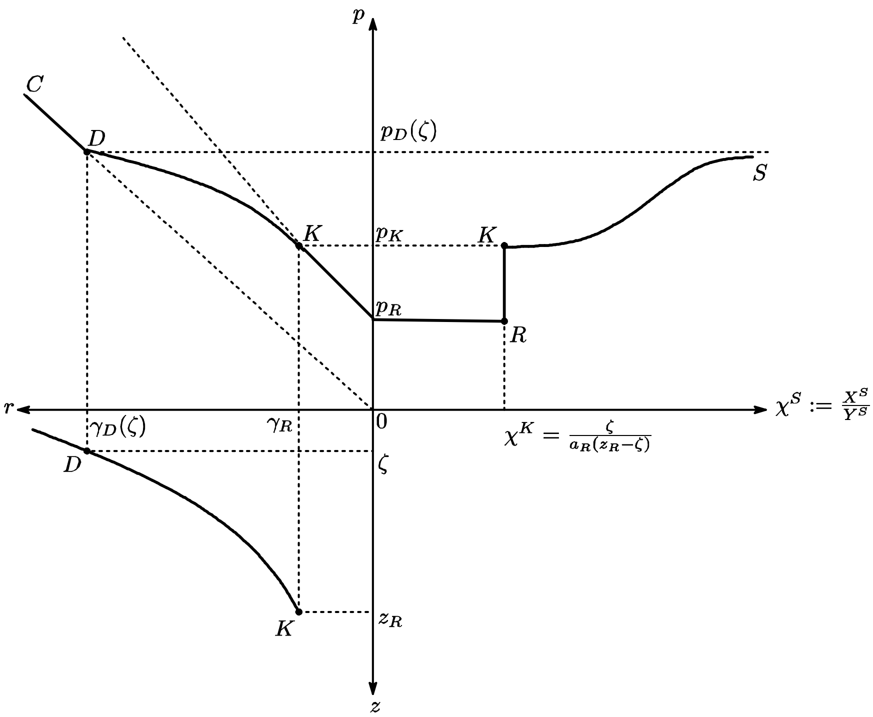

Figure 5: The relative supply curve

output of good X to good Y as

$$\chi^K = \frac{\zeta}{a_R(z_R - \zeta)}.$$

At this relative output, firms uses the most emission-intensive technology, z_R, and the permit price increases with the price of good X with the fixed slope e_R (see the second and third quadrant).

If the good X price is greater than p_K, then the substitution between labor and emission arises, and the competitive condition $p = c(1, r)$ determines the demand price of permits, $r_D(p)$. The set of factor constraints yields the equilibrium relative supply of good X to good Y,

$$\chi^S(p, \zeta) = \frac{X^s}{Y^s} := \frac{\zeta}{a(r_D(p))\,(z(r_D(p)) - \zeta)}. \tag{2}$$

For $p \in (p_K, p_D(\zeta))$, the relative supply of good X is strictly increasing in the relative price p due to $r'_D(p) > 0$ and $z'(r) < 0$. As shown in the second and third quadrant of Figure 5, an increase in the price of good X leads to a rise in the permit price and a fall in the emission intensity.

2.3 National Welfare

The national welfare of the country is measured by the utility enjoyed by the representative household with the following utility function,

$$U = U\left(u(X^c, Y^c), Z^W\right) \tag{3}$$

where X^c denotes the consumption of good X, Y^c the consumption of good Y, $u(\cdot)$ the sub-utility function, and Z^W the world total emission of GHG. We may impose the following assumption on the household's utility function.

Assumption 2 *The household's utility function satisfies the following properties.*

A 2-1: $U(u, Z^W)$ *is (i) strictly increasing in the sub-utility* u *(ii) strictly decreasing in* Z^W*, and (iii) twice continuously differentiable.*

A 2-2: $u(X^c, Y^c)$ *is (i) strictly increasing in the consumption of each good, (ii) twice-continuously differentiable, and (iii) homothetic. It also satisfies (iv)* $\lim_{\chi^C+0} \frac{\partial u(\chi^C,1)/\partial X^c}{\partial u(\chi^C,1)/\partial Y^c} = +\infty$ *and* $\lim_{\chi^C+\infty} \frac{\partial u(\chi^C,1)/\partial X^c}{\partial u(\chi^C,1)/\partial Y^c} = 0$ *where* $\chi^C := X^c/Y^c$*.*

Given Assumption 2, the expenditure share of good X depends only on its relative price p. Hereafter we denote the expenditure share of good X by $\delta_X(p)$ and that of good Y by $\delta_Y(p)$, and assume [3]

Assumption 3 *The expenditure share of good X is decreasing in the relative price* p*.*

This assumption implies that the relative demand for good X, $\chi^D(p)$, is in fact given by $\delta_X(p)/\delta_Y(p)$, which is strictly decreasing in the relative price p.

[3] One should note that this assumption is equivalent to the condition that the price elasticity of the demand for good X exceeds unity

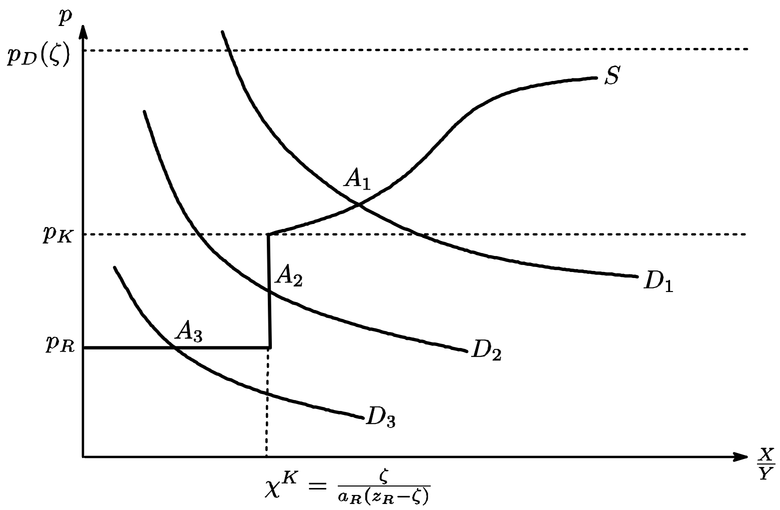

Figure 6: Autarky equilibrium

2.4 Autarky Equilibrium

Let us first explore the autarky equilibrium. The autarky equilibrium is governed by

$$\chi^S(p,\zeta) = \chi^D(p), \text{ or } \frac{\zeta}{a(r_D(p))\,(z(r_D(p)) - \zeta)} = \frac{\delta_X(p)}{\delta_Y(p)}.$$

Assumption 2 implies that the demand for good X relative to good Y, i.e., the relative demand for good X depends only on the relative price p. This relative demand is described by the downward sloping curve D in Figure 6.

There are possible equilibria, i.e., $A_i(i = 1, 2, 3)$ for each relative demand curve D_i. The emission quota is strictly binding at A_1, while it is strictly unbinding at A_3. At A_2, it is just binding.

3 Commodity-Trade Liberalization: Two-Country Model

In this section, we consider a two-country (home and foreign countries) model where both countries introduce GHG emission regulations. We first examine a symmetric technology case in which the countries have the same production technology but impose different GHG emission quotas on domestic production activities. We show that commodity trade liberalization may expand the world output of the dirty good, leading to the worsening in the global environment quality.

Second, we consider an asymmetric technology case in which the countries differ in the production technology, i.e., one country has the more emission-intensive technology than the other. In contrast to the symmetric case, the commodity trade liberalization may result in a reduction in the world GHG emissions. In fact, we show that the commodity trading improves the global environment regardless if the more generous emission quota is assigned to the home or foreign country. In the following, foreign variables and parameters are distinguished by asterisk.

3.1 Symmetric Case

Let us first consider the symmetric case in which the two countries have the same production technology but they differ only with respect to the evaluation on the external damages from global warming. Such a difference in the perception over the environmental damage leads to a different choice of the emission quotas by each government. Without the loss of generality, we assume that the percapita emission quota of the home country is smaller than that of the foreign country,

$$\frac{Z}{L} < \frac{Z^*}{L^*}.$$

This assumption implies that the foreign country's relative supply curve is located right to the home country's (see Figure 7). It also implies that, under the same commodity demand condition, the foreign country has a comparative advantage in good X given each country's emission quota policy.

Figure 8 shows the world trading equilibrium when the two countries liberalize the commodity trade given the emission quota chosen in autarky. In Figure 8, the home country's relative supply curve is given by S, the

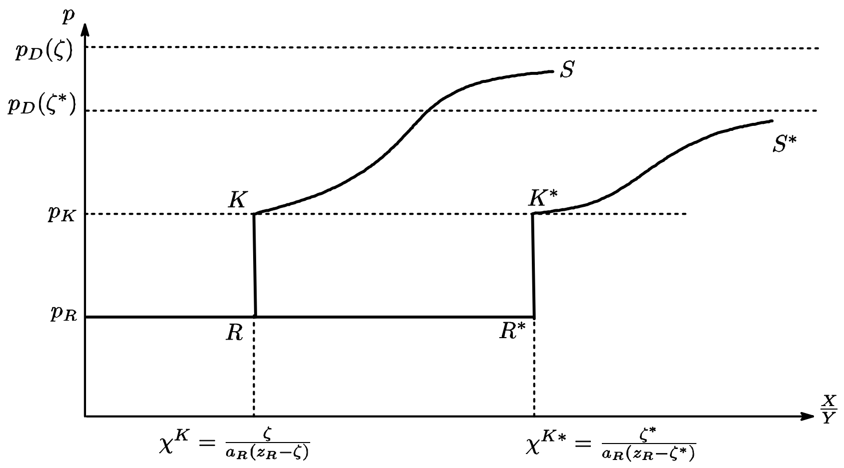

Figure 7: Relative supply curves in the symmetric technology case.

foreign country's by S^* and the world relative supply curve by S^T, while the three downwards sloping curves $D_i(i = 1, 2, 3)$ are possible relative demand curves showing the relative demand for each country as well as the world. Points $A_i(i = 1, 2, 3)$ show the associated autarky equilibrium for the home country and A_i^* the foreign counterpart. The world trading equilibrium is then shown by point T_i. Note that for each possible case, the foreign country has a comparative advantage in good X.

Let us inquire into each equilibrium more in detail. When the relative demand curve is given by D_1, each country faces the binding emission quota at both the autarky equilibrium and the commodity-trading equilibrium, because the two countries incompletely specialize in both goods. The world GHG emission does not change before and after the commodity-trade liberalization.

When the relative demand curve is given by D_2, the emission quota is strictly binding for the home country and just binding for the foreign country. After the commodity-trade liberalization, the two countries incompletely specialize in both goods and produce at the kinky point on the production possibility frontier. This implies that the emission quotas are just binding for both countries. Again, we have no change in the world GHG emissions.

Lastly as with the relative demand curve D_3, the situation is a little dif-

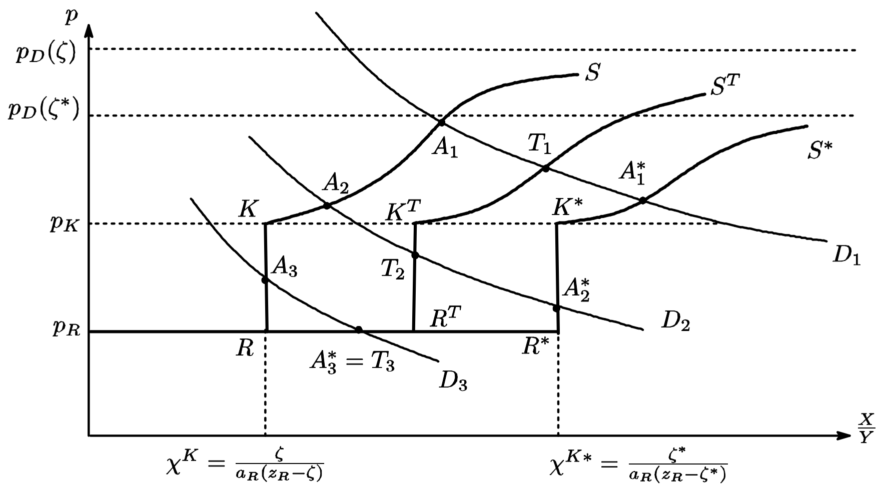

Figure 8: World commodity trading equilibrium in the symmetric technology case.

ferent. After free trade in commodities, the home country would produce both goods or specialize in producing good Y, while the foreign country would produce both goods. Only the home country gains from commodity trade since the world relative price at the free trade equilibrium is the same as the autarky price of the foreign country. Clearly, the free trade in commodities expands the world production of good X, increasing the world GHG emissions. If we take into account the effects of increased emission, the commodity trade hurts the foreign country but it may or may not benefit the home country.

3.2 Asymmetric Case

First, let us specify the technology difference in producing good X between the countries.

Assumption 4 *The production technologies for producing good X in the home and foreign countries satisfy*

A 4-1: $e_R < e_R^*$, $a_R > a_R^*$, *and* $\gamma_R > \gamma_R^*$

A 4-2: $z(r) < z(r)$ *for all* $r > \gamma_R^*$,

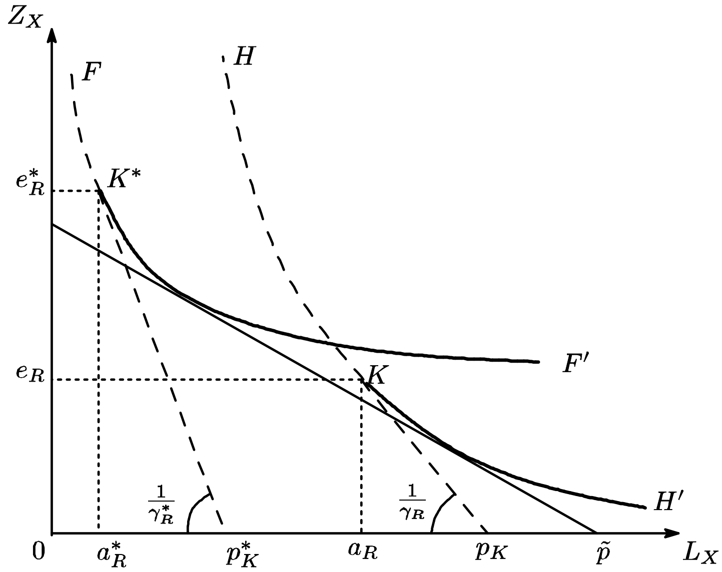

Figure 9: Technology difference between countries

A 4-3: there exists a pair $(\widetilde{p}, \widetilde{r}) \geq (p_K, \gamma_R)$ *such that* $c(1, \widetilde{r}) = \widetilde{p} = c^*(1, \widetilde{r})$.

The pair of unit isoquants under the above assumption are illustrated in Figure 9. The first condition implies that, without any emission regulation, the abatement activity in the home country is more costly than that in the foreign country, i.e., γ_R is higher than γ_R^*, because the home country producers of good X have introduced sufficiently less emission intensive technology than the foreign counterparts. The second condition means that, under the effective emission regulation, the home producers use environmentally more advanced (less emission intensive) technology than the foreign counterparts. The last condition implies that there exists a permit price that equalizes the unit costs across countries. Under this assumption, we may regard the home country as a developed country and the foreign country as a developing country.

The unit cost curves are drawn in Figure 10. At the zero permit price, the home unit cost curve, $p_R H$, has a higher intercept than the foreign counterpart, $p_R^* F$, because home producers use less emission (more labor) intensive technology than foreign producers. As the permit price becomes higher than

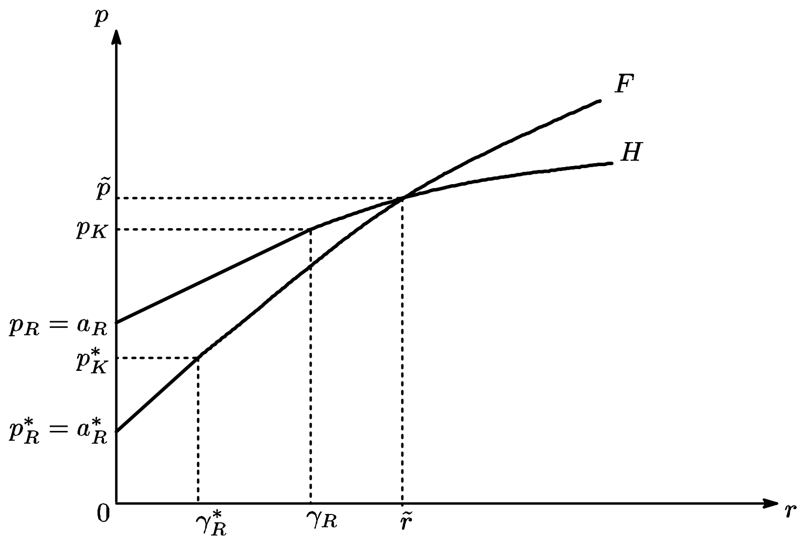

Figure 10: Unit cost curves in the asymmetric technology case

the critical level, the substitution between labor and emission arises so that the slope of each curve becomes flatter. Eventually, these two curves intersect with each other when the unit costs are equalized between the countries.

Now, let us turn to world commodity trading equilibrium. In contrast to the symmetric case, there are two sources for comparative advantage: the asymmetry in technology and the difference in per capita emission quota. If the emission regulation is not effective and emission permits are free, then the production structure is similar to the Ricardian case. As a result, comparative advantage is determined according to the labor productivity difference. The foreign country would have a comparative advantage in good X because the home producers of good X use the greater amount of labor for the abatement activity than the foreign counterparts. Once the emission regulation is effective and emission permits are not free, then the emission quota plays a role in determining comparative advantage in production of commodities. As a result, allocation of emission quotas across countries does matter for the pattern of commodity trade. We will consider two different cases.

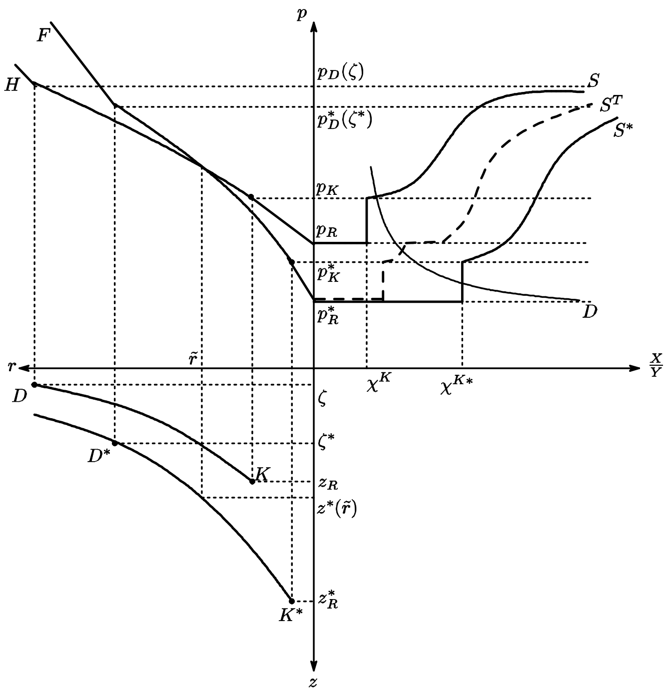

Figure 11: Commodity Trading equilibrium in a case in which the foreign country is sufficiently greater amount of emission quota than the home country.

3.2.1 Generous Quota for the Country Using Dirty Technology

First, suppose that the foreign country is given the sufficiently larger per capita emission quota than the home country and thus the relative output of good X to good Y in the foreign country is larger than that in the home country for all price of good X. This case arises when

$$\chi^K = \frac{\zeta}{a_R(z_R - \zeta)} < \frac{\zeta^*}{a_R^*(z_R^* - \zeta^*)} = \chi^{K*},$$

that is, the foreign country has the sufficiently larger capacity of good X even with the relatively more emission intensive technology.

The relative supply curves can be illustrated in Figure 11. In the first quadrant, the home relative supply curve is $p_R S$ and the foreign counterpart is $p_R^* S^*$. Clearly, the foreign country has a comparative advantage in good

X. Suppose that the relative demand curve is given by D. Then, at autarky equilibrium, the emission quota is binding and the permit price is positive for either country. Commodity trading equilibrium would be determined at a point in which the relative demand curve D intersects with the world relative supply curve S^T. At the trading equilibrium, the foreign country produces both goods and the emission quota is binding, but the home country completely specializes in good Y so that it does not emit GHG any more. This implies that commodity trading provides extra benefits as well as conventional gains from trade, i.e., it improves the global environment quality due to a reduction in world GHG emissions. We can state this result as follows:

Proposition 1 *Suppose that the foreign country is given sufficiently greater per capita emission quota than the home country, and as result, the foreign country has a comparative advantage in good X. Then, commodity trade can provide double gains from trade, i.e., benefits from an improvement in global environment and gains from commodity trade.*

3.2.2 Generous Quota for the Country Using Clean Technology

Second, let us consider a situation in which the greater emission quota is given to the home country instead of the foreign country. To give rise to this situation, transfer permits from the foreign country to the home country. The transfer raises the home capacity of producing good X, χ^K, and reduces the foreign capacity, χ^{K*}. As a result, for $p \in (p_R^*, p_R)$, the world relative supply of good X declines and S^T moves leftward due to the decline in the foreign capacity of producing good X, χ^{K*}. Meanwhile, for $p > p_R$, the transfer expands the world supply of good X so that S^T moves rightward. This is because the home country has the smaller emission coefficient than the foreign country and thus the transfer improves the efficiency of the world production of good X.[4]

As compared to the previous case in which the foreign country is given a sufficiently larger emission quota, the horizontal segment of S^T would expand in both sides. So, as long as the relative demand curve remains the same

[4]See Appendix A.

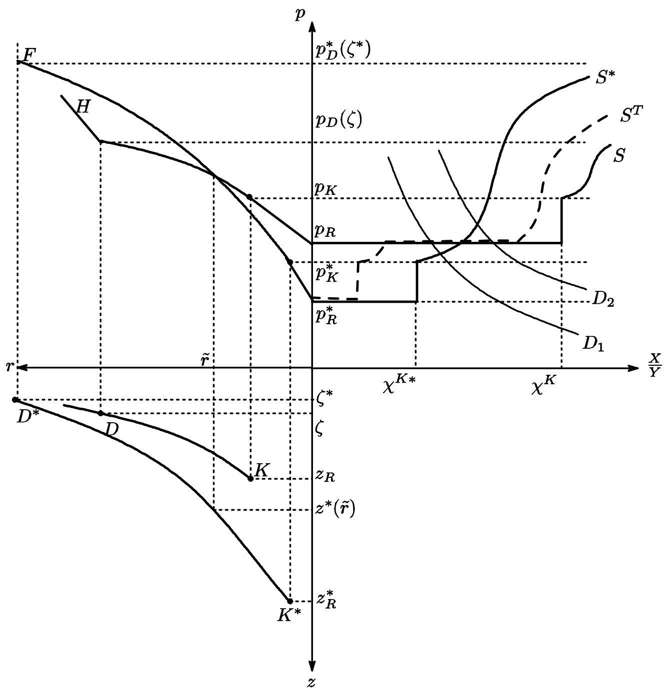

Figure 12: Commodity trading equilibrium in a case in which the home country is given greater emission quota than the foreign country.

as before, new trading equilibrium would be determined at a point on this horizontal segment of the world relative supply curve. If we continue to transfer permits in the same direction, then eventually χ^K would become greater than χ^{K*}.

Figure 12 shows commodity trading equilibrium in such a case. There are two possible equilibria. If the relative demand curve is D_1, the foreign country still has a comparative advantage in good X since it saves the labor cost for good X by using the more emission-intensive technology. Again, commodity trading induces the home country to specialize in good Y and as a result it does not emit GHG any more. So, the world GHG emissions decline and the global environment improves. Commodity trading provides double gains from trade.

If the relative demand curve is D_2, then the pattern of commodity trade would be reversed, i.e., the home country has a comparative advantage in good X since its generous emission quota allows to have the larger capacity of producing good X. Commodity trading leads to an expansion in GHG emissions by the home country since it expands the production of good X and it does not use up all of permits of GHG emissions. In contrast to the previous case, commodity trading may hurt the countries since the increase in global emissions deteriorates the world environment quality.

We can summarize the above results as follows:

Proposition 2 *Suppose that the home country is given the greater per capita emission quota than the foreign country. If the home country has a comparative advantage in good X, then commodity trade may hurt both countries because of the deterioration of global environment. Otherwise, both countries get better off due to gains from commodity trade and benefits from the improved global environment.*

4 Emission Trading After Commodity-Trade Liberalization

Let us now consider the welfare effect of emission-permit trade after the commodity trade is liberalized. As we have already shown, commodity trading may give rise to the double gains to the world, i.e., standard gains from commodity trade and extra benefits from an improvement in the global environment. In this section, we examine whether or not emission-permit trade generates further improvements in the global environment, providing additional benefits for the world.

After emission trading starts, the country having a comparative advantage in the dirty good can expand its output by importing emission permits. As a result, emission trading would increase global GHG emissions. In fact, we shall show that the country exporting the dirty good may suffer double losses from emission trading: the worsening of the terms of trade and the deterioration of the global environment. We shall also examine the assignment issue of emission quotas and show that emission trading may hurt the global environment regardless of which country is given more generous emission quota.

4.1 Production Patterns and Emission Allocations

As before, the home and foreign countries have the same production technology in the nemeraire, but different technologies in the production of good X, i.e., the home country has the less emission-intensive technology than the foreign country. Suppose that, before emission trading starts, the greater emission quota is assigned to the foreign country so that it has a comparative advantage in good X. Then, the world relative supply curve is illustrated as S^T in Figure 13.

If both countries open the markets for emission permits, the world relative supply curve would be drawn as S_Z^T. Let us first explain how to construct S_Z^T. We assume that either country's labor endowment is sufficiently large to absorb the world total amount of emission permits. To be more precise, the following conditions are satisfied,

$$Z^W < \min\{z_R L, z_R^* L^*\},$$

where $z_R = e_R/a_R$, $z_R^* = e_R^*/a_R^*$, and $Z^W = Z + Z^*$. This condition implies that the emission quota binds even if the total amount of permits is allocated to either country.

As shown in the second quadrant of Figure **??**, for $p \in (p_R^*, p_K^*)$, the foreign country offers the higher permit price. So, after emission trading starts, the foreign country imports all of permits issued by the home country. Then, the home country is specialized in good Y and the foreign country produces both goods. The world relative supply of good X to good Y is

$$\chi_2^W = \frac{\zeta^W}{a_R^*(z_R^* - \zeta^W)}$$

where $\zeta^W = Z^W/L^W$. Before emission trading, the home country produces good Y only and the foreign country produces both goods. So, the world

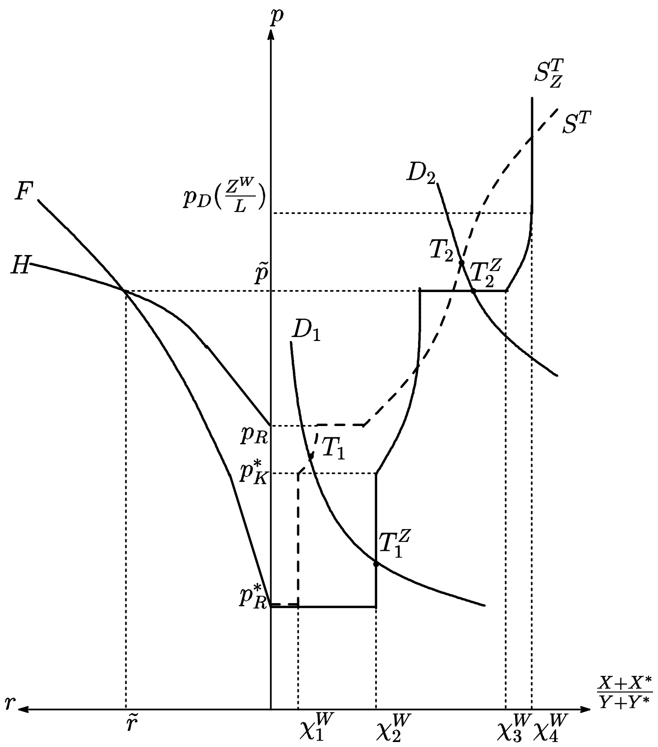

Figure 13: The world integrated equilibrium

relative output of good X is $\chi_1^W = \frac{Z^*/L^W}{a_R^*(z_R^* - Z^*/L^W)}$. Clearly, χ_2^W is greater than χ_1^W, i.e., emission trading expands the world relative supply of good X because it relaxes the capacity constraint of producing good X in the foreign country.

If $p \in (p_K^*, \widetilde{p})$, then the foreign country still imports all of permits issued by the home country, and the production pattern of each country is the same as above. An increase in the price of good X leads to an expansion of the world relative output of good X. This arises because the higher price of permits promotes the abatement activity in the foreign country, and the substitution of labor for emission allows an increase in the output of good X.

When the price of good X reaches $\widetilde{p}$, both countries offer the same price for emission permits, and the allocation of permits across the countries would not be determined without the demand side condition. As the more of permits are allocated to the home country, the world relative output of good X rises. This is because the home country's producers of good X has the smaller emission coefficient than the foreign counterparts. If the home country imports all of permits issued by the foreign country, the relative output would be

$$\chi_3^W = \frac{\zeta^W}{a(\widetilde{r})(z(\widetilde{r}) - \zeta^W)}.$$

As the price of good X increases further, the home country expands the output of good X along its production possibility frontier. When the price of good X reaches $p_D(\frac{Z^W}{L})$, complete specialization arises, i.e., the home country produces good X only and the foreign country does good Y. Then, the world relative output of good X is

$$\chi_4^W = \frac{Z^W}{e(r_D(\frac{Z_W}{L}))L^*}.$$

4.2 Welfare Effects of Emission Trading

Next, let us examine the impact of emission-trade liberalization on the welfare of countries. Suppose that the world relative demand for good X is given by D_1. Then, at the commodity-trading equilibrium T_1, the home country produces good Y only, and the foreign country produces both goods. As we have shown in Proposition 1, there are double gains from commodity trading. However, in this section, we shall show that emission trading may cause double losses from trade.

When both countries liberalize permit trade as well as commodity trade, the equilibrium is determined at T_1^Z. Emission trading allows the foreign country to expand the production of the dirty good by importing permits. Since the home country specializes in the clean good, the global GHG emissions increase due to the emission trade liberalization.

Let us first examine the welfare effect of emission trading on the foreign country. The welfare effect can be decomposed into three effects.[5] First, the import of permits benefits the foreign country because the less expensive permits become available. This is called the volume-of-trade-effect in emis-

[5] See Appendix for the algebraic derivation of the gains or losses from permit trade.

sion trading. Also, a decline in the price of the dirty good negatively affects the welfare of the foreign country due to the worsening of the terms of trade measured in goods. This is called the terms-of-trade effect. Furthermore, the expansion of the world production of the dirty good leads to the worsening of the global environment. This can be called the emission-volume effect on the global environment. Those results imply that the foreign country suffers double losses from trade: the worsening of the terms of trade and the deterioration in the global environment. However, the home country can benefit from emission trading if gains from the improvement in the terms of trade overwhelms losses from the worsening of the global environment.

We can summarize the above results as follows:

Proposition 3 *Suppose that the greater per capita emission quota is assigned to the foreign country using more emission intensive technology and it has a comparative advantage in good X (the dirty good). Emission trading allows the foreign country to expand the output of good X by importing emission permits. As a result, the global environment deteriorates because of an increase in the world output of the dirty good. Then, the foreign country suffers double losses from emission trade: the worsening of the terms of trade in commodities and the deterioration of the global environment.*

Next, suppose that the relative demand curve is given by D_2. Then, the emission quota is binding for either country before and after emission trading. Since global emissions does not change, emission trading does not affect the global environment. The home country expands the production of the dirty good by importing emission permits. Since the home country has the smaller emission coefficient, the world relative output of the dirty good increases, resulting in a reduction in the price of the dirty good. If the pattern of commodity trade remains the same as before emission trading, the foreign country would lose but the home country would gain from emission-permit trading.[6] However, the permit trade may cause the reversal of the pattern of commodity trade. That is, the home country can be an exporter of the dirty

[6] See Appendix for the proof.

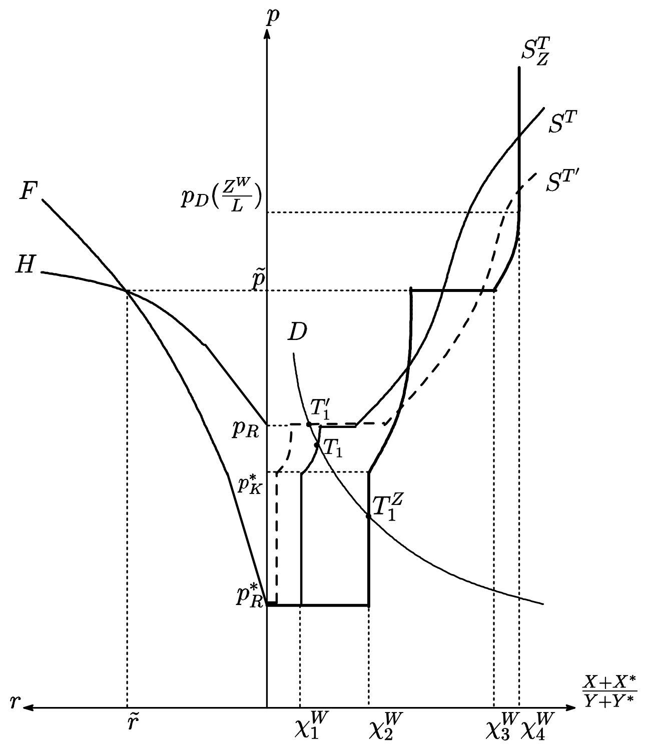

Figure 14: Emission trading equilibrium in a case in which the home country initially has the larger emission quota than the foreign country.

good. When such a reversal arises, the welfare effect of the permit trade would be ambiguous.

4.3 Assignments of Emission Quotas

There is a distributional question of which country should be given the larger quota when emission trade starts. In this section, we examine this issue in terms of the welfare effect of emission-permit trade. So far, we have considered a situation in which the foreign country is given the greater size of percapita emission quota and it exports the dirty good at the commodity-trading equilibrium. Instead, we shall examine a case in which the home country is assigned the greater percapita emission quota than the foreign country. This situation has been illustrated in Figure 14.

Before emission trading starts, the world relative supply curve is illustrated as $S^{T\prime}$ in Figure 14. As we have described before, due to the transfer of permits from the foreign country to the home country, the world relative supply curve has changed to $S^{T\prime}$ from S^T. Then, the commodity-trading equilibrium is determined at T_1'. As we have shown before, there are two possible trade patterns.

First, consider a case in which the home country produces both goods and exports good Y, while the foreign country exports good X. Then, as shown in Proposition 2, the commodity-trading liberalization generates double gains: the standard gains from trade and extra benefits from the improvement of the global environment. Since the foreign country's production of the dirty good is constrained by the emission quota, emission trading allows the foreign country to expand the production of the dirty good by importing the permits from the home country. Again, at the permit trade equilibrium T_1^Z, the global environment deteriorates and the terms of trade in commodities worsen for the foreign country. Thus, the foreign country suffers double losses from emission trading.

Proposition 4 *Suppose that the smaller emission quota is assigned to the foreign country using more emission intensive technology. If the foreign country exports good X (dirty good) due to its lower labor cost, then emission trading allows it to expand the production of the dirty good by importing emission permits. As a result, the global output of good X expands and the world environment deteriorates. And the foreign country suffers the double losses from the permit trade: the worsening in the terms of trade and the deterioration of the global environment.*

Proposition 3 and 4 lead to the following corollary:

Corollary 1 *Regardless of which country is assigned the generous emission quota, emission trading after the commodity-trade liberalization may deteriorate the global environment, and it may hurt the foreign country due to the worsening in the terms of trade and the deterioration of the global environment.*

Second, suppose that, at the commodity-trading equilibrium $T^{1\prime}$, the home country has a comparative advantage in good X due to its generous emission quota. Since the foreign country offers the higher price of emission permits, emission trading allows the foreign country to import all of permits from the home country. As a result, the foreign country becomes an exporter of the dirty good. That is, the pattern of commodity trade is reversed. Before emission trading, the emission quota is binding for the foreign country, but it might not be for the home country because of its sufficiently large quota. If the quota for the home country is not binding, the permit trade leads to an expansion of world emissions because emission trading allows the foreign country to use all of permits issued in the world. Once again, emission-permit trading may deteriorate the global environment. As we have shown in Proposition 2, the commodity-trade liberalization has already worsen the global environment. So, the permit trade generates additional damage to the world environment quality.

Proposition 5 *Suppose that the smaller emission quota is assigned to the foreign country using more emission intensive technology. If the home country exports good X (the dirty good) due to its generous emission quota, emission trading reverses the pattern of commodity trade since importing permits allows the foreign country to export the dirty good. Then, emission trading may increase global emissions so that it may further deteriorate the global environment in addition to the environment damage caused by commodity trading.*

5 Conclusion

In this paper, we have examined the welfare effect of emission trading. Before emission trading starts, the commodity trading benefits both countries due to the double gains from trade: the standard gains from trade and benefits from the improvement of the global environment. After commodity trading arises, global trade in emission permits does not guarantee further gains for the countries. The emission trading allows the country using the more emission-intensive technology to import permits, and it raises the world output of the dirty good. As a result, the world emissions increase and the global environment deteriorates. In fact, the country having the more emission-intensive technology suffers double losses from emission trading: the worsening of the terms of trade and the deterioration in the global environment.

We have also examined the distributional question of emission quotas among countries. The emission-permit trade may deteriorate the global environment regardless of which country is given the larger emission quota. Furthermore, emission trading could hurt the global environment in addition to the environmental damage caused by commodity trading. Also, the country using the more emission-intensive technology suffers the double loses from emission trading. The double losses arise regardless whether the country is given the more generous emission quota or not. This result suggests that emission trading tends to hurt a developing country using environmentally less advanced technology regardless if it is given more generous emission quota or not.

References

[1] Brecher, R. and E. U. Choudri (1982) "Immiserizing Investment from Abroad: The Singer-Prebisch Thesis Reconsidered," *Quarterly Journal of Economics* 97: 181-90.

[2] Copeland, B. R. and M. S. Taylor (1994) "North-South Trade and Environment," *Quarterly Journal of Economics* 109: 755-787.

[3] ———— and ———- (1995) "Trade and Transboundary Pollution," *American Economic Review* 85: 716-737.

[4] ———— and ———- (2003) "Free Trade and Global Warming: A Trade Theory View of the Kyoto Protocol," NBER Working Paper 7657, forthcoming, *Journal of Environmental Economics and Management.*

[5] Grossman, G. (1984) "The Gains from International Capital Movements," *Journal of International Economics* 17: 73-83.

[6] Ishikawa J. and K. Kiyono (2004) "Greenhouse-Gas Emission Controls in an Open Economy," forthcoming, *International Economic Review.*

[7] Jones, R. W. (1980) "Comparative and Absolute Advantage," *Swiss Journal of Economics*: 235-260.

[8] ———— (2000) *Globalization and the Theory of Input Trade*, Cambridge Mass., MIT Press.

[9] Frankel, J. (2007) "Formulas for Quantitative Emission Targets" *Architectures for Agreement: Addressing Global Climate Change in the Post Kyoto World*, edited by Joe Aldy and Robert Stavins, Cambridge University Press.

[10] Markusen, J. R. (1983) "Factor Movements and Commodity Trade as Complements," *Journal of International Economics* 43: 341-356.

[11] Meade, J. E. (1952) "External Economies and Diseconomies in a Competitive Situation," *Economic Journal* 62: 54-67.

[12] Mundell, R. A. (1957) "International Trade and Factor Mobility," *American Economic Review* 47: 321-335.

[13] Yomogida, M. (2006) "International Capital Movements: Who Gains and Who Loses?" *Asia-Pacific Journal of Accounting and Economics* 13: 123-139.

Appendix A: Effects of Permits Transfer on the Relative Supply

We shall show that the transfer of permits from the foreign country to the home country raises the world relative supply of good X. For $p > p_R$, the quotas are binding for both countries, and the outputs of good X are

$$X^S = \frac{Z}{\overline{e}} \text{ and } X^{S*} = \frac{Z^*}{e^*(r_D^*(p))},$$

where $\overline{e} = e_R$ for $p \in (p_R, p_K]$ and $\overline{e} = e(r_D(p))$ for $p > p_K$. Then, we have

$$\begin{aligned} dX^S + dX^{S*} &= \frac{dZ}{\overline{e}} + \frac{dZ^*}{e^*(r_D^*(p))} \\ &= \left(\frac{1}{\overline{e}} - \frac{1}{e^*(r_D^*(p))}\right) dZ > 0. \end{aligned} \tag{A1}$$

The second equality holds because Z^W is constant, and the third inequality obtains due to Assumption 5. From the labor constraints, for $p > p_R$, the outputs of good Y are

$$Y^S = L - \overline{a}X^S \text{ and } Y^{S*} = L^* - a^*(r_D^*(p))X^*,$$

where $\overline{a} = a_R$ for $p \in (p_R, p_K]$ and $\overline{a} = a(r_D(p))$ for $p > p_K$. We have

$$\begin{aligned} dY^S + dY^{S*} &= -\overline{a}dX^S - a^*(r_D^*(p))dX^* \\ &= -\left(\frac{1}{\overline{z}} - \frac{1}{z^*(r_D^*(p))}\right) dZ < 0, \end{aligned} \tag{A2}$$

where $\overline{z} = \overline{e}/\overline{a}$. The last inequality holds because the home country uses the less emission-intensive technology than the foreign country. From (A1) and (A2), we can see that, for $p > p_R$, $\frac{X^S + X^{S*}}{Y^S + Y^{S*}}$ rises due to the transfer.

Appendix B: Algebra on the Welfare Effects of Emission Trading

From the utility function (3), welfare effects can be decomposed into two components: effects in the sub-utility u and those in the emissions Z^W. We shall show that the effects in the sub-utility are further decomposed into two effects.

Taking a derivative of the sub-utility function of the home country, we have

$$du = u_X dX^C + u_Y dY^C, \tag{B1}$$

where u_i is the marginal utility of good $i = X, Y$. Dividing the both side of

(B1) with u_Y, we can obtain a change in the real income in terms of good Y.

$$d\widetilde{u} = \left(\frac{u_X}{u_Y}\right) dX^C + dY^C. \tag{B2}$$

With the use of the first order condition in the utility maximization problem, we can rewrite (B2) as

$$d\widetilde{u} = p^H dX^C + dY^C, \tag{B3}$$

where p^H denotes the domestic price of good X. Let p^W and r^W denote the world price of good X and the world price of permits, respectively. Then, the budget constraint for the home country is

$$p^W X^C + Y^C = p^W X + Y + r^W (Z - Z^D) \tag{B4}$$

where Z^D is the home employment of emission permits. The profit maximization conditions imply that

$$p^H dX + dY = -r^H d(Z - Z^D), \tag{B5}$$

where r^H denotes the domestic price of permits. Using (B3), (B4) and (B5), we can derive a change in the real income of the home country as follows:

$$\begin{aligned} d\widetilde{u} = {} & (X - X^C)dp^W + (Z - Z^D)dr^W \\ & + (p^W - p^H)d(X - X^C) + (r^W - r^H)d(Z - Z^D). \end{aligned} \tag{B6}$$

On the RHS, the first two terms are the terms-of-trade effects measured in good X and permits, respectively. The last two terms are the volume-of-trade effects measured in good X and permits, respectively. If we evaluate (B6) at the commodity-trade equilibrium, $p^H = p^W$ and $Z = Z^D$ hold. Thus, we can simplify (B6) as

$$d\widetilde{u} = (X - X^C)dp^W + (r^W - r^H)d(Z - Z^D). \tag{B7}$$

Similarly, we can derive the foreign counterpart as

$$d\widetilde{u}^* = (X^* - X^{*C})dp^W + (r^W - r^F)d(Z^* - Z^{*D}). \tag{B8}$$

When the world relative demand curve is given by D_1, the foreign country exports good X for the imports of good Y and permits. With (B8), we can derive gains from permit trade for the foreign country. Since the price of good X falls, the terms-of-trade effect measured in good X negatively affects the welfare of the foreign country. At the same time, the foreign price of emission permits declines, the volume-of-trade effects measured in permits positively affects the welfare of the foreign country.

On the other hand, if the demand curve is D_1, the home country exports good Y and permits for the import of good X. Using (B7), we can confirm that the home country gains from the permit trade since both the terms-of-trade effect in good X and the volume-of-trade effect in permits have the positive impacts on the home welfare.

Next, suppose that the relative demand curve is represented by D_2, and the trade pattern in commodity does not change due to permit trade. If the foreign country initially has the greater per-capita emission quota than the home country, then the home country exports good Y and imports permits as well as good X. Again, the home country gains from permit trade since both the terms-of-trade effect and the volume-of-trade effect are positive. On the other hand, the foreign country exports both good X and permits for the import of good Y. The foreign country loses from the permit trade since both the terms-of-trade effect and the volume-of-trade effect negatively affect the foreign welfare.