

International Trade in Emission Permits*

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Abstract

This paper examines the effect of international trade in emission permits on the national welfare of trading countries. We consider a situation in which countries introduce emission quotas and start trading permits after commodity-trade liberalization. We show that commodity-trade liberalization provides double gains from trade: standard gains from trade and improvement of the global environment. However, permit-trade after the commodity-trade liberalization may cause double losses from trade: the worsening of the terms of trade and the deterioration of the global environment. We also examine a distributional question of emission quotas across borders.

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1 Introduction

At the end of 1997, the global agreement on cutting carbon emissions was agreed on in Kyoto. It is, however, difficult to implement the targets for cuts in greenhouse gas emissions. In particular, how to control carbon emissions is one of the most important questions. Among some measures to cut emissions, governments have recently paid more attention to the market-based carbon trading system. For instance, European governments launched a pan-European carbon trading system in 2005 (*Economist*, 2005). International emission control through market-based trading has been discussed, but there is a distributional question of which country should be given the emission permits when trade starts.

In this paper, we examine the effects of permit trade on the national welfare of trading countries. We consider a situation in which countries introduce emission quotas and start trading emission permits as well as commodities. The effect of permit trade on the economic welfare generated controversy in recent years. Frankel (1999) states both developing and industrialized countries gain from trading emission rights. However, Copeland and Taylor (2000) shows that permit trade can be welfare-reducing due to the worsening of the terms of trade if countries are already trading goods. In our setting, welfare effects of permit trade can be decomposed into three effects: (i) the terms-of-trade effect in commodities, (ii) the volume-of-trade effect in emission permits, (iii) the emission-volume effect on the global environment. The first two effects are standard in trade theory. The last effect arises because international trade affects the world level of emission through a change in the production patterns of trading countries. We show that commodity-trade liberalization provides double gains from trade: gains from commodity trade and the improvement of the global environment. However, permit-trade liberalization after commodity trade causes double losses due to the worsening of the terms of trade and the deterioration of the global environment.

Our model is built on Ishikawa and Kiyono (2004) that develop a model in which (i) two goods are produced with labor, (ii) greenhouse gases (GHGs) are emitted during production, and (iii) there exists a technology to abate

GHG emissions by using labor as an input. They examine how greenhouse-gas emission controls affect country's industrial and trade structures with a model having both Ricardian and Heckscher-Ohlin features. This paper complements their work in that we examine the bilateral emission regulations, and allow international trade in emission permits in a two-country model.

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 welfare effects of commodity trade. In Section 4, we analyze the welfare effect of permit trade after commodity-trade liberalization. In Section 5, we close this paper with concluding remarks.

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, 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 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 resource subject to the constant returns-to-scale technology. Let us denote by w the wage and by r the price of this 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.

We allow some substitution between labor and emission as stated by the following assumption.

Assumption 1 *The input coefficients of good-X production satisfy the following properties.*

A 1-1: $e'(\gamma) < 0$ and $a'(\gamma) > 0$ for $\gamma > \gamma_R$.

A 1-2: $e(\gamma) = e_R$ and $a(\gamma_R) = a_R$ for $\gamma \leq \gamma_R$.

γ_R is the critical relative emission price above which the emission price regulation effectively promotes abatement in production of good X. 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 $z_R (= e_R/a_R)$. This technology can be visualized by the downward-sloping curve shown in Figure 1.

In the figure, $\zeta := \frac{Z}{L}$ denotes the per-capita emission quota where L represents the labor endowment and Z the total emission quota imposed by the government. 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

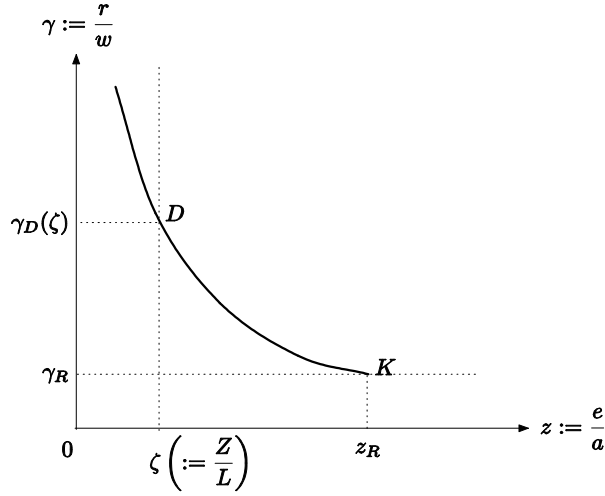


Figure 1: Substitution between labor and emission

γ_D , depends on the per-capita emission quota. We express this relation with the function $\gamma_D(\zeta)$ as shown in the figure.

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

Given the good-X price p , the competitive supply-side equilibrium is governed by the following set of equations.

$$\begin{aligned}
 L &= a(r/w)X^s + Y^s, \\
 Z &= e(r/ww)X^s, \\
 c(r, w) &\geq p, \quad X^s \geq 0, \quad (c(r, w) - p)X^s = 0 \\
 w &\geq 1, \quad Y^s \geq 0, \quad (w - 1)Y^s = 0.
 \end{aligned}$$

For the time being, assume that the country is in incomplete specialization, so that there holds $w = 1$ and $p = c(r, 1) = re(r) + a(r)$. In the second

emission with labor, and thus the slope of the tangent becomes the flatter as shown by the curve DK in the second quadrant of the figure.

For $r \geq \gamma_D(\zeta)$, the substitution between labor and emission ceases again, for the economy's emission intensity cannot be less than the per-capita emission quota ζ as shown in the third quadrant. 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 unit cost is equal to

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

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

2.2.2 Relative Supply Curve

Insofar as the country is in incomplete specialization, the zero-profit condition $p = c(r, 1)$ gives the demand price of the emission permit, which we express by $r_D(p)$.

Given this demand price for the emission permit $r_D(p)$, the factor market clearing conditions below determines the equilibrium output of each good.

$$\begin{aligned} a(r_D(p))X^s + Y^s &= L \\ e(r_D(p))X^s &= Z \end{aligned}$$

This set of equations yields the equilibrium relative supply of good X to good Y, i.e.,

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

In view of (2), it is straightforward to confirm that incomplete specialization is possible only when there holds $\zeta < z_R$.

Without loss of generality, we assume

Assumption 2 *The government imposes the per-capita emission quota $\zeta <$*

z_R .

Given this assumption, for $r_D(p) \in (\gamma_D(\zeta), \gamma_R)$, (2) implies that the relative supply of good X is strictly increasing in the relative price p , for $r'_D(p) > 0$ and $z'(r) < 0$.

The second quadrant shows the unit-cost curve in Figure 2 and the third quadrant the emission intensity curve in Figure 1. Given the commodity price p , the permit price is determined subject to the unit cost curve, which determines the emission intensity of good-1 production and the equilibrium output of each good.

When the commodity 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 as well as the relative supply stay constant, i.e., $\chi_K^S = \frac{\zeta}{a_R(z_R - \zeta)}$. This is because the economy is at the kinky point along the production possibility frontier. Once the permits become free, the economy is just Ricardian, so that at the resulting relative price $p_R := a_R$ the relative supply can take any value over $[0, \chi_K^S]$.

On the other hand, when the commodity price is as high as $p = p_D$, the relative supply of good X becomes infinite, i.e., the economy completely specializes in good X. The associated point along the unit-cost curve is shown by point D , i.e., the critical point for diversified production. The associated relative commodity price, denoted by p_D given by (1), depends on ζ . We express this relation by the function $p_D(\zeta)$.

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,

$$U = U(u(X^c, Y^c), Z_T)$$

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

Assumption 3 *The household's utility function satisfies the following properties.*

A 3-1: $U(u, Z_T)$ is (i) strictly increasing in the subutility u (ii) strictly decreasing in Z_T , and (iii) twice continuously differentiable.

A 3-2: $u(X^c, Y^c)$ is (i) strictly increasing in the consumption of each good, (ii) twice-continuously differentiable, and (iii) homothetic. It also satisfies (iv) $\lim_{\chi^C \rightarrow 0} \frac{\partial u(\chi^C, 1)/\partial X^c}{\partial u(\chi^C, 1)/\partial Y^c} = +\infty$ and $\lim_{\chi^C \rightarrow \infty} \frac{\partial u(\chi^C, 1)/\partial X^c}{\partial u(\chi^C, 1)/\partial Y^c} = 0$ where $\chi^C := X^c/Y^c$.

Given Assumption 3, 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 ¹

Assumption 4 *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 .

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 3 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 3.

¹One should note that this assumption is equivalent to the condition that the price elasticity of the demand for good X exceeds unity

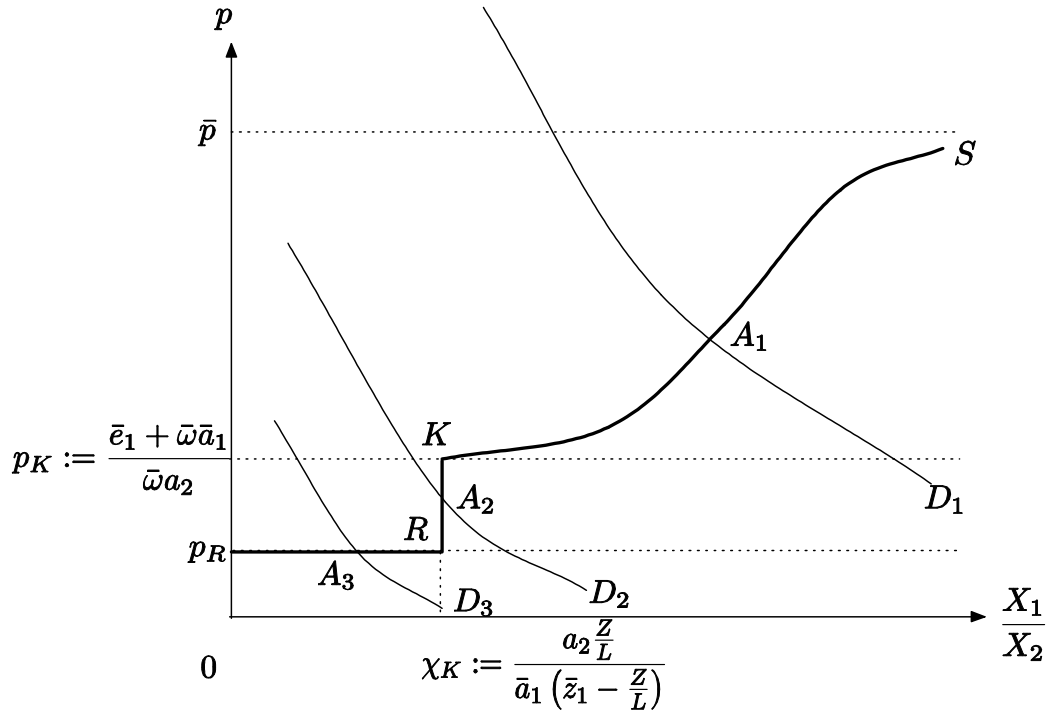


Figure 3: Autarky equilibrium

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.

The effect of an increase in the emission quota is straightforward as shown in Figure 4

3 Commodity-Trade Liberalization: Two-Country Model

In this section, we consider a two-country (home and foreign countries) model where both countries introduces GHG emission regulations. In the following, the foreign variables and parameters are distinguished by asterisk.

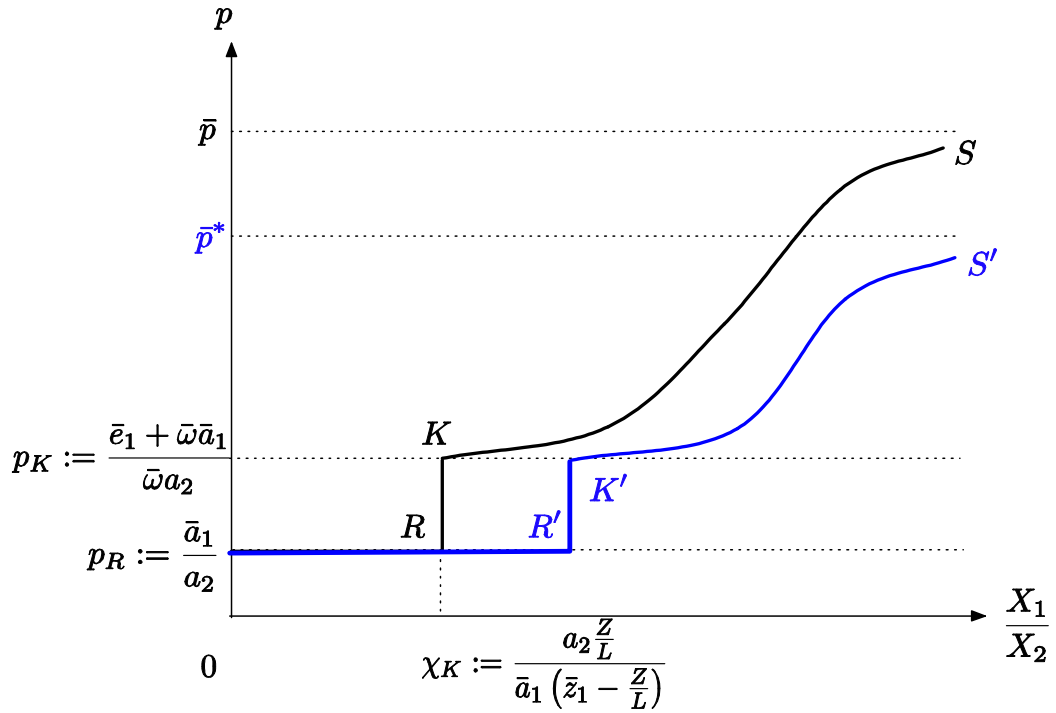


Figure 4: Effects of increased emission quotas

3.1 Symmetric Case

Let us first consider the symmetric case in which the two countries have the same production technology and preference over the commodity consumption. They differ only with respect to the evaluation on the external damages from global warming. Such difference in the perception over the environmental damage leads to different choice of the emission quotas by each government. Without loss of generality, we assume

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

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

The following figure shows the world trading equilibrium when the two countries liberalizes the commodity trade given the emission quota chosen in autarky.

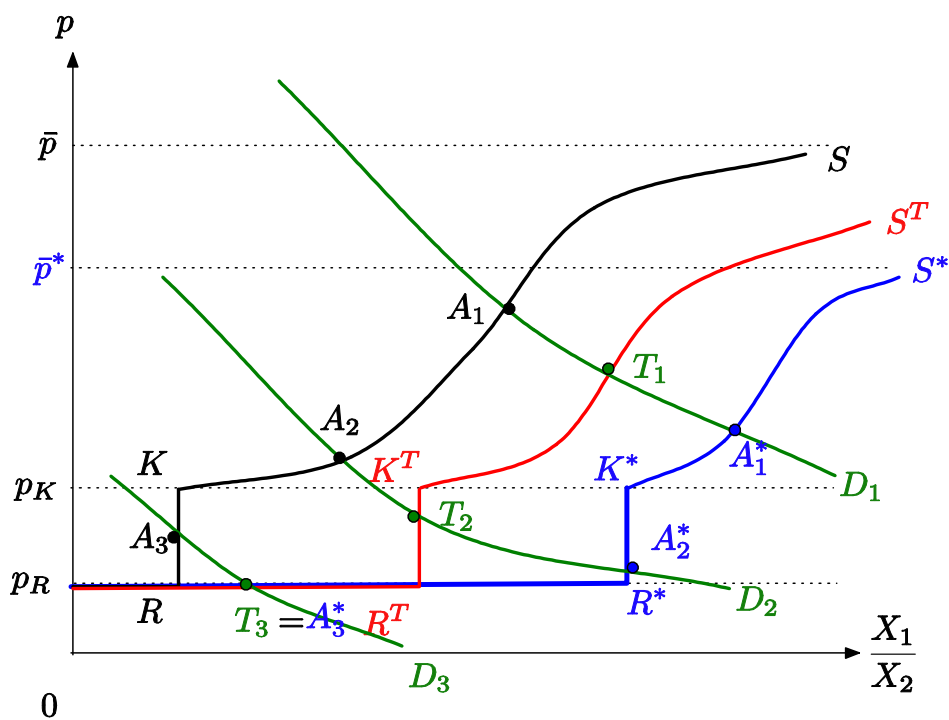


Figure 5: World commodity trading equilibrium: symmetric case

In Figure 5, the home country's relative supply curve is given by S , the 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,

for 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 emission.

Lastly as with the relative demand curve D_3 , the situation is a little different. After free trade in commodities, the home country would specialize in producing good Y and 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. On the other hand, the free trade in commodities expands the world production of good X , increasing the world GHG emission. 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

Now consider the asymmetric case in which the technologies differ between the two countries. Let us take a specific example shown by the following figure.

Given the world relative demand curve, which is the same as each country's, A shows the home country's autarky equilibrium and A^* the foreign counterpart, while T shows the world free commodity-trading equilibrium. The foreign country has comparative advantage in good X , and it expands good-1 production after trade. The home country completely specializes in good Y after trade. Note that before the commodity trade liberalization the emission quotas are binding for both countries, while after trade the quota is still binding for the foreign country but it is not for the home country. In fact, it produces none of good X , so that the emission by the home country before trade is totally eliminated after trade. Therefore both countries gains from

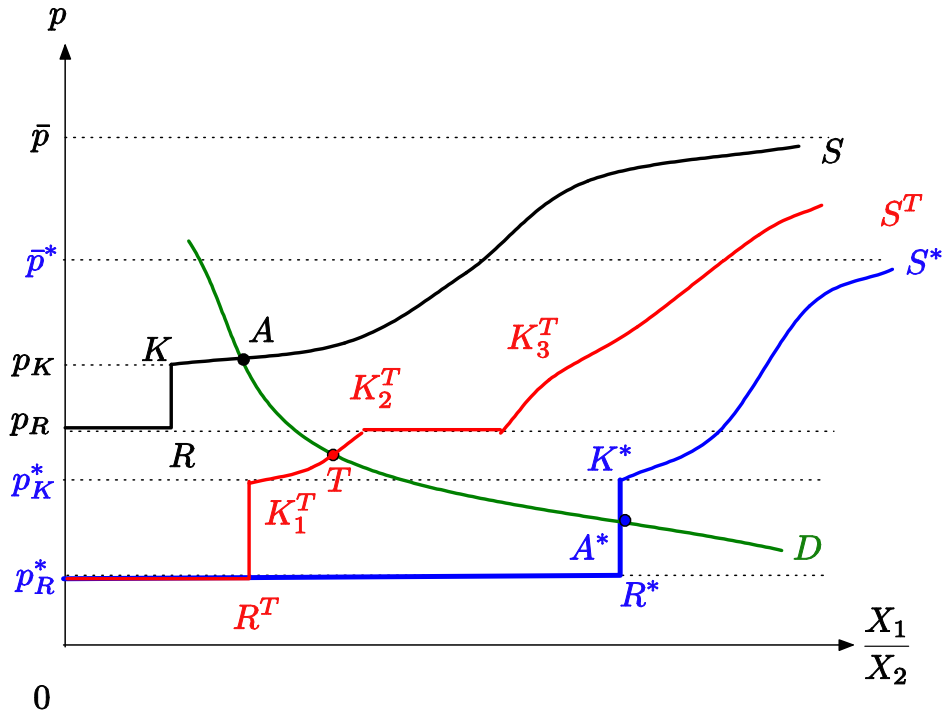


Figure 6: World commodity trading equilibrium: asymmetric case

both the commodity trade liberalization and improved global environment. This result can be generalized as follows.

Proposition 1 *Suppose that the emission quota is binding for each country at the autarky equilibrium. When either country completely specializes in good Y (the clean good) after commodity-trade liberalization, then both countries get better off because of gains from commodity trade and the improved global environment.*

4 Emission Permit Trade After Commodity-Trade Liberalization

Let us now consider the welfare effect of emission-permit trade after the commodity-trade liberalization. As we have already discussed, the commodity-

trade liberalization may give rise to double gains to the world, i.e., standard gains from commodity trade and additional one from an improvement in the global environment quality when either country completely specializes in the numeraire clean good. If it is the case, permit-trade liberalization allows the good-X producing country to expand its output more than when its production is constrained by its own emission quota. It will worsen the global environmental quality. Let us deal with this case as well as the one in which the two countries produces both goods subject to the binding emission quota, i.e., under the following assumption.

Assumption 5 *At the autarky equilibrium, the emission quota is binding for both countries.*

For simplicity of exposition, we also assume

Assumption 6 *The production technologies for producing good X in the home and foreign countries satisfy*

- (i) $e(r_D(p)) < e^*(r_D^*(p))$,
- (ii) $a(r_D(p)) > a^*(r_D^*(p))$ for all p .

This assumption implies that when both countries are diversified in free trade, then the emission intensity in good X production is higher in the foreign country than in the home country, i.e., $z(r_D(p)) < z^*(r_D^*(p))$. The unit-cost curves of the two countries are then shown by Figure 7. Curve HH' represents the home country's unit-cost curve and curve FF' the foreign counterpart. We assume that the two unit-cost curves have a single intersection as shown in the figure.

Assumption 7 *The unit-cost curves of the two countries intersect with each other only once.*

\bar{p} in Figure 7 shows the commodity price associated with the intersection of the two unit-cost curves.

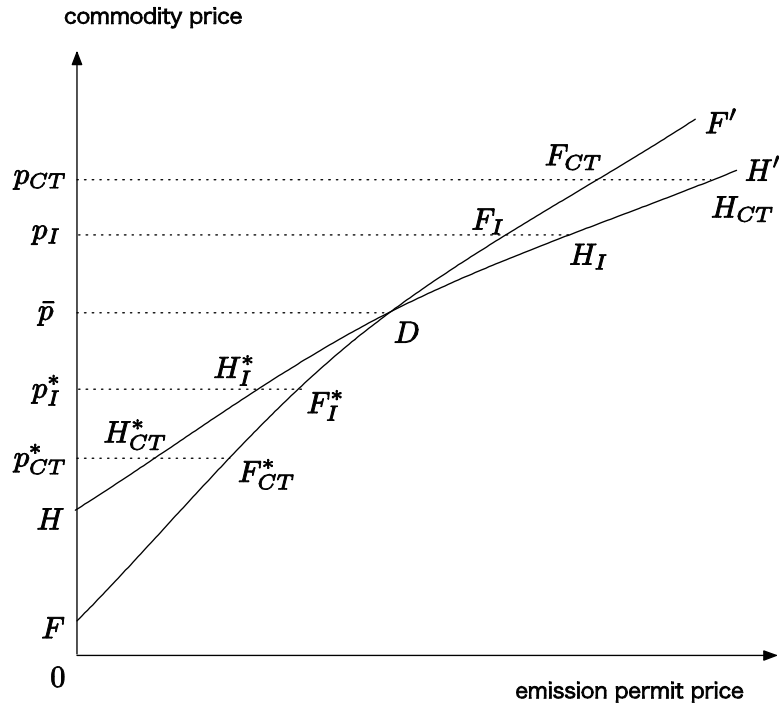


Figure 7: Unit-cost curves and the world integrated equilibrium

4.1 World Integrated Equilibrium

When emission-permit trade is liberalized, the commodity prices and the emission permit prices would be equalized between the two countries, which we call the *world integrated equilibrium*. We shall consider the case in which the home and foreign countries are asymmetric in the production side, i.e., they have the same production technology in the numeraire, but different technologies in the production of good X . In Figure 8, S^T is the world relative supply curve under commodity trade, which is the same as the one illustrated in Figure 6. If both countries open the markets for emission permits, the world relative supply curve is drawn as S_K^T . Let us first explain how to construct S_K^T . We assume that either country has sufficiently large labor force to absorb the world total amount of emission permits. To be

world relative supply of good X is described by

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

where $\zeta^W = Z^W/L^W$. Before permit-trade liberalization, the relative output of good X is $\chi_1^W = \frac{Z^*/L^W}{a_R^*(z_R^* - Z^*/L^W)}$, which is smaller than χ_2^W . Clearly, the permit trade expands the world relative output of the dirty good.

If $p \in (p_K^*, \tilde{p})$, then either country is engaged in the same production pattern as in the previous case, but the substitution of labor for emission works in the foreign production of good X . The higher price of good X leads to the higher price of permits, which promotes the substitution of labor for emission and expands the production of the dirty good.

When the price of good X reaches \tilde{p} , commodity production is diversified at either country. Then, both countries offer the same price for emission permits, and the allocation of permits across the countries is not determined without the demand side condition. As the home country employs more of permits, the world relative output of good X increases due to the home country's higher productivity in emission. When the home country uses all of permits, the relative output is maximized at

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

Clearly, the foreign country produces only good Y since it exports all of permits.

If $p \in (\tilde{p}, \hat{p})$, then the substitution of labor for emission works and an increase in the price of the dirty good raises the relative output along the home country's production possibility frontier. When p is equal to or greater than \hat{p} , complete specialization arises, i.e., the home country produces the dirty good and the foreign country does the clean good. Then, the world relative output of the dirty good is

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

4.2 Welfare Effects of Permit Trade

Next, let us examine the impact of permit-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-trade 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 trade, i.e., both countries benefit from commodity trade due to the standard gains from trade and the improvement of the global environment. However, in this section, we shall show that liberalization in permit trade may cause double losses from trade.

When both countries liberalize permit trade as well as commodity trade, the equilibrium is determined at T_1^K . The foreign country expands the production of the dirty good by importing emission permits. The home country imports the dirty good by exporting permits as well as the clean good. Let us first examine the effect of permit trade on the welfare of the foreign country. The welfare effect can be decomposed into three effects.² 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 permit trade. 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 in commodity trade. 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 from the double losses from trade: the worsening of the terms of trade and the global environment. However, the home country can benefit from the permit trade 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 2 *Suppose that the emission quota does not bind at either country at the commodity-trade equilibrium. After the permit-trade liberalization,*

²See Appendix for the algebraic derivation of the gains or losses from permit trade.

the country, at which the dirty-good production is constrained by the emission quota, is allowed to expand the output of the dirty good by importing emission permits. As a result, the global environment deteriorates because of an increase in the world output of the dirty good. Then, one country suffers double losses from the permit trade: the worsening of the terms of trade in commodities and the deterioration of the global environment.

Next, suppose that the commodity demand curve is given by D_2 . Then, the emission permit quota is biding for both countries before and after the liberalization of permit trade. Since the total level of global emissions does not change, the permit trade does not worsen the global environment. The home country imports permits and expands the production of the dirty good. Since the home country has the higher productivity of emission, 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 the one at the commodity-trade equilibrium, the permit trade hurts the foreign country but benefits the home country.³ 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 good. When such a reversal arises, the welfare effect of the permit trade would be ambiguous.

4.3 Initial Distribution of Permits and Welfare Effects of Permit Trade

There is a distributional question of which country should be given the larger quota when permit trade starts. In this section, we examine this issue in terms of the welfare effect of permit trade. So far, we have considered a situation in which the foreign country has the greater size of emission quota and it exports the dirty good at the commodity-trade equilibrium. Instead, we shall examine a case in which the home country has the greater emission quota and it exports the dirty good at the commodity-trade equilibrium. We assume that other things are equal, and thus the total level of emission permits is constant.

³See Appendix for the proof.

sufficiently large quota of emission permits and exports the dirty good at the commodity-trade equilibrium. Here, we assume that the foreign country does not have the sufficiently large size of emission quota and imports the dirty good. However, once again, the foreign country loses from the permit trade. This result suggests that the permit trade may hurt one country regardless of which country is given the larger emission quota.

5 Conclusions

In this paper, we have examined the welfare effect of international trade in emission rights. When the emission quotas are binding at both countries at the autarky equilibrium, the commodity-trade liberalization benefits both countries due to the double gains from trade: the standard gains from trade and the improvement of the global environment. After the commodity-trade liberalization, opening the emission-permit markets to international trade does not guarantee trade gains for the countries. If the emission quota is not binding at the country having the less emission-intensive technology, then the permit trade induces the country to export emission permits to the other country using the more emission-intensive technology, leading to a rise in the world emission level and the deterioration of the global environment. The country having the more emission-intensive technology suffers from double losses from the permit trade: the worsening of the terms of trade and the deterioration in the global environment.

We have also examined the distributional question of emission quotas. The permit trade induces the redistribution of permits across countries, resulting a change in the terms of trade in commodities. We have shown that one country may suffer from the deterioration of the terms of trade regardless of which country is given the greater emission quota when permit trade starts.

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Appendix: Algebra on the Welfare Effects of Permit Trade

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

$$du = u_X dX^C + u_Y dY^C, \tag{A1}$$

where u_i is the marginal utility of good $i = X, Y$. Dividing the both side of (A1) with u_Y , we can obtain a change in the real income in terms of good Y .

$$d\tilde{u} = \left(\frac{u_X}{u_Y} \right) dX^C + dY^C. \quad (\text{A2})$$

With the use of the first order condition in the utility maximization problem, we can rewrite (A2) as

$$d\tilde{u} = p^H dX^C + dY^C, \quad (\text{A3})$$

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

$$p^W X^C + Y^C = p^W X + Y + r^W (Z - Z^D) \quad (\text{A4})$$

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

$$p^H dX + dY = -r^H d(Z - Z^D), \quad (\text{A5})$$

where r^H denotes the domestic price of permits. Using (A3), (A4) and (A5), we can derive a change in the real income of the home country as follows:

$$\begin{aligned} d\tilde{u} &= (X - X^C) dp^W + (Z - Z^D) dr^W \\ &+ (p^W - p^H) d(X - X^C) + (r^W - r^H) d(Z - Z^D). \end{aligned} \quad (\text{A6})$$

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 (A6) at the commodity-trade equilibrium, $p^H = p^W$ and $Z = Z^D$ hold. Thus, we can simplify (A6) as

$$d\tilde{u} = (X - X^C) dp^W + (r^W - r^H) d(Z - Z^D). \quad (\text{A7})$$

Similarly, we can derive the foreign counterpart as

$$d\tilde{u}^* = (X^* - X^{*C})dp^W + (r^W - r^F)d(Z^* - Z^{*D}). \quad (\text{A8})$$

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 (A8), 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 (A7), 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. 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.