HITOTSUBASHI UNIVERSITY

Global COE Hi-Stat Discussion Paper Series 180

Research Unit for Statistical
and Empirical Analysis in Social Sciences (Hi-Stat)

Is Emission Trading Beneficial?

Jota Ishikawa
Kazuharu Kiyono
Morihiro Yomogida

March 2011

Hi-Stat Discussion Paper

Hi-Stat
Institute of Economic Research
Hitotsubashi University
2-1 Naka, Kunitatchi Tokyo, 186-8601 Japan
http://gcoe.ier.hit-u.ac.jp

Is Emission Trading Beneficial?*

Jota Ishikawa[†]
Hitotsubashi Univ.
and RIETI

Kazuharu Kiyono
Waseda Univ.

Morihiro Yomogida[‡]
Sophia Univ.

February 8, 2011

Abstract

We develop a two-country (North and South), two-good, general equilibrium model of international trade in goods and explore the effects of domestic and international emission trading under free trade in goods. Whereas domestic emission trading in North may result in carbon leakage by expanding South's production of the emission-intensive good, international emission trading may induce North to expand the production of the emission-intensive good by importing emission permits. Emission trading may deteriorate global environment. North's (South's) emission trading may not benefit South (North). International emission trading improves global efficiency but may not benefit both countries.

Keywords: global warming, emission quota, emission trading, carbon leakage, Kyoto Protocol
JEL Classification Number: F18

*We wish to thank two anonymous referees of this journal, Brian Copeland, Masahiro Endoh, Tim Hazledine, Naoto Jinji and Kenji Kondoh, and participants of the 5th Australasian Trade Workshop, the Hitotsubashi Conference on International Trade & Industrial Organization 2010, the Bari Workshop on Economics of Global Interactions, the ETSG 2010, and seminars at Keio University, Kyoto University, Soul National University, University of New South Wales and University of Tasmania for their helpful comments on earlier versions of this paper. The usual disclaimer applies. Ishikawa acknowledges financial support provided by the MEXT under the Global Center of Excellence Project and the Grant-in-Aid for Scientific Research (A). Yomogida acknowledges financial support provided by the Sumitomo Foundation. Ishikawa and Yomogida dedicate this paper to the late Professor Kiyono who passed away before this paper was completed.

[†]Faculty of Economics, Hitotsubashi University, Kunitachi, Tokyo 186-8601, Japan, E-mail: jota@econ.hit-u.ac.jp, Fax: 81-42-580-8882.

[‡]Faculty of Economics, Sophia University, 7-1 Kioi-cho, Chiyoda-ku, Tokyo 102-8554, Japan, E-mail: m-yomogi@sophia.ac.jp, Fax: 81-3-3238-3086.

1 Introduction

To combat global warming, an international environmental treaty, the United Nations Framework Convention on Climate Change (UNFCCC), was made at the Earth Summit in 1992. Then the first session of the Conference of Parties (COP) to the UNFCCC was held in Berlin in 1995. Since then, the COP has met every year. Among these COP sessions, the third session, so called COP3, is the most noteworthy, because the Kyoto Protocol was adopted.

In the protocol, two important agreements were made. First, the industrialized countries called Annex I Parties made a commitment to decrease their greenhouse-gas (GHG) emissions to 5.2% below their 1990 baseline levels over the 2008 to 2012 period. Second, three market-based mechanisms, so called the Kyoto mechanisms, were introduced. These three mechanisms are emission trading, clean development mechanism and joint implementation. In particular, emission trading, meaning the creation of markets to freely trade emission permits, has attracted considerable attention. For example, the European commission states that market-based carbon trading is an instrument for countries to reach their targets at least cost.

Recently, discussions on a post-Kyoto framework have been getting active. The Kyoto Protocol is a notable step towards the reduction of GHG, but a major drawback is that developing countries have no obligation to the reduction.[1] Moreover, it is expected that emission trading is inevitable for many countries to meet their targets, but emission trading (international emission trading especially) has not been well developed. Therefore, the post-Kyoto framework needs to design an international emission trading system that involves developing countries,[2] particularly the fastest-growing emitters such as China and India.[3] However, international trade in emission permits has not been investigated satisfactorily.

In this paper, we explore the effects of domestic emission trading and international emission trading between developed countries (North) and de-

[1] The United States, which is a signatory to the protocol, has not ratified the protocol.

[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.

[3] According to the International Energy Agency (IEA), China became the largest CO_2 emitter in 2007. The shares of CO_2 emissions in the world were 21% for China and 20% for the United States. The IEA expects that the China's share will be about 28% in 2030.

veloping countries (South). To this end, we develop a two-country (North and South), two-good, general equilibrium model of international trade in goods and emission permits. The two goods are produced using a primary factor, called labor. Following an idea of Meade (1952), however, we specifically regard GHG emissions as an input of environmental resources for production.[4] In our model, the government sets an aggregate level of domestic GHG emissions, which can be implemented by issuing tradable emission permits. Moreover, we specifically focus on the case with a technology gap between North and South. To be concrete, North requires less labor and generates less emissions in the production of the emission-intensive good.[5]

We first explore the effects of domestic emission trading in North alone under free trade in goods and then consider a situation where South also introduces domestic emission trading. In our analysis, domestic emission trading means that an emission quota implemented by issuing the emission permits that can be traded freely within the economy. After examining domestic emission trading, we allow international trade in emission permits to analyze international emission trading.

Our model is built on Ishikawa and Kiyono (2006) that develops a model having both Ricardian and Heckscher-Ohlin features to compare different measures of emission regulations in an open economy. In particular, North has a comparative advantage in the production of the emission-intensive good. This feature enables us to examine economic and environmental effects of emission trading between developed and developing countries. However, Ishikawa and Kiyono examine unilateral emission regulations (including emission quotas) alone. Thus, emission trading is allowed only within North in their analysis. We extend their analyses to the case of "bilateral" emission regulations.

We show that North's emission trading under free trade in goods may result in carbon leakage by expanding South's production of the emission-intensive good, while international emission trading under free trade in goods may induce North to expand the production of the emission-intensive good

[4]For example, Copeland and Taylor (1994), Ishikawa and Kiyono (2006), and Abe et al. (2011) follow this idea.

[5]For example, Japanese technology of manufacturing steel is one of the most efficient and most energy-saving technologies in the world. According to the Asia-Pacfic Partnership Clean Development and Climate, 130 million tons of CO_2 can be reduced without affecting the total output if Japanese technology is used by steel mills in the USA, China, Korea, Australia, and Canada.

by importing emission permits. Emission trading in North alone may increase global GHG emissions. We point out, however, that North may have incentive to introduce emission trading even if total world emissions increase. It is also shown that either North or South may suffer from international emission trading.

Copeland and Taylor (2005) develop a general equilibrium model of international trade and examine the welfare effects of emission trading. They consider a Heckscher-Ohlin model with three countries (i.e., two North countries: West and East, and South) and assume that West and East are constrained by the emission treaty, but South is not. It is shown that emission trading between West and East may make them worse off and may not cause carbon leakage in South although South is free from emission control. Unlike Copeland and Taylor, we use a model having both the Heckscher-Ohlin and Ricardian features, and show that emission trading may not benefit both North and South.[6]

Kiyono and Ishikawa (2010) explore emission taxes and quotas in the presence carbon leakage caused by changes in the fossil fuel price. Constructing a three-country model (two fossil-fuel-consuming countries and one fossil-fuel-producing country) which explicitly takes trade in fossil fuel into account, they also show that permit trade between the fossil-fuel-consuming countries may not benefit them. In their analysis, trade in fossil fuel, which is absent in our model, plays a crucial role.

Our work is also related to the literature on trade theory with capital mobility.[7] 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. Thus, we evaluate the welfare effect of emission trading in terms of the global environment quality in addition to the standard effects of factor

[6] As is well known, in the Heckscher-Ohlin model, the factor prices are equalized in free trade equilibrium when countries are incompletely specialized. This property holds in Copeland and Taylor (2005) so that the prices of emission permits are equalized in free trade equilibrium with incomplete specialization. Obviously, in such an equilibrium, there is no incentive for trade in emission permits. To consider permit trade between countries, they assume that West is completely specialized in the clean good, while East produces both clean and dirty goods. As a result, permits are exported from East to West. In our model, the asymmetric technology results in a difference in the permit prices between countries. In particular, North imports permits from South.

[7] See Mundell (1957), Jones (1980), Brecher and Choudri (1982), Markusen (1983), Grossman (1983), Jones (2000), and Yomogida (2006), among others.

mobility. Moreover, the level of emissions is not fixed unlike the stock capital being fixedly endowed and fully employed.

The rest of this paper is organized as follows. In Section 2, we develop a basic model. In Section 3, we consider the effects of domestic emission trading in the North-South model. In Section 4, we explore international emission trading under free trade in goods. Section 5 concludes.

2 The Basic Model

In this section, we present a basic model. Without any emission regulation, the model is simply Ricardian. That is, two goods are produced using a single factor (labor) with a constant-returns-to-scale (CRS) technology and consumed by the household. Production of both goods emits greenhouse gases (GHG) and deteriorates the global environmental quality leading to damages on the household. To examine emission trading, we first introduce domestic emission trading under free trade in goods and then consider international emission trading.

2.1 Production Technology

We first describe the production technology of each good. Two goods (X and Y) are produced using a single factor (labor) with a CRS technology. The labor coefficient of good i ($i = X, Y$) is given by $a_i(> 0)$. Perfect competition prevails in the economy. The endowment of labor is given by L. Labor can freely move between two sectors and is fully employed.

Production of one unit of good i ($i = X, Y$) emits $e_i(> 0)$ units of GHGs. GHGs reduce economic welfare, but does not generate production externalities. Following the idea of Meade (1952), we may regard GHG emissions as the input of the environmental resource for producing goods. This environmental resource is an unpaid factor of production and socially overused without any regulation. 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 refer to the environmental resource as emissions for simplicity.

Therefore, both goods X and Y require both labor and environmental resources for production. That is, the output of good i ($i = X, Y$) is a function of labor input, L_i, and the amount of GHG emissions generated during production, Z_i. For simplicity, we assume away the substitutability between labor and emissions, that is, we do not allow emission abatement through labor input:[8]

$$X = \min(\frac{L_X}{a_X}, \frac{Z_X}{e_X}), Y = \min(\frac{L_Y}{a_Y}, \frac{Z_Y}{e_Y}).$$

Obviously, if there is no environmental regulation, firms would not pay for emissions and the model is simply Ricardian.

For the following analysis, we define the emission intensity of production of good i $(i = X, Y)$:

$$z_i \equiv \frac{e_i}{a_i} = \frac{Z_i}{L_i}$$

and impose the following assumption:

Assumption 1 *Good X is relatively more emission-intensive than good Y. That is, $z_X > z_Y$ holds.*

2.2 Emission Quotas

We assume that under free trade in goods, the government sets an aggregate level of domestic GHG emissions which is denoted by Z. To implement the emission level, the government issues Z units of the emission permit that can be traded freely within the economy. Full employment of labor is still assumed in the presence of the emission quota. Noting Assumption 1, we impose the following assumptions:

Assumption 2 *A 2-1: $Z/e_Y > L/a_Y$*

A 2-2: $Z/e_X < L/a_X$

The first assumption is necessary to guarantee full employment of labor, while the second assumption makes the quota binding. This can be

[8] We can incorporate emission abatement through labor input into the model such as in Ishikawa and Kiyono (2006). In this case, the production possibility frontier (Figure 1), the unit cost curves (Figure 2), and the relative supply curve (Figure 3) have somewhat different shapes. KN becomes strictly concave to the origin in Figure 1; a part of each unit cost curve becomes strictly convex to the origin in Figure 2; and KS is not vertical but upward-sloping in Figure 3 (for details, see Ishikawa and Kiyono, 2006). However, these changes make the analysis complicated without gaining further insights.

confirmed by the production possibility frontier (PPF) in Figure 1. Factor constraints are represented by

$$a_X X + a_Y Y = L,$$
$$e_X X + e_Y Y \leq Z.$$

Since producers do not incur the cost of emitting GHG without the emission quota, the PPF is illustrated by a downward straight line as in the Ricardian model (MM' in Figure 1). After the government imposes the total emission quota on production activities and creates the market for trading emission permits, producers would incur the costs of emissions. Given the total emission quota Z, the PPF is illustrated as MKN in Figure 1. Under Assumption 2, point K, the coordinates of which are

$$\left(\frac{Za_Y - Le_Y}{e_X a_Y - e_Y a_X}, \frac{Le_X - Za_X}{e_X a_Y - e_Y a_X} \right), \tag{1}$$

is located between M and M'. Full labor employment is realized on MK and both factor constrains are binding only at point K.

We next determine the wage rate, w, and the price of the permit, r. The unit cost function of good i ($i = X, Y$) is expressed by

$$c_i(r, w) = re_i + wa_i.$$

Letting good Y be the numeraire, we have the following conditions under perfect competition:

$$c_X(r, w) \geq p, c_Y(r, w) \geq 1,$$

where p is the (relative) price of good X. The unit cost curves are illustrated in Figure 2: XX' for good X and YY' for good Y. As long as the quota is binding, both labor and emission permits are fully used and hence point B determines the wage rate and the permit price:[9]

$$r = \frac{-a_X + pa_Y}{e_X a_Y - e_Y a_X}, w = \frac{e_X - pe_Y}{e_X a_Y - e_Y a_X}.$$

[9] If the quota is unbinding, then $r = 0$ holds. In this case, point Y determines the wage rate ($w = 1/a_Y$) as long as good Y is produced.

2.3 Relative Supply Curve

The relative supply curve is illustrated in Figure 3. Before an emission quota is introduced, the relative supply curve is given by OMM''. That is, the relative supply curve coincides with the vertical axis for $0 < p \leq p_A$ (where $p_A(\equiv a_X/a_Y)$ is the autarky price) and is horizontal at $p = p_A$. When an emission quota is introduced, the relative supply curve becomes as follows. As long as the quota is unbinding ($p \leq p_A$), the relative supply curve coincides with that of the Ricardian case (i.e., OMK). When the quota is binding ($p \geq p_A$), there are two cases. If production takes place at the kinky point K on the PPF (see Figure 1), then the relative supply curve becomes vertical at K (i.e., KS) in Figure 3.[10] If production takes place at point N on the PPF, the relative supply curve becomes horizontal at S (i.e., SN). Thus, the relative supply curve is given by $OMKSN$. It should be noted that only KS is consistent with both binding quotas and full employment of labor.

2.4 National Welfare

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

$$U = U\left(u(X^c, Y^c), Z^W\right), \tag{2}$$

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

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

A 3-1: $U(u, Z^W)$ is (i) strictly increasing in the sub-utility u (ii) strictly decreasing in Z^W, 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, (iii) strictly concave, and (iv)

[10] As the emission quota becomes tighter, KS moves to the left. When point K coincides with M (M') in Figure 1, point K coincides with M (M') in Figure 3 as well. The coordinates of point K in Figure 3 are $\left(\frac{Za_Y - Le_Y}{Le_X - Za_X}, \frac{a_X}{a_Y}\right)$.

homothetic. It also satisfies (v) $\lim_{\chi^c \to +0} \frac{\partial u(\chi^c,1)/\partial X^c}{\partial u(\chi^c,1)/\partial Y^c} = +\infty$ *and* $\lim_{\chi^c \to +\infty} \frac{\partial u(\chi^c,1)/\partial X^c}{\partial u(\chi^c,1)/\partial Y^c} = 0$*, where* $\chi^c \equiv X^c/Y^c$*.*

Given Assumption 3, the relative demand for good X, $\chi^D(p)$, depends only on its relative price p and is decreasing in p.

3 North-South Model

In this section, we consider a two-country (North and South) model where emission quotas are introduced under free trade in goods. North is a developed country, while South is a developing country.

3.1 Free Trade in Goods without Emission Quotas

We first consider free trade in goods without emission quotas. For this, we impose the following assumption regarding technologies:[11]

Assumption 4 *A 4-1: North and South have the same technology of producing good* Y*, that is,* $a_Y = a_Y^*$*,* $e_Y = e_Y^*$*.*

A 4-2: The production technologies of producing good X *satisfy* $a_X < a_X^*$*,* $e_X < e_X^*$*.*

The second assumption implies that North can produce good X more efficiently with less emissions than South. Under Assumption 4, North has a comparative advantage in good X.[12] Under free trade, therefore, North and South specialize in good X and good Y, respectively, and at least one country is completely specialized. That is, one of the following three cases arises:

1. North and South completely specialize in good X and good Y, respectively;
2. North is diversified, while South completely specializes in good Y;
3. North completely specializes in good X, while South is diversified.

[11] South's variables and parameters are denoted by asterisk.

[12] Even if North has an absolute advantage in both goods in terms of the labor productivity, i.e., $a_Y < a_Y^*$ and $a_X < a_X^*$, we can derive the same results as long as North has a comparative advantage in good X, i.e., $a_X/a_Y < a_X^*/a_Y^*$.

These cases are shown in Figures 3 and 4. In Figure 3, the world relative supply curve is given by $OMM'M^{*'}M^{*"}$, while three downwards sloping curves are possible relative demand curves showing the relative demand for each country as well as the world. Point T_i ($i = 1, 2, 3$) shows the associated free-trade equilibrium corresponding to Case i above. Figure 4 illustrates the world PPF, $MM'M^{*"}$. In the figure, MM' corresponds to North's PPF and $M^{*'}M^{*"}$ corresponds to South's PPF. Moreover, point T_i ($i = 1, 2, 3$) in Figure 4 corresponds to that in Figure 3.

3.2 Introduction of Domestic Emission Quotas

We now examine the introduction of an emission quota with the creation of the domestic market to trade emission permits in each country. We first consider the case in which only North introduces an emission quota and then the case in which South also introduces an emission quota. To focus on the case where labor is fully employed in the presence of emission quotas, we impose the following assumption.[13]

Assumption 5 $e_X/e_Y > a^*_X/a^*_Y$

Suppose that under free trade in goods, a domestic emission quota is introduced in North alone and that the quota is binding. Assumption 5 implies that SN is located above $M^*M^{*"}$ in Figure 3. In Figure 4, North's quota shifts the world PPF from $MM'M^{*''}$ to $MKM^{*''}_N M'_N$.[14] In Figure 5, North's relative supply curve is given by $OMKSN$, while South's relative supply curve is given by $OM^*M^{*"}$.[15] The world relative supply $(X+X^*)/(Y+Y^*)$ becomes $OMK^TM^TK^{*T}S^T$.[16] Point E_i shows a possible world trading equilibrium. Point E_i ($i = 1, 2, 3, 4$) in Figure 4 corresponds to that in Figure 5. We should mention that the world relative supply curve with North's emission quota is located to the left of that without it, $OMM'M^{*'}M^{*"}$, and hence the world price of good X, p^W, rises as a result of North's emission quota.

[13]This assumption is satisfied when $e_Y \approx 0$. When $e_Y = 0$, we do not need this assumption.

[14]With Assumption 5, the slope of KM^*_N is less steep than that of $M^*_N M'_N$. Note that at any point between M^*_N and M'_N, labor unemployment arises.

[15]SN is not illustrated in Figures 5 and 6.

[16]K^TM^T that is located between MM^* and KS, while $K^{*T}S^T$ is located to the right of KS.

Intuitively, North's quota increases p^W, because the quota decreases the supply of good X and increases the supply of good Y in North. Depending on the resulting world price, three cases are possible. First, if $p^W < p_A^*$, then South remains to completely specialize in good Y (point E_1, for example). Second, if $p^W = p_A^*$, then South as well as North is diversified (points E_2 and E_3, for example).[17] Third, if $p^W > p_A^*$, South completely specializes in good X. With $p^W > p_A^*$, therefore, the trade pattern is reversed, that is, the introduction of North's emission quota leads North to export good Y and South to export good X (point E_4, for example). We should mention that the trade pattern is reversed even with $p^W = p_A^*$ if the relative demand curve cuts the world relative supply curve to the right of North's relative supply curve. If they intersect at point E_3, for example, the autarky relative price is given by point A in North and by point E_3 in South, and North exports good Y and imports good X under free trade.[18]

North's quota under free trade in goods could cause carbon leakage, that is, North's quota could reduce North's GHG emissions, but increase South's emissions by expanding South's production of good X. Unless South remains to completely specialize in good Y, the carbon leakage necessarily occurs. In fact, world total GHG emissions could rise as a result of North's emission quota. This is more likely to occur when e_X^* is sufficiently large relative to e_X.

Thus, we obtain the following proposition.

Proposition 1 *Suppose that only North introduces a domestic emission quota. Then p^W rises. The carbon leakage exists when $p^W \geq p_A^*$ in equilibrium. If e_X^* is sufficiently large relative to e_X, then world total GHG emissions may increase due to the carbon leakage. The trade pattern is reversed (i.e., North exports good Y and imports good X) only if $p^W \geq p_A^*$ in equilibrium. In particular, the trade pattern is necessarily reversed if $p^W > p_A^*$.*

We now consider the introduction of a domestic emission quota in South in the presence of North's quota. This is illustrated in Figures 6 (a) and (b). Suppose that South's emission quota makes South's relative supply curve

[17] Strictly speaking, if the intersection point is M^T (K^{*T}), then South remains to completely specialize in good Y (X).

[18] Here, the autarky price is hypothetical one, because emission quotas are introduced under free goods trade and hence are absent under autarky.

$OM^*K^*S^*$. As a result of South's quota, $K^{*T}S^T$ shifts to the left and is located between KS and K^*S^*. As long as the quota level is large, K^*S^* is located to the right of KS (Figure 6 (a)). As South's quota becomes tighter, both $K^{*T}S^T$ and K^*S^* shift to the left. However, K^*S^* shifts more than $K^{*T}S^T$ and K^*S^* particularly coincides with $K^{*T}S^T$ on KS. Eventually, K^*S^* shifts to the left of KS (Figure 6 (b)). Since $K^{*T}S^T$ shifts to the left by tightening South's quota, p^W increases. South's quota makes the world PPF $MKK^*M'_SM^{*''}_S$ in Figure 4. Point E'_4 in Figure 4 corresponds to that in Figure 6 (a).

Noting (1), we can easily verify the following lemma:

Lemma 1 *K^*S^* is located to the right of KS if and only if* $(Z^*a_Y - L^*e_Y)/(L^*e^*_X - Z^*a^*_X) > (Za_Y - Le_Y)/(Le_X - Za_X)$.

We should mention that there is no effect at all when South's quota is unbinding. In the following analysis, therefore, we focus on the case where it is binding. If the equilibrium remains to be at the same point (say, point E_3 in Figures 6(a)) after the introduction of South's emission quota, the quota is not binding. This is because a binding quota decreases the supply of good X and increases that of good Y and hence p^W rises. That is, South's quota is binding if $p^W > p^*_A$ (point E'_4 in Figure 6 (a)) but is unbinding if $p^W \leq p^*_A$ (points E_1, E_2 and E_3 in Figure 6 (a)).[19]

The following should be noted. First, even if South's quota is binding, world total GHG emissions could be greater relative to the case without any emission quota in both countries. This is because North's quota could cause international carbon leakage and increase world total GHG emissions before South's quota is introduced. Second, South's quota may reverse the trade pattern. When the trade pattern is reversed by North's quota, this pattern could be reversed again by South's quota (for example, point $E^{''}_4$ in Figure 6 (b).[20] If North's quota does not reverse the trade pattern, then the pattern remains unchanged even in the presence of South's quota.

Therefore, the following proposition is established.

[19] Strictly speaking, if the intersection point is K^*, then South's quota is just binding.

[20] In the absence of South's quota, the autarky relative price is given by A in North and by A^*_1 in South in Figure 6 (b). Thus, North imports good X and p^W is determined somewhere between A and A^*_1. In the presence of South's quota, however, South's autarky relative price is given by A^*_2 and North exports good X.

Proposition 2 *Suppose that South also introduces a binding emission quota. Then p^W rises and $p^W > p_A^*$ holds. North exports good X and imports good Y if and only if $(Za_Y - Le_Y)/(Le_X - Za_X) > (Z^* a_Y - L^* e_Y)/(L^* e_X^* - Z^* a_X^*)$.*

We next examine the welfare effects of the introduction of domestic emission quotas. Three effects are generated by the emission quotas. That is, the emission quotas affect world total GHG emissions (henceforth the emission effect), p^W (henceforth the terms-of-trade (TOT) effect), and the production possibility set (PPS) (henceforth the PPS effect).

When only North introduces an emission quota, we have three cases to analyze. In the first case, South remains to completely specialize in good Y. North's emissions decrease, while South's emissions remain unchanged. Therefore, both countries gain from the reduction of world total GHG emissions. However, the quota also generates the other two effects. Since the world output of good X falls, p^W rises. Thus, North benefits from the improvement of the TOT, because North remains exporting good X with the quota. That is, the TOT effect is positive for North. At the same time, however, the PPS shrinks in North (see Figure 1). In general, therefore, it is ambiguous whether North gains from introducing an emission quota. Similarly, South may or may not gain, because the global environment improves but the TOT for South deteriorate.

In the second case, South is diversified. In this case, the carbon leakage occurs and hence world total GHG emissions may increase. North gains from an increase in p^W unless the trade pattern is reversed. If the trade pattern is reversed, then, because of both TOT and PPS effects, North's consumption point is located in KNM' in Figure 1. Thus, the sub-utility necessarily falls in North. Since South's TOT coincide with the autarky relative price, the TOT effect is necessarily negative for South regardless of trade patterns. If North's emission quota raises world total GHG emissions, South loses.

In the third case, South completely specializes in good X. As in the second case, the carbon leakage exists. Since the trade pattern is reversed, the combination of the TOT effect and the PPS effect is adverse to North. South may or may not gain from an increase in p^W. Again the welfare effects are generally ambiguous for both countries.

The following should be noted. First, North has no incentive to voluntarily introduce emission quotas if it loses from them. In particular, this is the case if all three effects are detrimental to North. Thus, when the trade pattern is reversed (which necessarily occurs with $p^W > p_A^*$), it is inferred that North's quota decreases world total GHG emissions regardless of the carbon leakage. Second, North could gain even if world total GHG emissions increase as a result of its emission quota. This is the case if the positive TOT effect dominates the negative emission and PPS effects. Thus, North may be willing to introduce emission quotas not because emissions fall but because the TOT improve.

Thus, we obtain the following proposition when only North introduces an emission quota and North gains from it.

Proposition 3 *Suppose that $p^W \neq p_A^*$ holds under North's quota. Then, world total GHG emissions decrease but South's welfare may not improve. Suppose that $p^W = p_A^*$ holds under North's quota. Then, North may have an incentive to introduce an emission quota even if world total GHG emissions increase. South gains only if world total GHG emissions decrease.*

We now consider the case in which South introduces a domestic emission quota in the presence of North's quota. When South's quota is binding, world total GHG emissions obviously fall. Thus, the emission effect is positive for both countries. The adverse PPS effect arises only in South. An increase in p^W is favorable for the country remaining to export good X and is unfavorable for the other country. If North remains to export good X (good Y), then the TOT effect is beneficial (detrimental) to North. If South's quota leads North to export good X, the TOT effect may or may not be beneficial to North. A tighter emission quota decreases the emissions more. However, the PPS shrinks to a larger extent and South is more likely to import good X. Thus, although North is more likely to prefer a tighter quota in South, South may introduce only a lax quota. North may lose from South's emission quota if South's quota does not induce North to export good X.

Thus, noting Lemma 1, we obtain the following proposition when South introduces a binding emission quota in the presence of North's quota.

Proposition 4 *North may or may not gain form South's quota. If $p^W < p_A^*$ holds under North's quota alone and $(Za_Y - Le_Y)/(Le_X - Za_X) \geq (Z^* a_Y - L^* e_Y)/(L^* e_X^* - Z^* a_X^*)$ holds under both North's and South's quotas, then North gains.*

Comparing the situation with emission quotas in both countries with the situation without any emission quota, we can state the following. Since world total GHG emissions could be greater than those without any emission quota because of carbon leakage caused by a North quota, the emission effects are ambiguous. The PPS effect is detrimental to both countries. The TOT effect works positively for the country exporting good X and negatively for the country importing good X.

Therefore, the following proposition is established.

Proposition 5 *Suppose that North introduces an emission quota and then South introduces an emission quota. Although each quota reduces GHG emissions in each country, world total GHG emissions could increase relative to the case without any emission quota. Both countries gain from such quotas only if world total GHG emissions fall.*

4 International Trade in Emission Permits

In this section, we introduce international emission trading into the model and compare the case with international emission trading against the case with domestic emission trading alone. When the emission permits can be traded internationally, the production and trade patters of goods could be affected. We explore the effects of international trade in emission permits. To this end, we impose the following assumption.

Assumption 6 $Z + Z^* < \min\{z_X L, z_X^* L^*\}$ *holds, that is, the labor endowment is large enough to absorb world total emission permits in both North and South.*

Under Assumption 4, the permit price is always higher in North than in South. In Figure 2, the broken line $X^*X^{*\prime}$ is South's unit cost curve of good X. South's unit cost curve of good Y is given by YY', because the technologies to produce good Y are identical between North and South. The permit price and the wage rate are determined at point B in North and at point B' in South. Since $X^*X^{*\prime}$ is always located below XX' with Assumption 4, $r > r^*$ always holds.[21]

[21] One may think it somewhat weird that North's wage rate is lower than South's wage rate. However, when labor is measured by efficiency units, North worker could earn higher wage if workers are more efficient in North than in South.

Under international emission trading, therefore, North imports the permit from South. The output of good X increases but that of good Y decreases in North, and vice versa in South. Trade in permits continues until South is completely specialized in good Y. Once South completely specializes in good Y, $X^*X^{*\prime}$ disappears and South's permit price and wage rate become equal to North's. That is, South is completely specialized in good Y and North is diversified in equilibrium under international emission trading. Even if South exports good X without international emission trading, the emission trading leads South to import good X from North.

Thus, we obtain

Proposition 6 *Suppose that international trade in emission permits is allowed. Then South is completely specialized in good Y by exporting permits to North.*

We next examine how international emission trading affects the outputs. Letting $\Delta Z(>0)$ denote the traded permits, we obtain the following relations:

$$\begin{aligned} e_X \Delta X + e_Y \Delta Y &= \Delta Z, \\ e_X^* \Delta X^* + e_Y \Delta Y^* &= -\Delta Z, \end{aligned}$$

where ΔX and ΔY are, respectively, the change in the output of good X and that of good Y. Since $\Delta Y = -(a_X/a_Y)\Delta X$, we have

$$\Delta X = \frac{\Delta Z}{e_X - e_Y \frac{a_X}{a_Y}}, \Delta X^* = \frac{-\Delta Z}{e_X^* - e_Y \frac{a_X^*}{a_Y}}.$$

By noting that $e_X < e_X^*$, $a_X < a_X^*$, and $(e_X/e_Y) - (a_X/a_Y) > 0$ hold, $\Delta X + \Delta X^* > 0$ holds if and only if $(e_X/e_Y) - (a_X/a_Y) < (e_X^*/e_Y) - (a_X^*/a_Y)$. This condition is likely to hold when e_X^* is sufficiently large relative to e_X and/or a_X^* is not very large relative to a_X. In other words, international emission trading is more likely to increase the world output of good X as South's emission intensity increases.

Similarly, we obtain

$$\Delta Y = \frac{\Delta Z}{e_Y - a_Y \frac{e_X}{a_X}}, \Delta Y^* = \frac{-\Delta Z}{e_Y - a_Y \frac{e_X^*}{a_X^*}}.$$

Noting Assumption 1, we have $\Delta Y + \Delta Y^* < 0$ if and only if $(e_X/a_X) < (e_X^*/a_X^*)$, which is again likely to hold when e_X^* is sufficiently large relative to e_X and/or a_X^* is not very large relative to a_X.

In Figure 6, the world relative supply curve is given by OMK^WS^W. Figure 6 (a) shows a case where K^WS^W is located to the left of $K^{*T}S^T$, while Figure 6 (b) illustrates a case where K^WS^W is located to the right of $K^{*T}S^T$.[22] When both emission quotas are binding before international emission trading, $p^W \geq p_A^*$ holds (i.e., the relative demand curve intersects $K^TM^TK^{*T}S^T$ on $K^{*T}S^T$). Therefore, international emission trading lowers the world price of good X if and only if K^WS^W is located to the right of $K^{*T}S^T$ in Figure 6. Noting that South is completely specialized in good Y and and North is diversified under international emission trading, we can claim that K^WS^W is located to the right of $K^{*T}S^T$ if and only if the following condition holds:

$$\left(\frac{X+X^*}{Y+Y^*}\right)_{K^{*T}S^T} \equiv \frac{\frac{Za_Y - Le_Y}{e_Xa_Y - e_Ya_X} + \frac{Z^*a_Y - L^*e_Y}{e_X^*a_Y - e_Ya_X^*}}{\frac{Le_X - Za_X}{e_Xa_Y - e_Ya_X} + \frac{L^*e_X^* - Z^*a_X^*}{e_X^*a_Y - e_Ya_X^*}}$$
$$< \frac{\frac{\widetilde{Z}a_Y - Le_Y}{e_Xa_Y - e_Ya_X}}{\frac{Le_X - \widetilde{Z}a_X}{e_Xa_Y - e_Ya_X} + \frac{L^*}{a_Y}} \equiv \left(\frac{X+X^*}{Y+Y^*}\right)_{K^WS^W}$$

where $\widetilde{Z} \equiv Z + Z^* - (L^*e_Y/a_Y)$. This condition is more likely to be satisfied when e_X^* is sufficiently large relative to e_X and/or a_X^* is not very large relative to a_X.

Thus, the following lemma is established:

Lemma 2 *International emission trading between North and South lowers the world price of good X if and only if* $\left(\frac{X+X^*}{Y+Y^*}\right)_{K^{*T}S^T} < \left(\frac{X+X^*}{Y+Y^*}\right)_{K^WS^W}$.

Next, we examine the impact of international emission trading on welfare. International emission trading changes the world outputs of goods X and Y, which affects the TOT for goods. Since all permits are used with and without international emission trading, however, international trade in permits does not affect world total GHG emissions.

[22] K^WS^W is necessarily located to the right of K^TM^T.

We can show[23]

$$E(1, p_1^W, u_1) - E(1, p_1^W, u_0) \geq (p_1^W - p_0^W)(X_0 - X_0^c),$$

where E is the expenditure function. Subscripts 0 and 1, respectively, denote the equilibrium before and after international emission trading. $u_1 > u_0$ holds if $(p_1^W - p_0^W)(X_0 - X_0^c) > 0$. When free trade in goods has already been established, the welfare effect of international emission trading crucially depends on the TOT for goods. For example, if North exports good X without international emission trading, i.e., with $X_0 > X_0^c$, North (South) benefits from international emission trading if p^W rises (falls). We should mention that trade in permits improves global efficiency, but both countries may not gain.[24]

The above analysis establishes the following proposition:

Proposition 7 *Suppose that international trade in emission permits does not change the pattern of trade in goods (i.e., North exports good X without trade in permits). Then if the world price of good X rises (falls), North (South) gains from international emission trading but South (North) may lose. Suppose that international trade in emission permits changes the pattern of trade in goods (i.e., North exports good Y without trade in permits). Then if the world price of good X rises (falls), South (North) gains from international emission trading but North (South) may lose.*

5 Conclusion

We explored domestic emission trading and international emission trading between the developed country (North) and the developing country (South). To this end, a simple two-country, two-good, general equilibrium model was developed. We first introduced North's emission quota into a Ricardian trade model in which North has a comparative advantage in the emission-intensive good. Then we introduced South's emission quota in the presence of North's emission quota. Finally, we examined international trade in emission permits between the two countries.

[23] The proof is provided in the Appendix. The same condition is found in the case of capital movements (see Grossman, 1984).

[24] In Figure 4, the equilibrium with international emission trading is given by a point between K and M' and hence global efficiency is improved.

We specifically focused on the case in which North can produce the emission-intensive good more efficiently with less emissions. Whereas North's domestic emission trading under free trade in goods may result in carbon leakage by expanding South's production of the emission-intensive good, international emission trading induces North to expand the production of the emission-intensive good by importing emission permits. When only North introduces an emission quota, total world emissions may increase due to carbon leakage. North's emission quota may not benefit South. Similarly, South's emission quota (in the presence of North's quota) may not benefit North. International emission trading generates two effects: the standard gains from trade in emission permits and the changes in the TOT for goods. Although trade in permits improves global efficiency, one country suffers from a deterioration of the TOT. Thus, international emission trading may not benefit both countries.

Final remarks are in order. First, in our analysis, we did not explicitly consider the optimal emission quotas. This is mainly because welfare crucially depends on how the effects of world total GHG emissions are evaluated. If the damage from GHG emissions is highly evaluated, for example, the emission effect dominates the other two effects (the TOT and the PPS effects) and hence tough emission quotas are desirable.

Second, emission regulations may induce firms to circumvent them. When only North introduces regulations, North firms may move to South to avoid burdens.[25] Firms may also have an incentive to abate emissions. In particular, firms may invest in developing new technologies to reduce emissions. Moreover, North firms may have an incentive to transfer their technologies to South in the presence of clean development mechanism. To investigate R&D and technology transfer, however, we need models that explicitly deal with firm behaviors.

Last, it would be interesting to take into account strategic behaviors of two countries. For example, when North introduces its emission quota, it may expect the introduction of South's emission quota and international trade in permits and move strategically. Moreover, even if South loses from South's quota in the presence of North's quota, South may gain by introducing South's quota and international emission trading simultaneously.

[25] Regarding FDI caused by environmental regulations, see Markusen et al. (1993,1995) and Ishikawa and Okubo (2008,2010), for example.

The investigations along the above remarks are left for the future analysis.

References

[1] Abe, K., Y. Sugiyama, and K. Kiyono (2011) "International Transfer, Environmental Policy, and Welfare", forthcoming *Japanese Economic Review.*

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

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

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

[5] ———— and ———- (2005) "Free Trade and Global Warming: A Trade Theory View of the Kyoto Protocol," *Journal of Environmental Economics and Management* 49: 205-34.

[6] 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.

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

[8] Ishikawa J. and K. Kiyono (2006) "Greenhouse-Gas Emission Controls in an Open Economy," *International Economic Review* 47: 431-50.

[9] Ishikawa, J. and T. Okubo (2008) "Greenhouse-gas Emission Controls and International Carbon Leakage through Trade Liberalization," Center for Research on Contemporary Economic Systems Discussion Paper No.3, Hitotsubashi University.

[10] Ishikawa, J. and T. Okubo (2010) "Environmental Product Standards in North-South Trade," Center for Research on Contemporary Economic Systems Discussion Paper No.27, Hitotsubashi University, forthcoming in *Review of Development Economics.*

[11] Jones, R. W. (1980) "Comparative and Absolute Advantage," *Swiss Journal of Economics* 116: 235-260.

[12] ———— (2000) *Globalization and the Theory of Input Trade*, Cambridge Mass., MIT Press.

[13] Kiyono, K. and J. Ishikawa (2010) "Environmental Management Policy under International Carbon Leakage," Hitotsubashi University, mimeo.

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

[15] Markusen, J.R., E.R. Morey and N.D. Olewiler (1993) "Environmental policy when market structure and plant locations are endogenous", *Journal of Environmental Economics and Management* 24, 69–86.

[16] Markusen, J, E. Morey and N. Olewiler (1995) "Competition in regional environmental policies when plant locations are endogenous", *Journal of Public Economics* 56, 55–77.

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

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

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

Appendix: The Welfare Effect of International Emission Trading

From the utility function (2), the welfare effect can be decomposed into two components: the effect on the sub-utility u and that on world total GHG emissions Z^W. In this appendix, we show that the effect of international emission trading on the sub-utility u crucially depends on the TOT.

Using the expenditure function $E(\cdot)$ and the revenue function $R(\cdot)$, we have

$$\begin{aligned}
E(1, p_1^W, u_1) &= R(1, p_1^W, L) - r\Delta Z \\
&\geq Y_0 + p_1^W X_0 \\
&= (Y_0 + p_1^W X_0) + \{(Y_0^c + p_0^W X_0^c) - (Y_0 + p_0^W X_0)\} \\
&+ \{(Y_0^c + p_1^W X_0^c) - (Y_0^c + p_1^W X_0^c)\} \\
&= (Y_0^c + p_1^W X_0^c) + (p_1^W - p_0^W)(X_0 - X_0^c) \\
&\geq E(1, p_1^W, u_0) + (p_1^W - p_0^W)(X_0 - X_0^c)
\end{aligned}$$

where subscripts 0 and 1, respectively, denote the equilibrium before and after international emission trading. Thus, we obtain

$$E(1, p_1^W, u_1) - E(1, p_1^W, u_0) \geq (p_1^W - p_0^W)(X_0 - X_0^c).$$

This implies that trade in emission permits enhances North's welfare if $(p_1^W - p_0^W)(X_0 - X_0^c) > 0$ holds. Similarly, South's welfare improves if $(p_1^W - p_0^W)(X_0^* - X_0^{*c}) > 0$ holds.

Figure 1. Production possibility set

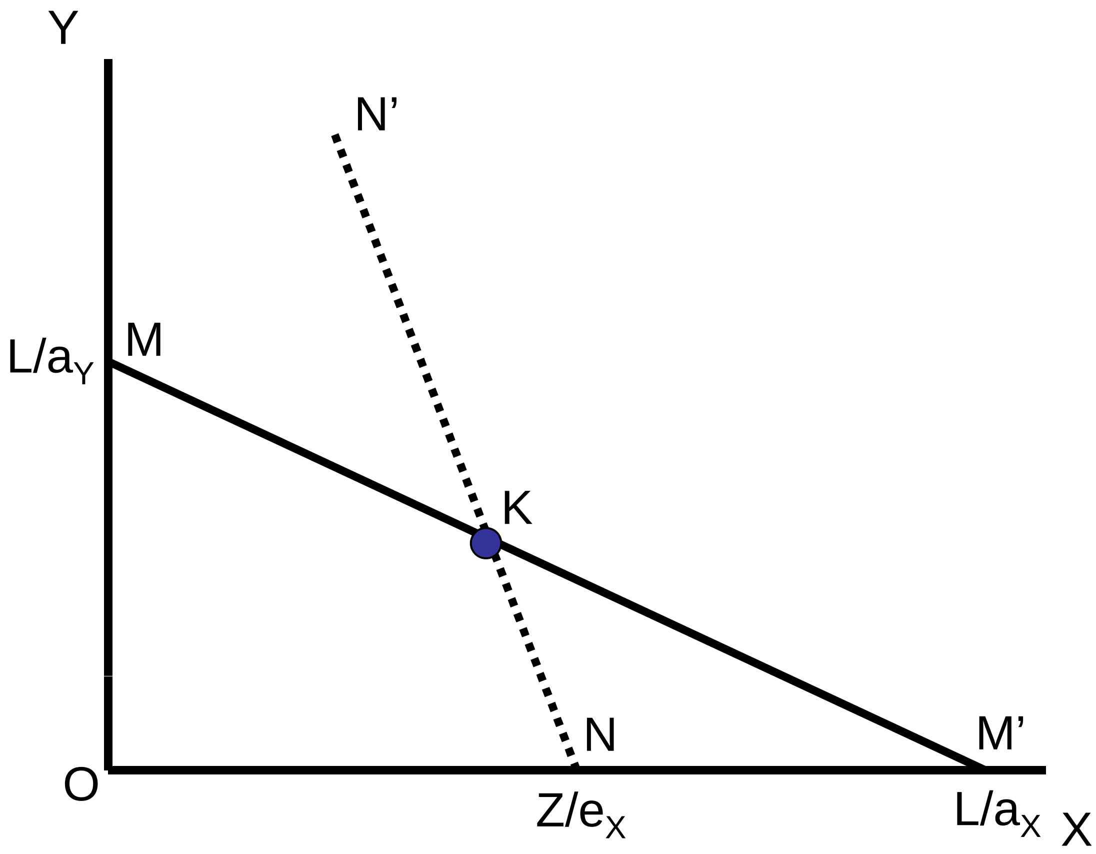

Figure 2. Unit cost curves

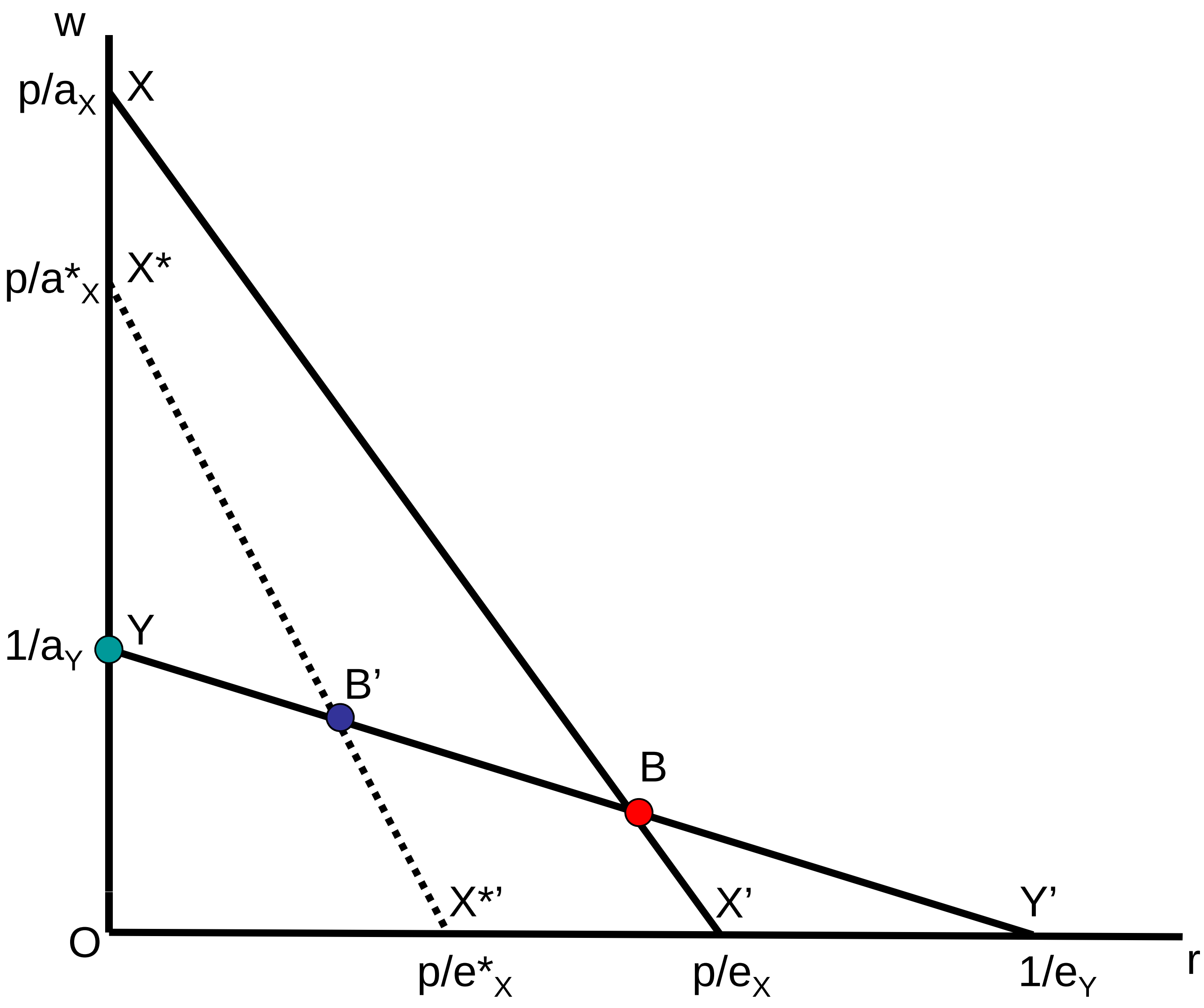

Figure 3. Relative supply and demand curves

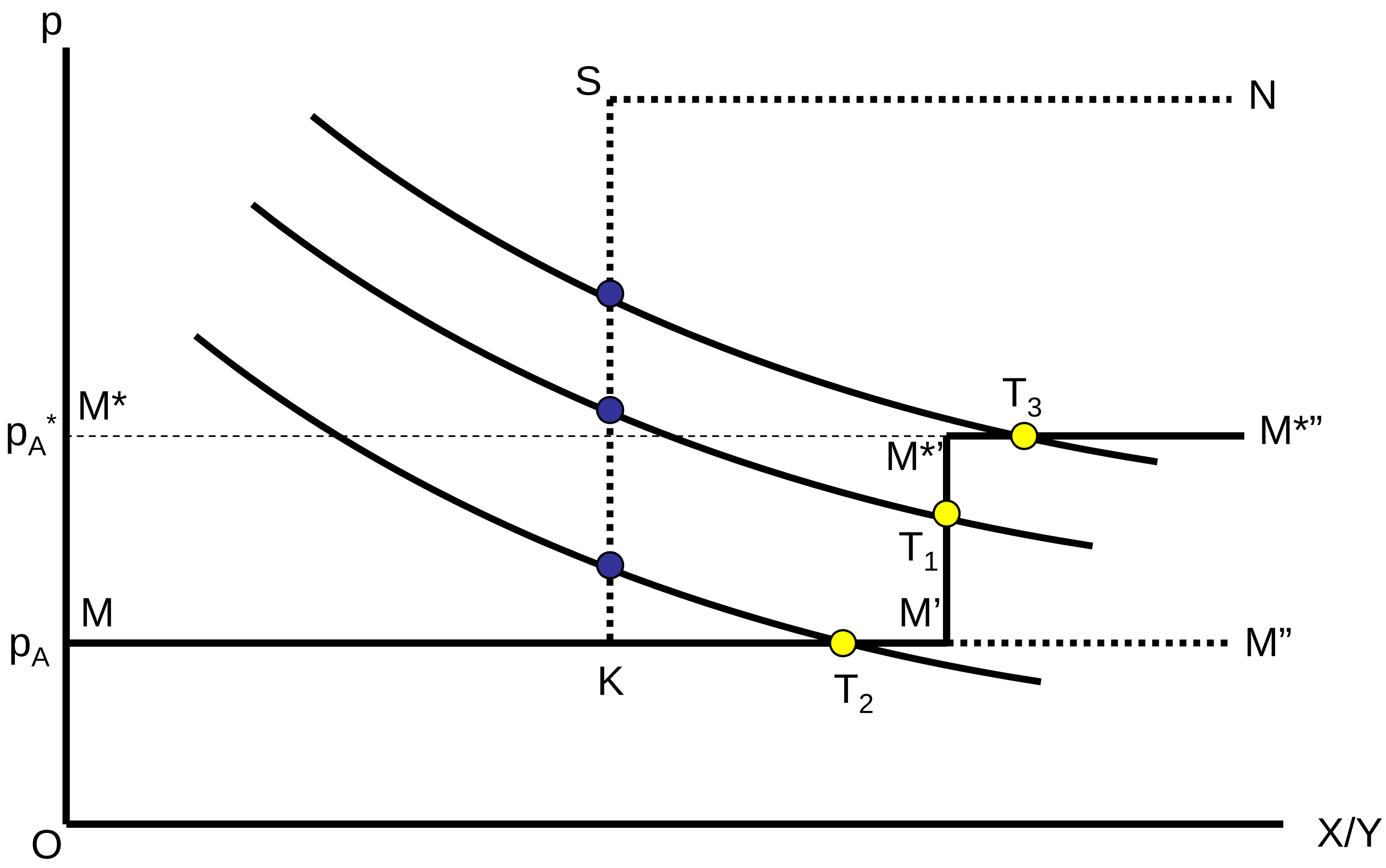

Figure 4. World production possibility frontier

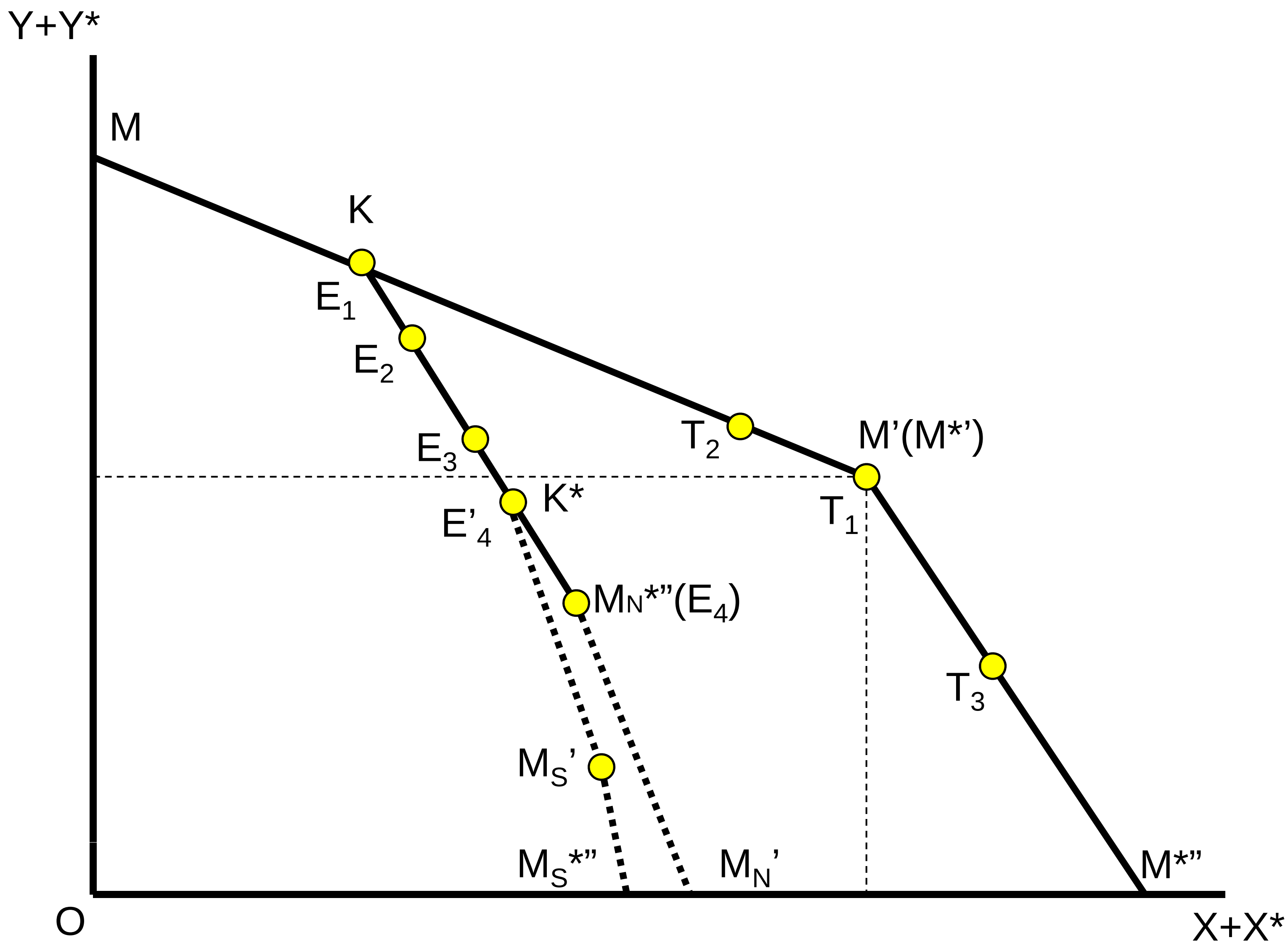

Figure 5 Emission quota only in North

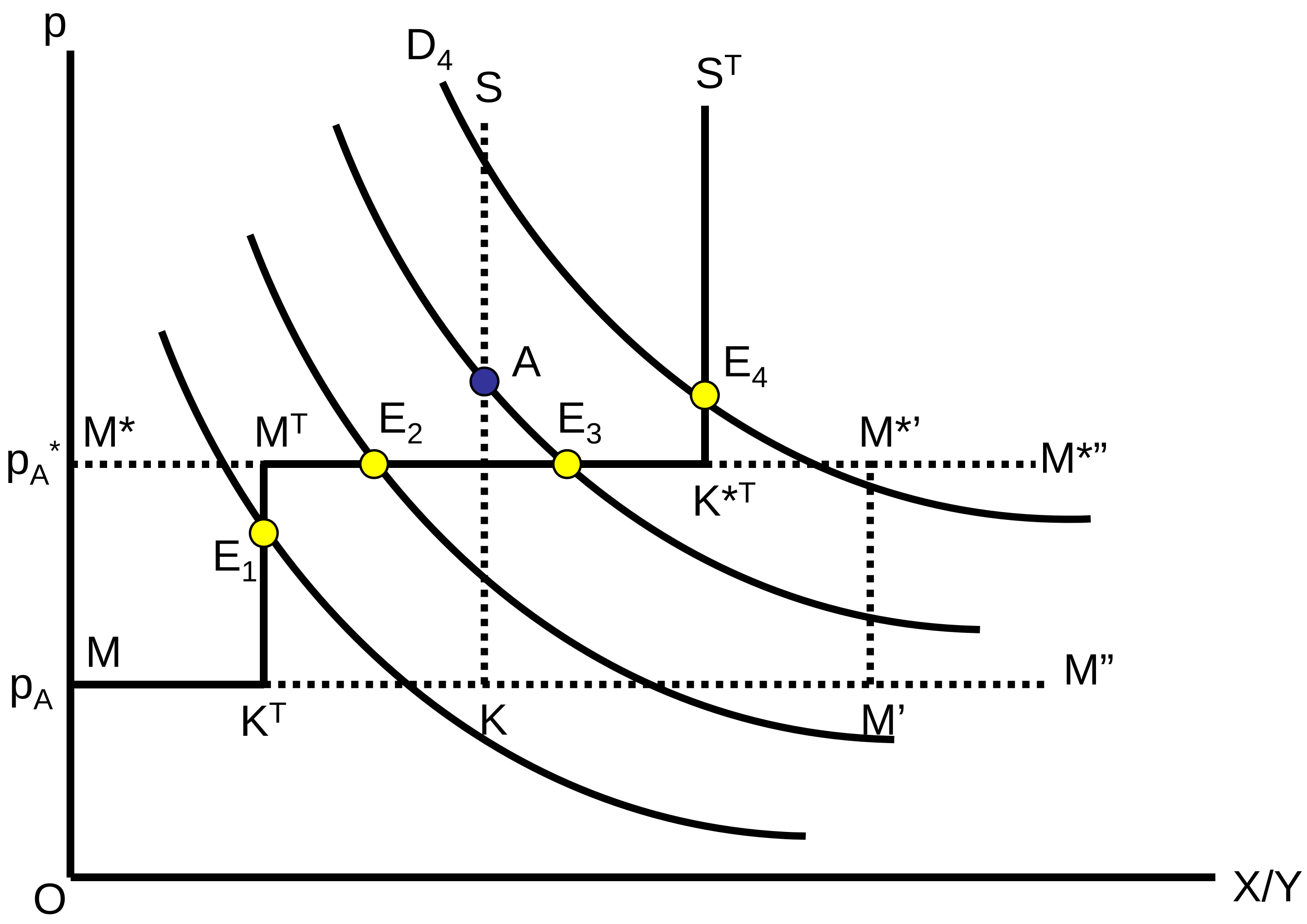

Figure 6 (a) Emission quotas in both countries

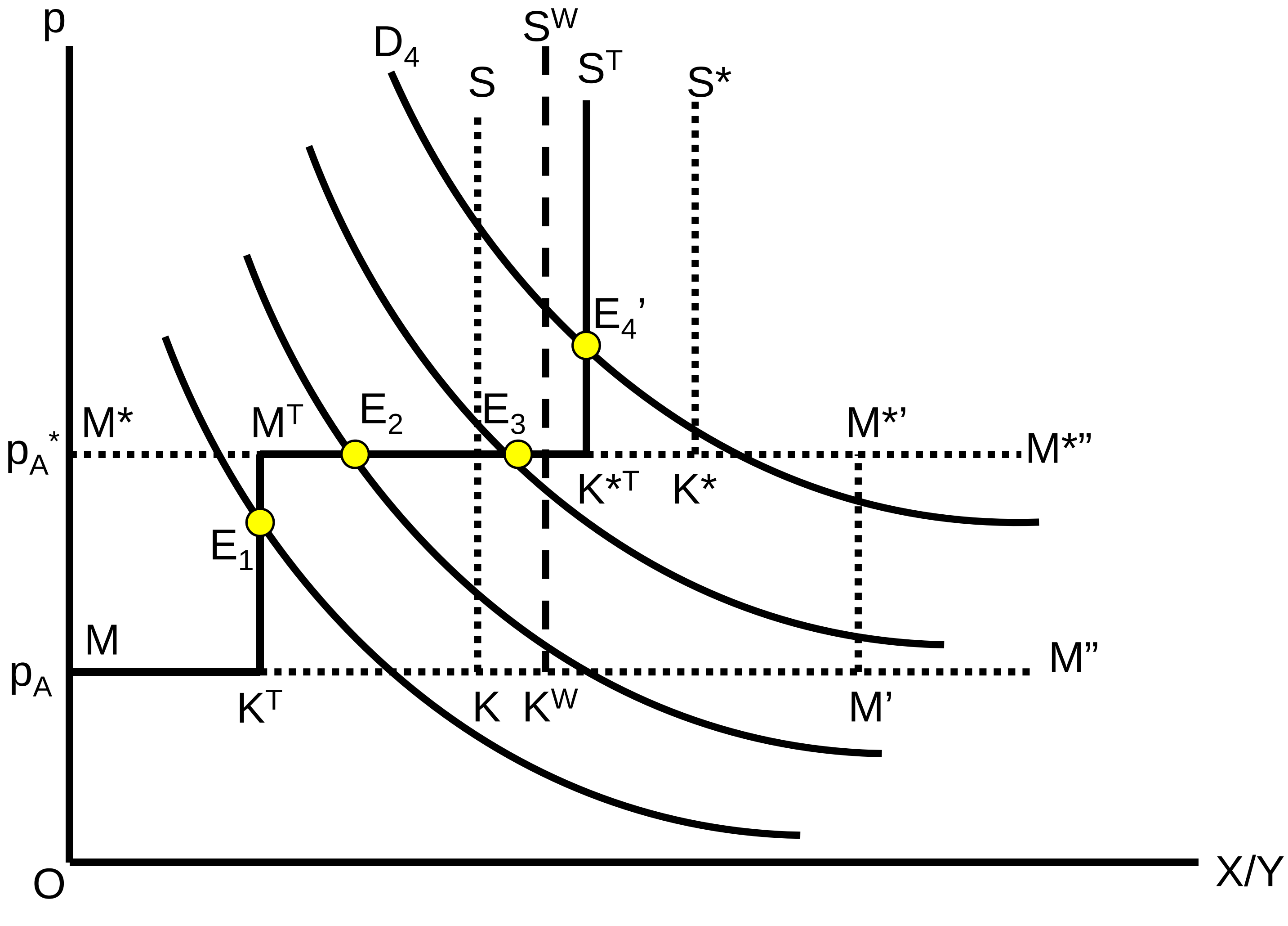

Figure 6 (b) Emission quotas in both countries