Presentation Sheets

The CO_2 Emissions Trading Market System and its Evaluation as an Environmental Policy

— Focusing on the Effect of Intertemporal Trading —

Dr.Kazuya Fujime

Managing Director, The Institute of Energy Economics, Japan (Tokyo)

Tel: 81-3-5547-0211 Fax: 81-3-5547-0223

E-mail: fujime@tky.ieej.or.jp

Section 1: Narrowing the subject scope

The emissions trading system offers the following advantages over the environmental tax system as a cost-effective measure for protecting the environment. The major objective of this paper is to discuss and demonstrate the effects of intertemporal emissions trading.

1) **If emission rights can be traded without limitations, the internationally agreed-upon GHG reduction goals are sure to be attained at minimum emission-reduction cost through market mechanisms (guaranteed achievement of goals).**

2) **If emission rights can be traded without limitations, multi-national (interregional) emissions trading may make it possible to achieve the internationally agreed-upon GHG-reduction goals through market mechanisms at minimum cost (spatial control through international adjustment etc.).**

3) If emission rights can be traded without limitations, intertemporal trading will make it possible to achieve the internationally agreed-upon GHG reduction goals through market mechanisms at minimum cost (intertemporal control).

Section 2: Emissions trading as a means of executing environmental policy

Economic measures can be used to minimize the social cost of environmental protection and sustainable growth. The emissions trading system and taxation systems such as environmental taxes have different effects and functions. Roughly speaking, many Europe nations have adopted environmental taxes, while the United States has adopted the emissions trading approach. However, in Europe, quite a few nations have begun to introduce domestic emissions trading systems in combination with environmental taxes to take advantage of the emissions trading system. The EU has also decided to adopt an intra-EU emissions trading system. Environmental issues, particularly global warming, must be discussed on an international basis, since pollutants emitted from one nation flow across borders and affect other nations.

The Kyoto mechanism is regarded as a flexible measure, implying a mechanism for solving environmental problems with the lowest economic cost based on market principles. To achieve the GHG reduction goals for Annex 1 Countries at minimum cost, we must make the most of the emissions trading system to minimize the gaps between the targeted emission reductions specified in the Kyoto Protocol for each nation and the optimized emission reductions that equalizes individual marginal reduction costs across nations and minimizes overall cost.

The Kyoto Protocol contains a clause that establishes this flexible measure as a supplement to domestic measures. The extent of this supplementarity is not clearly quantified. At COP7 (held in Marrakech), it was decided not to impose quantitative limitations on the degree of this supplementarity, leaving the sense of "supplementarity" ambiguous. In terms of time flexibility, "banking" is limited to a set period of time. "Borrowing" is generally not permitted.

Section 3: Emissions trading mechanism

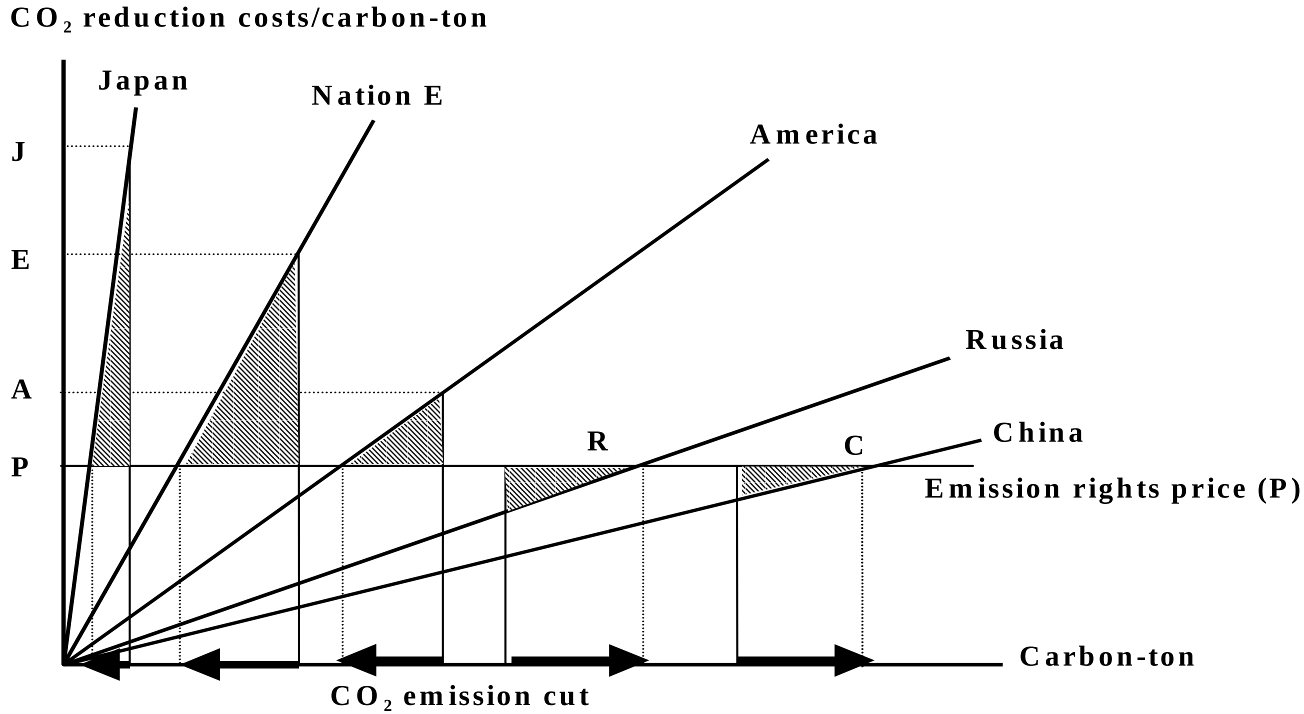
Fig.1 Global trading of emission rights–emissions trading construed in the broadest sense (Kyoto Mechanism)

- **Trading in emission rights construed in the narrow sense; i.e., remaining allowable emissions after goals are achieved**
  (among the Annex 1 Countries)

- **Cooperative trading in emission-reduction credits**
  (among the Annex 1 Countries)

- **Trading in emission-reduction credits within the clean development mechanism**
  (among the Annex 1 Countries as well as the Non-Annex 1 Countries / developing countries)

Fig.2 Marginal emission-reduction cost curves for the five major nations and emission rights prices



X=Economic surplus (Emission-rights import nation)

Y=Economic surplus (Emission-rights export nation)

J (Marginal cost (MC) of Japan)> E (MC of Country E) > A (MC of America) > P (Emission rights cost) = R (MC of Russia) = C (MC of China)

J: marginal emission-reduction cost for Japan

E: marginal emission-reduction cost for nation E

A: marginal emission-reduction cost for America

R: marginal emission-reduction cost for Russia

C: marginal emission-reduction cost for China

P: Emission rights price

X: Economic surplus = Hatched area above P, Y: Economic surplus = Hatched area below P

Section 4: Flexibility in the emissions trading market

The primary role of the emissions trading market is to internalize external costs of preventing global warming and to cut CO_2 most efficiently to achieve the established goals, that is, to equalize CO_2 marginal emission-reduction costs across regions and time periods. The flexible trading of emission rights in two realms (time and space) offers the potential for minimizing the global cost of reducing CO_2 emissions.

The second type of system flexibility is time flexibility, which permits trade in emission rights on an intertemporal basis. Banking (carrying over) of emission rights is one tool of the intertemporal trading system. If one believes that certain technological advances will significantly reduce emission-reduction costs, along with the value of emission rights, one may choose to borrow emission rights, and cut emissions or buy emission rights in the future, rather than cutting CO_2 emissions in the present. The CO_2 reduction cost (cost of achieving the goal) declines as the time flexibility in the emission rights market grows through intertemporal trading.

Section 5: Estimated effects of intertemporal emissions trading

(1) Total cost reductions in a two-nation, two-period trading model and optimal solution

Broadly speaking, emission rights can be traded among many nations and many periods of time. In this paper, we will clarify the essence of the emissions trading system by simulations based on a highly simplified two-nation, two-period trading model. In these simulations, the commodity traded is called emission rights. The theory underlying the model can show that emissions trading will narrow the gap between the politically determined goal set by international negotiations and the optimal solution (optimized emission reduction).

The following equations express two-nation, two-period trading and the solution providing the lowest emission-reduction costs:

x_1^1 = **Optimized emission reductions for the first nation for the first period**
x_1^2 = **Optimized emission reductions for the first nation for the second period**
x_2^1 = **Optimized emission reductions for the second nation for the first period**
x_2^2 = **Optimized emission reductions for the second nation for the second period**

x_{10}^1 = **CO_2 targeted emission reductions for the first nation for the first period**
x_{10}^2 = **CO_2 targeted emission reductions for the first nation for the second period**
x_{20}^1 = **CO_2 targeted emission reductions for the second nation for the first period**
x_{20}^2 = **CO_2 targeted emission reductions for the second nation for the second period**

$x^*{}_1{}^1$ = Volume of emissions trading for the first nation for the first period

If $x_1{}^1 - x_{10}{}^1 > 0$, emission rights are sold or deposited by $x^*{}_1{}^1$;

If $x_1{}^1 - x_{10}{}^1 < 0$, emission rights are purchased or borrowed by $x^*{}_1{}^1$;

If $x_1{}^1 - x_{10}{}^1 = 0$, no trading occurs.

$x^*{}_1{}^2$ = Volume of emissions trading for the first nation for the second period

If $x_1{}^2 - x_{10}{}^2 > 0$, emission rights are sold or deposited by $x^*{}_1{}^2$;

If $x_1{}^2 - x_{10}{}^2 < 0$, emission rights are purchased or borrowed by $x^*{}_1{}^2$;

If $x_1{}^2 - x_{10}{}^2 = 0$, no trading occurs.

$x^*{}_2^1$ = Volume of emissions trading for the second nation for the first period

If $x_2^1 - x_{20}^1 > 0$, emission rights are sold or deposited by $x^*{}_2^1$;

If $x_2^1 - x_{20}^1 < 0$, emission rights are purchased or borrowed by $x^*{}_2^1$;

If $x_2^1 - x_{20}^1 = 0$, no trading occurs.

$x^*{}_2^2$ = Volume of emissions trading for the second nation for the second period

If $x_2^2 - x_{20}^2 > 0$, emission rights are sold or deposited by $x^*{}_2^2$;

If $x_2^2 - x_{20}^2 < 0$, emission rights are purchased or borrowed by $x^*{}_2^2$;

If $x_2^2 - x_{20}^2 = 0$, no trading occurs.

$y_1^i = ax_1^i$ marginal emission-reduction cost curve for the first nation for i-th period, i=1, 2;

$y_2^i = bx_2^i$ marginal emission-reduction cost curve for the second nation for i-th period, i=1, 2;

Y_1^i = Total emission-reduction cost for the first nation for i-th period, i=1, 2

Y_2^i = Total emission-reduction cost for the second nation for i-th period, i=1, 2

$Y_1 = \sum Y_1^i$: Total emission-reduction cost for the first nation over all periods, i=1, 2;

$Y_2 = \sum Y_2^i$: Total emission-reduction cost for the second nation over all periods, i=1, 2;

$Y = Y_1 + Y_2$: Total emission-reduction cost for the world over all periods

Min Y must meet the requirement:

$$\sum_{i=1}^{2}\sum_{j=1}^{2} x_i^j = x_1^1+x_1^2+x_2^1+x_2^2 = x_{10}^1+x_{10}^2+x_{20}^1+x_{20}^2=\alpha$$

Lagrange's equation is then given by:

$$L\ (x_1^1 \cdots x_2^2, \lambda) = Y + \lambda\,(\alpha - x_1^1 - x_1^2 - x_2^1 - x_2^2)$$

where λ is the equalized marginal emission-reduction cost (balanced value).

Partial differentiation of L by x_1^1, x_1^2, x_2^1, x_2^2 and λ yields the following, where CDR is a composite discount rate.

$$\frac{\partial L}{\partial x_1^1} = \mathbf{a}\, x_1^1 - \lambda = 0 \quad \textbf{(1)} \qquad \frac{\partial L}{\partial x_1^2} = \mathbf{a}\, x_1^2\ \mathbf{(CDR)} - \lambda = 0 \quad \textbf{(2)}$$

$$\frac{\partial L}{\partial x_2^1} = \mathbf{b}\, x_2^1 - \lambda = 0 \quad \textbf{(3)} \qquad \frac{\partial L}{\partial x_2^2} = \mathbf{b}\, x_2^2\ \mathbf{(CDR)} - \lambda = 0 \quad \textbf{(4)}$$

$$\frac{\partial L}{\partial \lambda} = \alpha - x_1^1 - x_1^2 - x_2^1 - x_2^2 = 0 \quad \textbf{(5)}$$

x_1^1 = **λ/a** $\qquad x_1^2$ = **λ/a (CDR)**

x_2^1 = **λ/b** $\qquad x_2^2$ = **λ/b (CDR)**

Substituting the above into Eq. (5),

$$\lambda = \frac{\alpha}{(\frac{1}{a}+\frac{1}{b})(1+\frac{1}{(CDR)})} \quad \textbf{(6)}$$

Then,

$$x_1^1 = \lambda/a = \underline{\alpha/\ (1+\ (a/b))\ (\ (1+1/\ (CDR))}$$

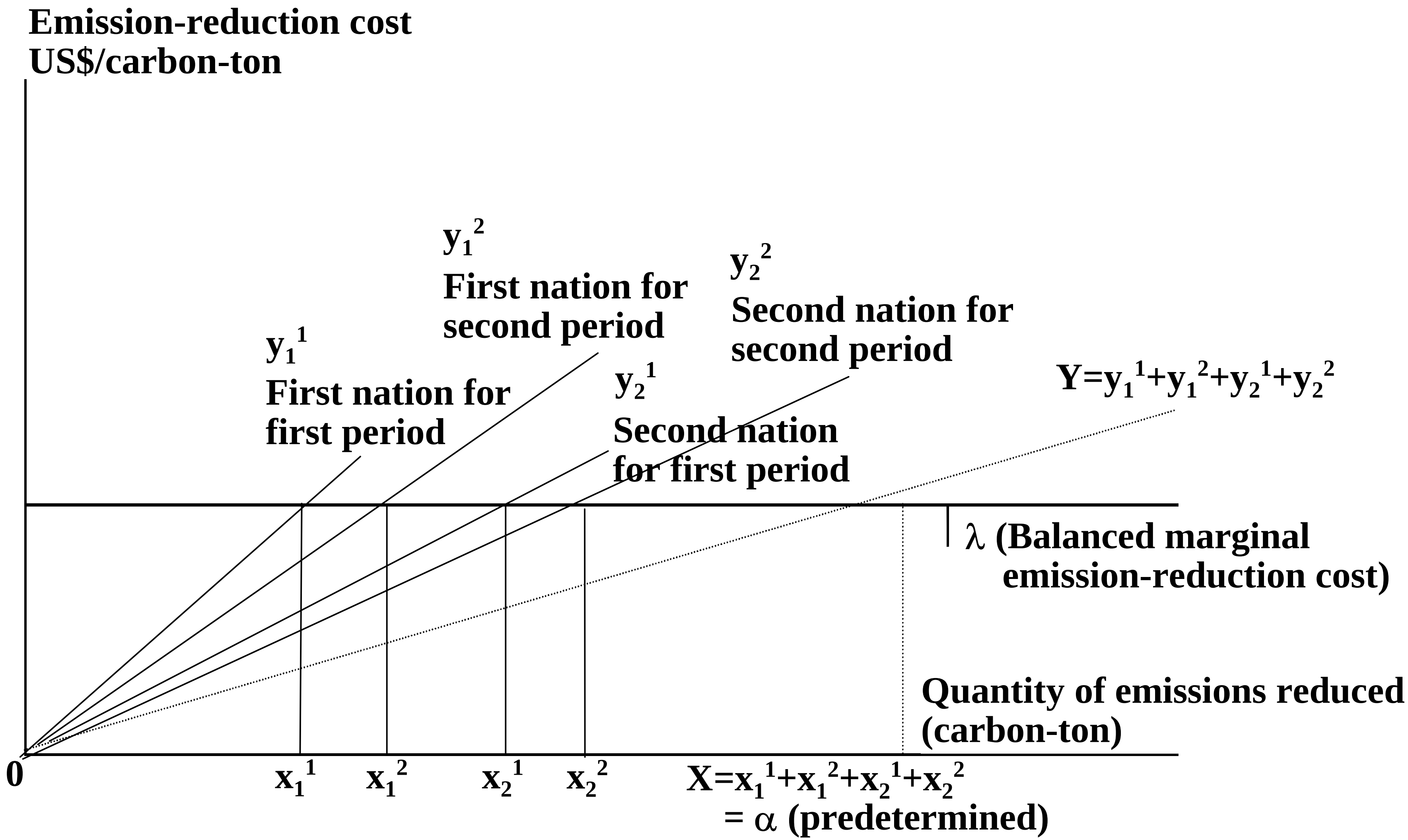
$$x_1^2 = \lambda/a\ (CDR) = \underline{\alpha/\ (1+\ (a/b))\ (1+\ (CDR))}$$

$$x_2^1 = \lambda/b = \underline{\alpha/\ (1+\ (b/a))\ (1+1/\ (CDR))}$$

$$x_2^2 = \lambda/b\ (CDR) = \underline{\alpha/\ (1+\ (b/a))\ (1+\ (CDR))}$$

Figure 3 illustrates the optimized balancing results obtained above.

Fig.3 Optimized emission reductions and equalized marginal emission-reduction cost (balanced value) provided by the two-nation, two-period model



For this optimized balancing calculation, Y (total emission-reduction cost for the world over all periods) is given by:

$$Y = Y_1^1 + Y_1^2 + Y_2^1 + Y_2^2$$

$$Y_1^1 = a\,(x_1^1)\,(x_1^1)/2 = a\,(x_1^1)^2/2$$

$$Y_1^2 = a\,(CDR)\,(x_1^2)\,(x_1^2)/2 = a\,(CDR)\,(x_1^2)^2/2$$

$$Y_2^1 = b\,(x_2^1)\,(x_2^1)/2 = b\,(x_2^1)^2/2$$

$$Y_2^2 = b\,(CDR)\,(x_2^2)\,(x_2^2)/2 = b\,(CDR)\,(x_2^2)^2/2$$

$Y = \alpha\lambda/2$ (the area of a triangle with base α and height λ)

From Eq. (6),

$$Y = \alpha\ \{\alpha / \left(\frac{1}{a} + \frac{1}{b}\right) \left(1 + \frac{1}{(CDR)}\right)\}\ /2 = (\alpha^2/2) / \left(\frac{1}{a} + \frac{1}{b}\right) \left(1 + \frac{1}{(CDR)}\right)$$

As shown above, the amount of emission rights traded by each nation for each period, $x^{*}{}_i^t$ (i=1, 2; t=1, 2) can be easily calculated. The total sum, $\sum\sum x^{*}{}_i^t$, is zero under the above conditions. There is no need to meet any further requirements for calculation. For instance, in the case of the first example in this Section, $x^{*}{}_1^1= (x_{10}^2-x_1^2)+ (x_{20}^1-x_2^1)+ (x_{20}^2-x_2^2)>0$ and $x^{*}{}_1^2=x_1^2-x_{10}^2<0$, $x^{*}{}_2^1=x_2^1-x_{20}^1<0$, $x^{*}{}_2^2=x_2^2-x_{20}^2<0$. A third party will purchase the surplus emission reductions of a nation for a single period.

This model assumes that the four economic entities (the first nation in the first period, the first nation in the second period, the second nation in the first period, and the second nation in the second period) are given individual goals for emission reductions, which are determined by an external party. These economic entities then assume that the emission right prices are predetermined, and either buy or sell emission rights, depending on the price. This model provides λ = emission rights price (marginal cost =) as the general balanced solution resulting from trading.

(2) Composite discount rate

We cannot treat intertemporal trading as a simple analogy to spatial trading for emission reductions because it is affected by interest rates, advances in technology, declines in CO_2 absorption capacity, or the increasing price of emission rights. Condition changes accompanying the lapse of time, absent from spatial trading, must be taken into account.

We consider the following to be major factors that may affect intertemporal trading:

Rate of emission rights price rise (%/year): p

Interest rate (%/year): r

Rate of technological improvement (%/year): t

Rate of CO_2 absorption capacity decrease (Decrease in the CO_2 absorption capacity of the sea and other natural elements) (%/year): s

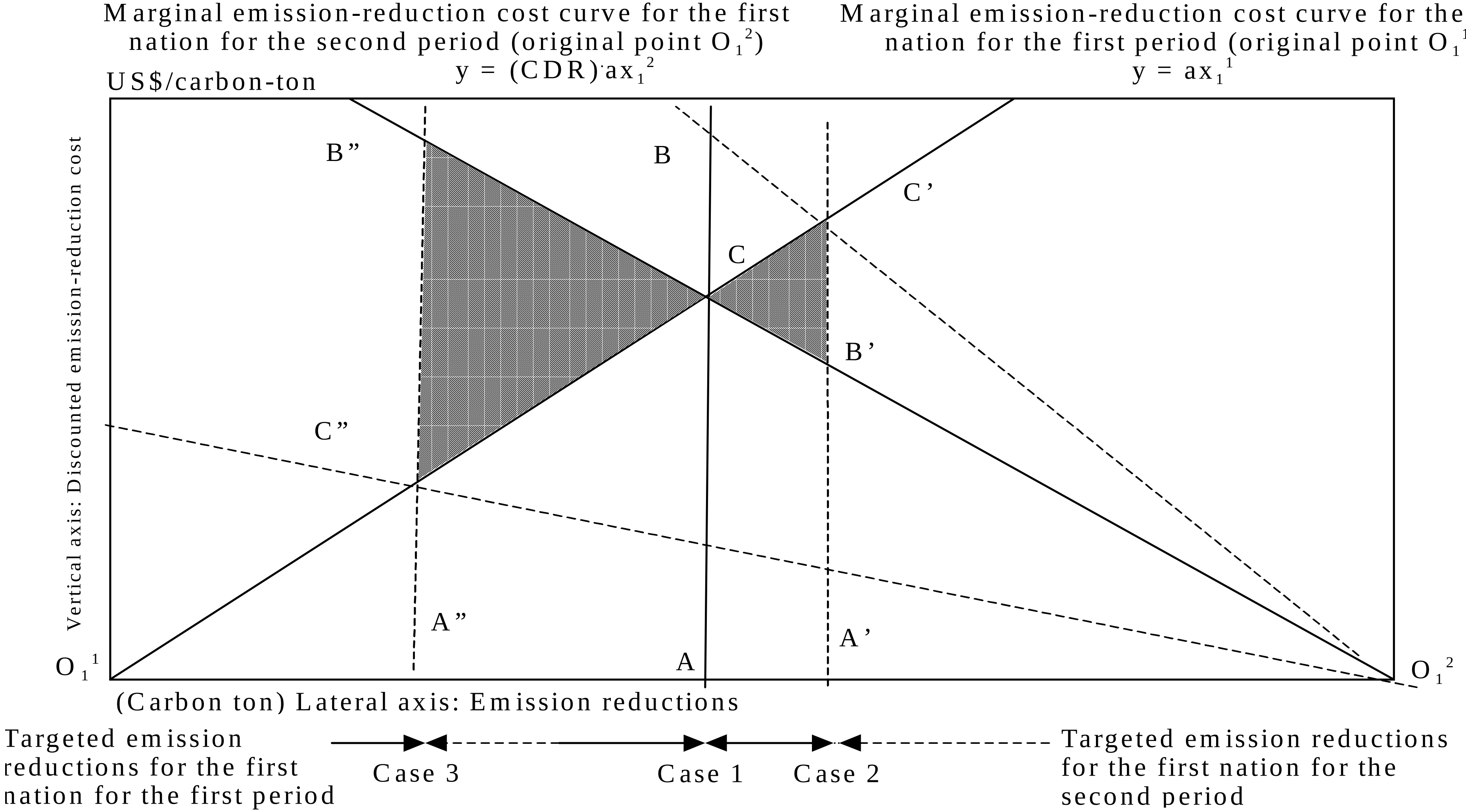
We express the composite discount rate with CDR and assume that intertemporal trading will occur over as many as *n* years. The factors *p* and *s* would encourage banking, while *r* and *t* would discourage banking. These factors have the reverse effects with respect to borrowing. The relationship between CDR in the *n*-th year and the above four factors is given below:

$$CDR_n = \frac{(1+p)^n(1+s)^n}{(1+r)^n(1+t)^n}$$

(3) Emission-reduction cost savings from intertemporal trading

Figure 13 is an example of reducing emission-reduction costs by intertemporal trading, analogous to spatial trading. A single diagram indicates whether the composite discount rate is larger, smaller, or equal to 1, and whether banking or borrowing occurs across two periods of time; if none of these factors is met, no trading occurs. This illustrates intertemporal trading within a single economic entity (region). Intertemporal trading across different economic entities (regions) is not described in Fig.13. Fig.14 illustrates intertemporal trading between different regions. With respect to the format of intertemporal trading between two nations for two periods of time, there can be trades over the first and second periods within the same economic entity (nation) and between different economic entities (nations). Now the optimized emission reductions by intertemporal trading for narrowing the gap between the optimal solution for each case and its goal, equalized marginal emission-reduction cost and requirements for banking, borrowing and balancing, are expressed by predetermined total CO_2 -emission reductions (α), composite discount rate (CDR), and gradients (a, b) of the marginal emission- reduction costs.

Fig.4 Example of emission-reduction cost savings by intertemporal emissions trading (Between two nations over two periods – No.1): First nation, first period x first nation, second period



Emissions trading between the first nation for the first period and the first nation for the second period can be described as follows, where x_2^1 is the optimized emission reduction for the second nation for the first period, x_{20}^2 is the targeted emission reduction for the second nation for the first period, x_2^2 is the optimized emission reduction for the second nation for the second period, x_{20}^2 is the targeted emission reduction for the second nation for the second period, α is the targeted total emission reduction (predetermined), $x_2^1=x_{20}^1, x_2^2=x_{20}^2$, and $\alpha-(x_{20}^1+x_{20}^2)=O_1^1O_1^2$.

Now suppose that the marginal emission-reduction cost curve for the first nation for the first period is expressed by $y=ax_1^1$ while that for the first nation for the second period is expressed by $y=(CDR)\ ax_1^2$. The economic entity trading emission rights is the world energy industry. When the emission rights of the first nation for the first period is traded (whether banking or borrowing, as determined by this entity), the optimized balancing condition for this trading is $ax_1^1=(CDR)\ ax_1^2$.

Case 1: CDR=1

The optimized emission reductions for the first nation for the first period is given by $x_1^1=O_1^1A$, while that for the first nation for the second period is given by $x_2^2=O_1^2A$. If the targeted emission reductions in the first nation for the first period (x_{10}^1) is O_1^1A and that in the first nation for the second period (x_{10}^2) is O_1^2A, no trade occurs, because $O_1^1A=O_1^2A$.

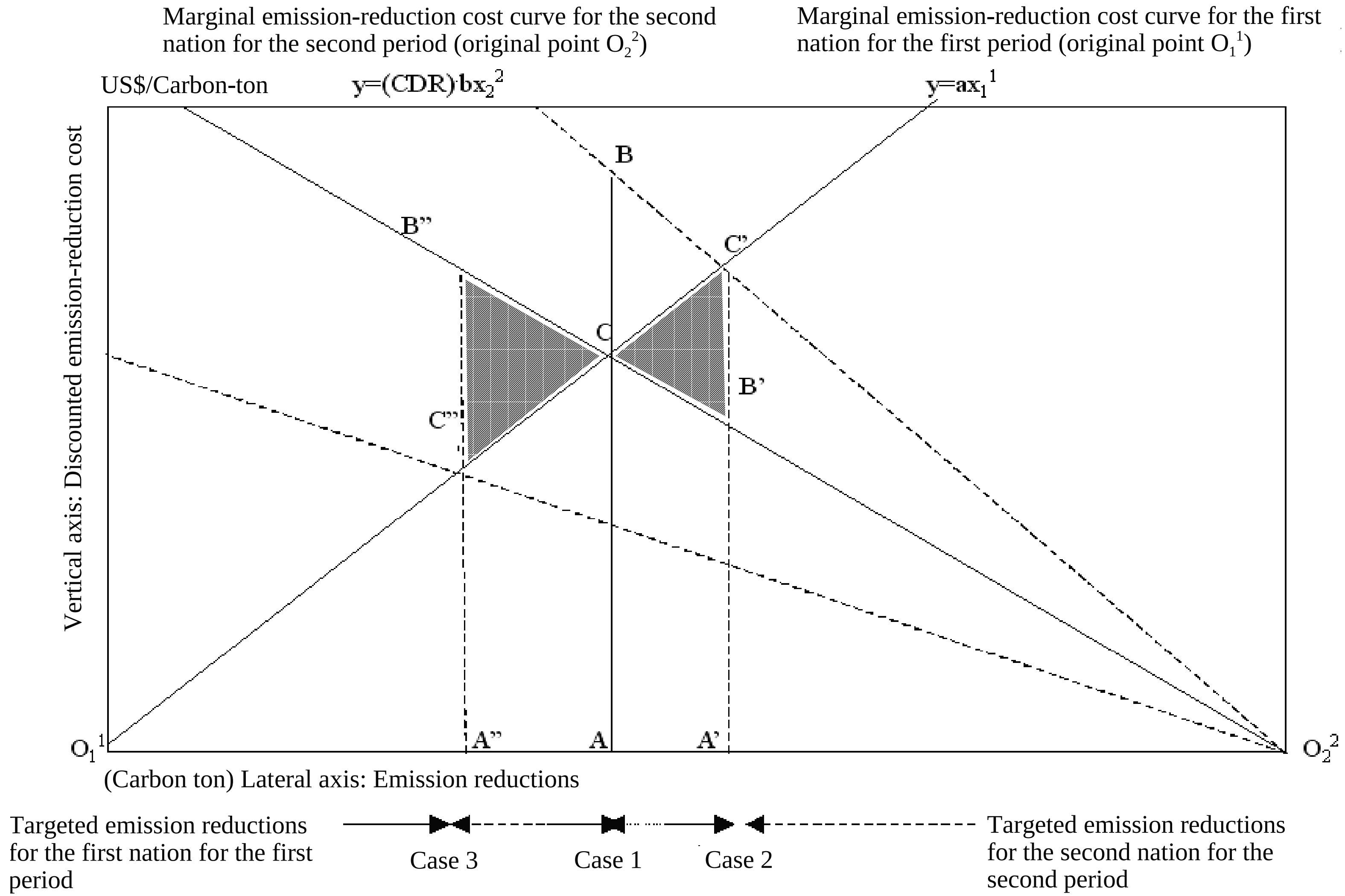
Case 2: CDR>1

If O_1^1A (targeted emission reductions: x_{10}^1) + AA' is reduced by the first nation for the first period and O_1^2A (targeted emission reductions: x_{10}^2) - AA'= O_1^2A' is reduced by the first nation for the second period, and AA' is reserved for banking by the former entity, total cost drops by ΔB'CC' (hatched area).

Case 3: CDR<1

If O_1^1A (targeted emission reductions: x_{10}^1) - AA" = O_1^1A'' is reduced by the first nation for the first period and O_1^2A (targeted emission reductions: x_{10}^2) + AA'' is reduced by the first nation for the second period, and AA" is borrowed by the former entity to offset the shortage, the total cost drops by ΔB"CC" (hatched area).

Fig.5 Example of emission-reduction cost saving by intertemporal emissions trading (Between two nations over two periods – No.2): First nation, first period x second nation, second period



Emissions trading for the first nation for the first period and for the second nation for the second period can be described as follows, where x_1^2 is the optimized emission reduction for the first nation for the second period, x_{10}^2 is the targeted emission reduction for the second nation for the first period, x_2^1 is the optimized emission reduction for the second nation for the first period, x_{20}^1 is the targeted emission reduction for the second nation for the second period, and α is the targeted total emission reductions (predetermined), $x_1^2=x_{10}^2$, $x_2^1=x_{20}^1$, and $\alpha-(x_{10}^2+x_{20}^1)=O_1^1O_2^2$.

Now suppose that the marginal emission-reduction cost curve for the first nation for the first period is expressed by $y=ax_1^1$ while that for the second nation for the second period is expressed by $y= (CDR)bx_2^2$. For trade involving the first nation for the first period, the optimized balancing condition is given by $ax_1^1= (CDR)bx_2^2$.

Case 1: CDR=a/b

The optimized emission reduction for the first nation for the first period is given by $x_1^1 = O_1^1A$, while that for the second nation for the second period is given by $x_2^2 = O_2^2A$. If the targeted emission reduction in the first nation for the first period (x_{10}^1) is O_1^1A and that in the second nation for the second period (x_{20}^2) is O_2^2A, no trade occurs, because $O_1^1A = O_1^2A$.

Case 2: CDR>a/b

If O_1^1A (targeted emission reductions: x_{10}^1) + AA' is reduced by the first nation for the first period and O_2^2A (targeted emission reductions: x_{20}^2) - AA' is reduced by the second nation for the second period, and AA' is reserved for banking by the former entity, the total cost drops by ΔB'CC' (hatched area).

Case 3: CDR<a/b

If $O_1{}^1A$ (targeted emission reductions: $x_{10}{}^1$) - AA"=$O_1{}^1A$" is reduced by the first nation for the first period and $O_1{}^2A$ (targeted emission reductions: $x_{20}{}^2$) + AA" is reduced by the second nation for the second period, and AA" is borrowed by the former entity to offset the shortage, the total cost drops by ΔB"CC" (hatched area).

(4) Simulation of the effects of intertemporal emissions trading

Fig.6 Energy flow in the "world energy industry – emissions trading model" and flow of calculation of emission-reduction cost

This figure demonstrates energy flow from production to sale in the world energy industry; CO_2 emission reductions and emission-reduction costs.

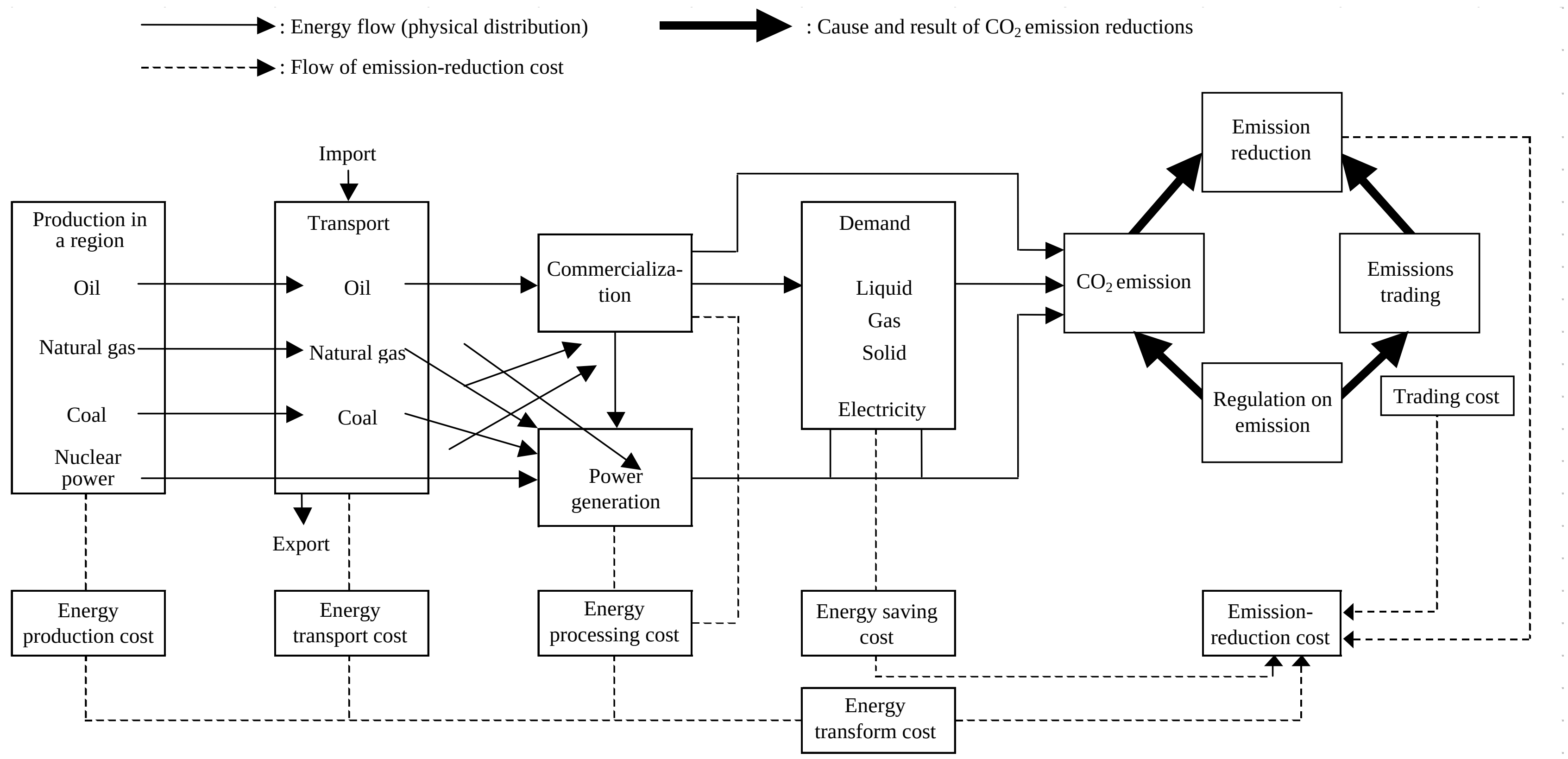


Table1. Structure of the world energy industry--emissions trading model (Linear programming matrix)

					1	2	3	4	5	6	7	8	9
				Definition of variables	Production of primary energy	Energy production by grade	Energy import/ export	Capacity of the converter	Increase in capacity of the converter	Generated electric power	Final energy demand	Demand control by grade	Amount of traded emission right
	Definition of constraints	Name of constraint	Left term	Name of variables	P (e_1,i,t)	Σ_kP(e_1,i,t,k)	T(e_1,e_2,i,j,t)	CCP(c,i,t)	CCP(c,i,τ)	EL(e_1,i,t)	DM(e_2,dm,i,t)	Σ DC(e_2,dm,i,t,k)	X(i,t,j,τ)
0	System cost	OB (Object function)				CSUP(e_1,i,k)	CT(e_1,e_2,i,j)	CPL(c)				CDC(e_2,dm,i,t,k)	
1	Energy balance	EB (e_1,e_2,i,t)	0	≤	1		Import 1 Export -1	When c ≠ e1 e_1 = Input energy -1 e_2 = Output energy EFF(c, i, t)		e_1 = Input energy -1 e_2 =el= Electric power EFF(e1, i, t)	-1		
2	Constraint governing primary energy production-1	P (e_1,i,t)	0	=	1	-1							
3	Constraint governing primary energy production-2	P (e_1,i,t,k)	SUP(e_1,i,t,k)	≥		1							
4	Constraint governing CO_2 emission	CO_2 (i,t)	CO_2LIM (i,t)	≥	CO_2(e_1,t)		Import CO_2(e_1,e_2,t) Export-CO_2(e_1,e_2,t)						Buy -1 Sell 1
5	Constraint governing converter equipment	CCP(e_2,i,t)	0	=				1	τ=1~t-1				
6	Relation between power generator capacity and power supply	EL (e1,i,t)	0	=				When c = e1 -8760×KD (e1, i, t)		1			
7	Demand and demand control-1	DM(e_2,dm,i,t)	DM(e_2,dm,i,t)	=							1	1	
8	Demand and demand control-2	DM(e_2,dm,i,t,k)	DM(e_2,dm,i,t,k)	≥								1	
9	Lower limit of specific energy in demand	RH(e2,dm,i,t)	0	≤							e2 = Specific energy 1-OWN (e_2, i, t) Other energies -OWN(e_2, i, t)		

Fig.7 Supply curve and demand curve

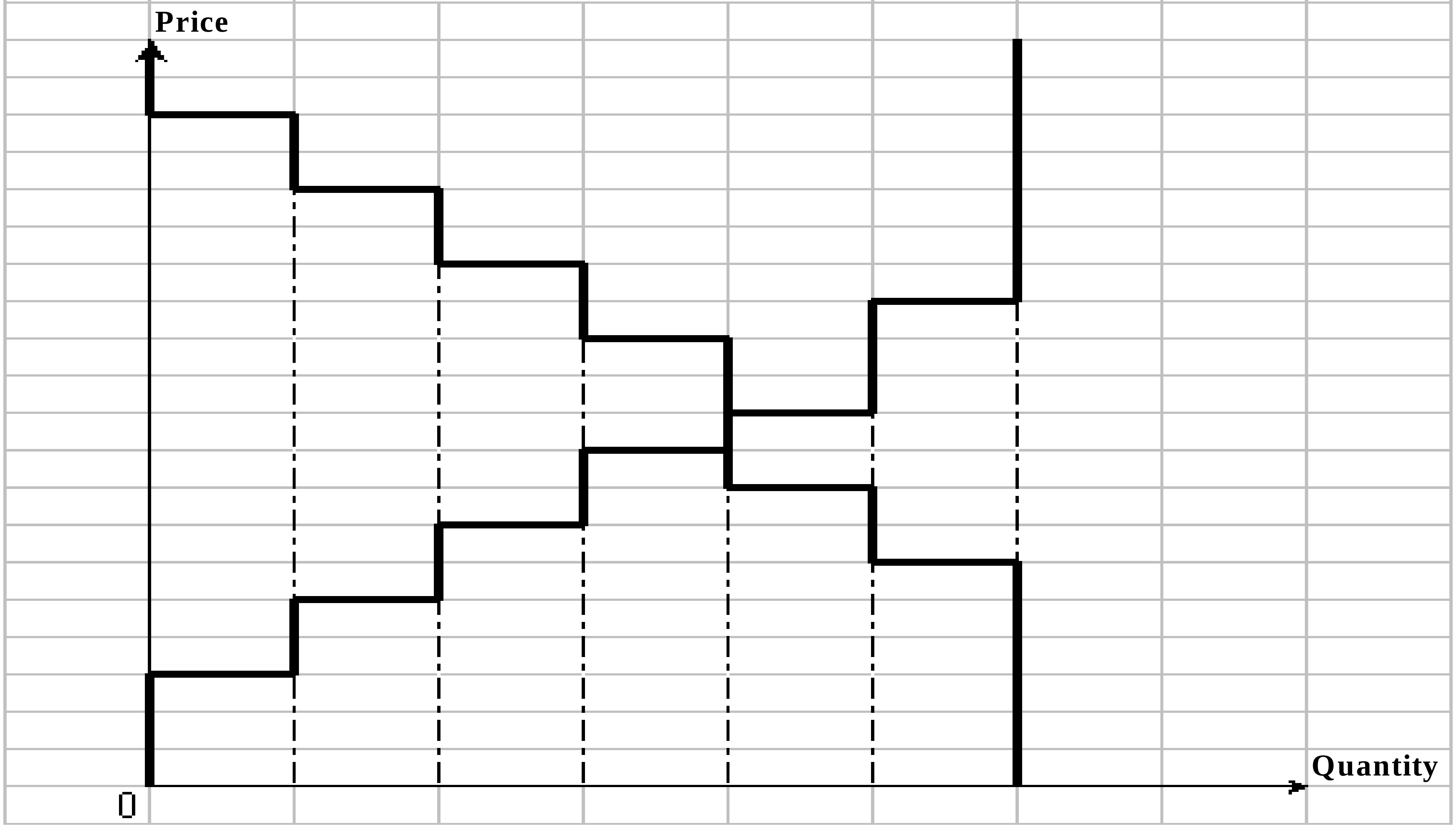


Table 2. Major 4 factors and composite discount rate affecting intertemporal trading

Scenario	4 major factors / Test name	Interest rate (r)	Technology improvement rate (t)	Rate of emission rights price increase (p)	Rate of absorption-capacity decrease(s)	Composite discount rate (CDR_n)
Tightened environmental regulations	Test A	5%	1%	7%	0.4%	$1<CDR_n$
	Test B	7%	1%	2%	0.4%	$1>CDR_n$
Comply with the goals in Kyoto Protocol	Test C (China and India: Upper limits, after 2020)	5%	1%	7%	0.4%	$1<CDR_n$
	Test D	7%	1%	2%	0.4%	$1>CDR_n$
	Test E	5%	2%	–2%	0.4%	$1>CDR_n$
	Test F (US absent, until 2020)	5%	2%	–2%	0.4%	$1>CDR_n$

The simulation considered the test cases listed in Table 7 based on the flowchart of Fig.8 to provide solutions (cost savings).

Fig.8 Case study and cost savings

Case 0: No trading of emission rights
Case 1: No banking or borrowing (only inter-region trading)
Case 2: One period of banking
Case 3: One period of banking and one period of borrowing from another region
Case 4: Free banking and free borrowing

↓ Indicating specifically how the emission-reduction cost changes as restrictions on intertemporal trading are relaxed

Compared to Case 1 involving no intertemporal trading, emission-reduction costs can be lowered by 3-20% in the scenario involving compliance with the Kyoto Protocol and 5-7% in the scenario involving tightened environmental regulations

Table 3. Simulated savings rate in CO_2 emission-reduction costs resulting from emissions trading (reduction rates compared to Case 0–no trading)

	Case 1 Only effects of inter-region trading	Case 2 Effect of intertemporal trading for one period of banking	Case 3 (Current state) Effect of intertemporal trading for one period of banking and one period of borrowing from another region	Case 4 Effect of intertemporal trading with free banking and free borrowing
Test A	Δ50.0%	Δ4.5%	Δ4.5%	Δ6.6%
Test B	Δ68.9%	Δ0.2%	Δ4.7%	Δ4.7.%
Test C	Δ36.5%	Δ2.1%	Δ2.1%	Δ2.6%
Test D	Δ59.2%	0%	Δ12.5%	Δ19.2%
Test E	Δ55.7%	0%	Δ13.0%	Δ20.3%
Test F	Δ44.6%	Δ0.1%	Δ9.6%	Δ17.9%

Section 6: Measures against swings in emission rights prices caused by speculation in emissions trading

The emissions trading system should be protected from the fluctuations in emission rights prices likely to result from speculation. This is essential for the success of the emissions trading system (no less than is true for the environmental taxation system). Specifically, a complementary system (policy mix) will make it possible to take advantage of both the emissions trading system and the environmental tax system. We would like to present a system capable of restraining the cost of environmental protection incurred by industries in efforts to prevent global warming to within the range from *s* (lower limit) to *f* (upper limit). This paper explores this question only in part. A full investigation is a major undertaking for the future.

Under this system, a company may sell emission rights at a specified price, s (US$), to the government (or to an international organization), rather than selling it on the open market. On the other hand, the company may purchase emission rights from the government at a specified price, f (US$) ($s \leqq f$), rather than buying it on the open market, if the company has emitted more than the permissible amount of greenhouse gases. This system combines price regulation and quantity regulation. Since the emission rights prices fall within the range between the lower limit, s, and the upper limit, f, the emissions trading market remains protected from fluctuations caused by speculation. In a similar system, the government may provide a subsidy *s* to a company, in turn place a tax *f* on this subsidy. The goal of this complementary system is to stabilize by price regulation the price volatility accompanying the quantity regulation during emissions trading (price regulation, however, does not have much power to control quantities). In other words, either price regulation or quantity regulation is a specific example of the system. In fact, if s=f, it produces the same result as the greenhouse gas taxes, while if s=0 and f=+∞, it produces the same result as the quantity regulation system.

Section 7: Conclusions–problems in the Kyoto Protocol and some suggestions

The Kyoto protocol is a first step toward preventing global warming. However, when the goals for emission reductions were determined for individual nations, the cost of GHG emission reductions in each nation or region was not considered. In terms of economic efficiency, individual goals for optimized emission reductions should have been determined to minimize total global emission-reduction costs involved in achieving the targeted emissions reduction and to equalize emission-reduction costs among nations. In reality, the targeted figure for each nation was determined by politics and these figures are far from economically ideal. As a result, the efforts of individual member nations to attain their goals will likely result in very high total costs. Japan is a typical case. Corresponding to oil-price hikes and energy policies taken since the two oil crises during the 1970s, Japanese industries have sought to use alternative energy sources (shift from oil to nuclear power, natural gas, etc.) and to conserve energy to reduce CO_2 emissions. Few effective measures remain for Japan to reduce its CO_2 emissions at low cost. Nevertheless, Japan would be required to cut its CO_2 emissions by significant amounts, equal to those imposed on other nations and regions where cheap reduction measures remain unimplemented and therefore are still available. Japan's options at this point would be considerably higher. Compliance with such a program is not economically reasonable, nor would any party benefit from such compliance.

The emissions trading system is a mechanism by which the politically determined goals for emission reductions in individual nations are brought close to the economically optimal solutions, and by which emissions reduction costs are minimized by the spatial and time flexibility in the emissions trading market. Our simulation indicates that intertemporal trading as well as spatial trading may lead to this optimization. In particular, intertemporal trading may solve problems even when views on technological improvements differ among nations. Indeed, individual nations have their own schedules for carrying out measures to prevent global warming. Thus, we should make the most of the emissions trading system, which provides time flexibility, by removing limitations on spatial (geographic) trading and on intertemporal trading. This approach will be an incentive to serve to persuade the United States to join the Kyoto protocol framework as early as possible, even if after the first commitment period (2008-2012). It would also benefit Japan to adopt an emissions trading system that reduces emission-reduction costs through market mechanisms. By joining the international emissions trading market, Japan can help prevent global warming. Efficient application of market mechanisms requires a market free of significant defects, indicating the need for tools to avoid various risks. We believe that an approach combining environmental taxes (policy mix) offers great potential for mitigating fluctuations in emission rights prices resulting from speculation.

In conclusion, we wish to point out that the Kyoto Protocol is the product of an international political compromise for reducing GHG emissions; that the emissions trading system has an important role to play in narrowing the gap between the politically determined emission reductions targets and optimal solutions; and that such emissions trading should not be subject to constraints. The last point is of particular importance in persuading the United States to join the Kyoto Protocol framework, and will help nurture efforts to prevent global warming in many other nations, including developing nations.

Contact: ieej-info@tky.ieej.or.jp