CO_2 Emissions Trading Market Systems as An Environmental Policy Option and Assessment of Its Effect

- Evaluating Intertemporal Trading In Particular -

Kazuya Fujime, Managing Director & Chief Executive Economist IEEJ

1. Introduction

This paper intends to offer an in-depth examination from the standpoint of economics of the "Kyoto Protocol" generally perceived as a product of international coherence in global warming abatement. A collective target set under the Kyoto Protocol requires industrialized countries to cut their combined greenhouse gas (GHG) emissions as of 2010 to a level "their annual average emissions in 2008~2012 should stay 5.2% below 1990 records." The Protocol also specifies reduction targets to be met by individual countries (areas).

In theory of economics, to get the whole of GHG reduction targets satisfied efficiently, it is imperative to set a target amount of GHG reductions achievable by each country at a marginal cost equal to all countries. But, a gap is due between theory and a given target actually. In efficiency terms, it is desirable if each country could freely trade on market the "gap," or any difference between an optimal reduction amount for a country and a target specified by the politically compromised Kyoto Protocol. It is emissions trading that provides a mechanism of adjustment by selling or buying emissions (emissions permits). To explain clearly why emissions trading can have a cost reduction effect with a theoretical model in use, this paper first verifies an inherent function to emissions trading, which helps minimize a total reduction cost by adjusting any "gap" between optimal and political targets in both spatial and temporal terms. Lagrangian function of a bilateral two-period trading model is used in verification. Also, in order to demonstrate an effect of intertemporal trading, "World Energy Industry Model," originally provided with an inter-area emissions trading function, was modified and given an additional intertemporal trading function to inter-area one before run for simulation. On top of the commitment period up to 2010 proposed under the Kyoto Protocol, during which specified targets should be met, subsequent five-year commitment periods to 2015, 2020, 2025 and 2030, each, were set and two scenarios were prepared. One is a "business-as-usual (BAU)" scenario in which the Kyoto target would remain unchanged even in the post-2010 periods. The other is a "tightening environmental constraint (TEC)" scenario, which assumes the Kyoto target would be the tighter in the later commitment periods. By varying banking and borrowing conditions, each scenario was simulated in a total of 36 cases.

Simulation results showed that intertemporal trading was effective in cutting the emissions reduction cost by 3~26% in the BUA case, and by 4~7% in the TEC case, thus proving a cost reduction effect of intertemporal trading thanks to its temporal flexibility.

Based on consideration described in this paper, the Kyoto Protocol can be counted as the first step toward warming abatement. In the capacity of environmental policy, the protocol can be evaluated as a step forward.

2. Total Cost Minimization and Optimal Solution by Bilateral Two-period Trading Model

Emissions trading in a broad sense will be in practice multilaterally and over multiple periods. But, for a simplification purpose, a theoretical model of bilateral two-period trading is used here in clarifying essential nature of emissions trading, in which subject to trading is a goods called emissions permits. In stricter terms, this model deals in synchronous bilateral trading, but does not cover intertemporal trading within a single country. On the contrary, intertemporal trading includes not the former but the latter. Anyhow, it remains unchanged that this theoretical model can explain theoretic grounds for the inherent function to emissions trading to help adjust any "gap" between an optimal solution and a political target.

With bilateral two-period trading expressed in equations, the question of how to minimize the emissions reduction cost can be solved as described below.

X_1=First country's CO_2 reductions

X_2= Second country's CO_2 reductions

$Y_1=ax_1$ First country's marginal reduction cost curve

$Y_2=bx_2$ Second country's marginal reduction cost curve

Y_1^i=First country's marginal reduction cost in i period, i=1, 2

Y_1^i=First country's total reduction cost in i period, i=1, 2

Y_2^i=Second country's total reduction cost in i period, i=1, 2

$Y_1=\Sigma Y^{1^i}$=: First country's total reduction cost throughout a given period, i=1, 2

$Y_2=\Sigma Y_2^i$=: Second country's total reduction cost throughout a given period, i=1,2

$Y=Y_1+Y_2=$: World's total reduction cost throughout a given period

$Y=1/2(a(x_1^1)^2+a(x_1^2)^2CDR+b(x_2^{1})^2+b(x_2^{2})^2CDR)$(To be explained at the end of this section.)

CDR=Composite discount rate=$(1+p)\times(1+s)/(1+r)\times(1+t)$

x_1^1=First country's optimal reductions throughout a given period

x_1^2=First country's optimal reductions in the second period

x_2^1=Second country's optimal reductions throughout a given period

x_2^2=Second country's optimal reductions in the second period

Min Y, constraints are put as follows: (s, t) $\sum_{i=1}^{2}\sum_{j=1}^{2}x_i^j=x_1^1+x_1^2+x_2^1+x_2^2=\alpha$

Here, Rangange's equations are put as follows.

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

λ represents a marginal reduction cost.

x_1^1, x_1^2, x_2^1, x_2^2, λ are differentiated.

$\delta L/\delta x_1^1=L_1^1=ax_1^1-\lambda_1=0$ (1)

$\delta L/\delta x_1^2=L_1^2=ax_1^2CDR-\lambda=0$ (2)

$\delta L/\delta x_2^1=L_2^1=bx_2^1-\lambda=0$ (3)

$\delta L/\delta x_2^2=L_2^2=bx_2^2CDR-\lambda=0$ (4)

$\delta L/\delta\lambda=L_\lambda=\alpha-x_1^1-x_1^2-x_2^1-x_2^2=0$ (5)

$x_1^1=\lambda/a$ $\quad x_1^2=\lambda/aCDR$

$x_2^1=\lambda/b$ $\quad x_2^2=\lambda/bCDR$

With these put in the equations (5):

$\alpha-\lambda/a-\lambda/aCDR-\lambda/b-\lambda/bCDR$

$=\alpha-\lambda(1/a+1/aCDR+1/b+1/bCDR)=0$

Hence,

$\lambda=\alpha/(1/a+1/aCDR+1/b+1/bCDR)=\alpha/(1/a+1/b)+(1/a+1/b)/CDR=\alpha/(1/a+1/b)(1+1/CDR)$

Accordingly,

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

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

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

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

Optimal equilibrium above can be illustrated as shown in Fig. 1.

Y(the world's minimum total reduction cost)can be described as follows.

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

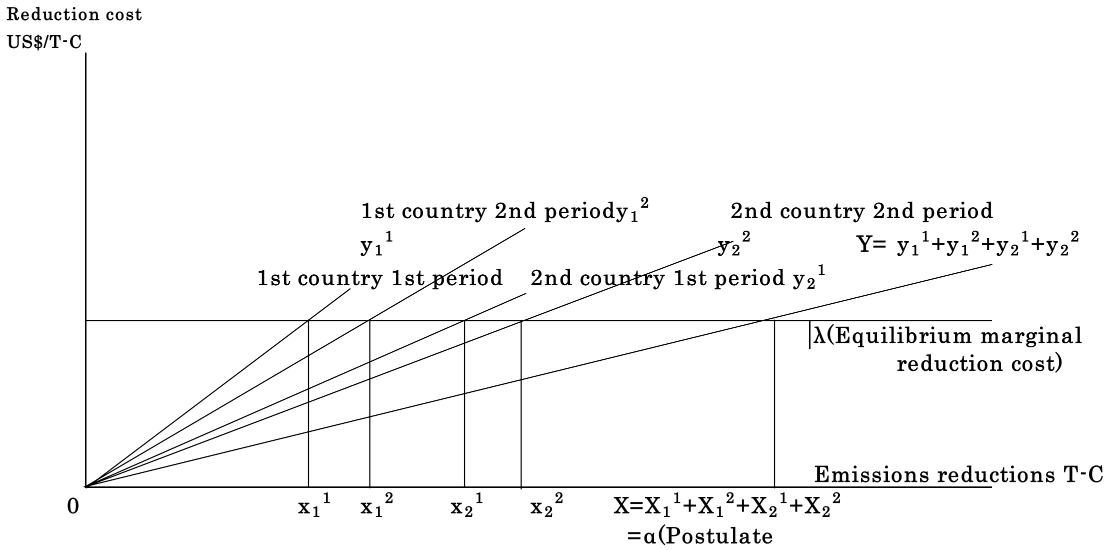
$Y_1^1=ax_1^1x_1^1/2=a(x_1^1)^2/2$

$Y_1^2=aCDRx_1^2x_1^2/2=aCDR(x_1^2)^2/2$

$Y_2^1=bx_2^1x_2^1/2=b(x_2^1)^2/2$

$Y_2^2=bCDRx_2^2x_2^2/2=bCDR(x_2^2)^2/2$ $Y=(1/2)(a\ (x_1^1)^2+a(x_1^2)^2\quad CDR+b(x_2^1)^2+b(x_2^2)^2CDR$

Fig. 1 Optimal Reductions with Bilateral Two-period Trading and Equilibrium Marginal Emissions Reduction Cost



3. Theoretic Grounds for Emissions Reduction Cost Cutting Effect Inherent to Intertemporal Trading

First, the tools provided by intertemporal trading are banking and borrowing of emissions permits. Literally banking means to bank emissions permits, consumable in a coming period, otherwise sold or leased. Borrowing means to borrow emissions permits to be consumed during a current period, with equivalent ones to be paid back in a coming period. Theoretically not only trading partners include others (other areas) but also owned permits in current or coming periods are tradable. Moreover, a coming period is not limited to the next period to come but includes any period ahead. (Fig. 12 illustrates the mechanism of intertemporal trading.)

Effects of intertemporal trading have analogy with those of spatial trading, which means this trading can be considered as if temporal dimensions were identical to spatial dimensions.

However, affected by interest rate, technological advance, aggravating capacity of CO_2 sinks, emissions-permits price rises, etc., intertemporal trading itself does not allow application of a simple analogy by extrapolating the emissions cutting effect of spatial trading. It is because intertemporal trading requires changing conditions with time to be taken into consideration, a crucial difference from spatial trading.

Listed below are major variables that are assumed to affect intertemporal trading:

Emissions-permits price increase (%/year): p

Interest rate (%/year): r

Rate of technological advance (%/year): t

Rate of aggravating capacity of CO_2 sinks (rate of gradually diminishing capacity with time of such sinks as oceans)(%/year): s

Of these variables, it is p and s that can facilitate banking of emissions, or emissions permits, by cutting more emissions than targeted for a current period, which can be used in achieving a target to be met in a period to come, or sold to earn profits. The variables that impede banking of emissions are r (advantageous if held in cash but working ill when possessed in the form of emissions permits) and t (to hold emissions permits accrued from immediate reduction efforts works ill because the same reduction efforts should cost less in the future). Conversely, when emissions permits are borrowed from those consumable in a period to come in order to meet an unattained portion of a reduction target for a current period during which few reduction efforts are made actually, r and t act as positive contributors, while p and s become impediments. By the way, s, counted as a net penalty for a delay in time, can be taken as part of the penalty of 1.3 times (5.4%/year) for a delayed attainment of the first-period (5 years) target agreed at reconvened COP6 (in Bonn, Germany). For example, of the penalty, 5%/year can be attributed to interest rate (r), and 0.4%/year to aggravating capacity of sinks (s). But, as far as s is concerned, it is not easy to get it scientifically grounded well enough to yield an international accord. It is because forests and oceans are found to have different relations between rising CO_2 concentrations and their capacities as sinks. In natural science terms, these involve too complex casual relations to permit quantification after all. And yet, they are taken as linear variables here as a matter of convenience (Masayuki Tanaka, 1993).

The cost cutting effect of intertemporal trading has been confirmed by SO_2 (sulfur oxide) emissions trading in practice in acid rain control programs under the Clean Air Act of the U.S. (A.D. Ellerman et al 2000). Though not detailed here, most of the cost cutting effect of intertemporal trading can be explained by analogy with the cost cutting effect of spatial flexibility. Yet, when emissions reductions are put on the x-axis and reduction cost/T-C (US$) on the y-axis, what's essential is to apply the same yardstick to all costs on the y-axis, which incur in different times. In short, the costs incurring in different times need to be discounted in present values. The question is what discount rate should be set. Simply considering, a discount rate can be identical to interest rate (r). But, as already discussed, intertemporal trading is affected particularly by emissions-permit price rises (p), aggravating capacity of CO_2 sinks (s), and technological advance (t), which means these too should be reflected on a discount rate in present values. Namely, it was thought necessary to reduce the four principal factors (p, r, t, s), influential on intertemporal trading, to present values by a discount rate that takes them into consideration in a composite manner or the so-called composite discount rate, instead of a simple discount rate.

What's discussed above is taken as CDR (composite discount rate), and the duration of years to carry out intertemporal trading as n years. It is p and s that facilitate banking, while r and t pose impediments. The relations between CDR and the four factors in the n^{th} year can be expressed as follows:

$$CDRn=(1+p)^n \cdot (1+s)^n/(1+r)^n \cdot (1+t)^n$$
$$=(1+p)^n/(1+r)^n \times (1+s)^n/(1+t)^n$$

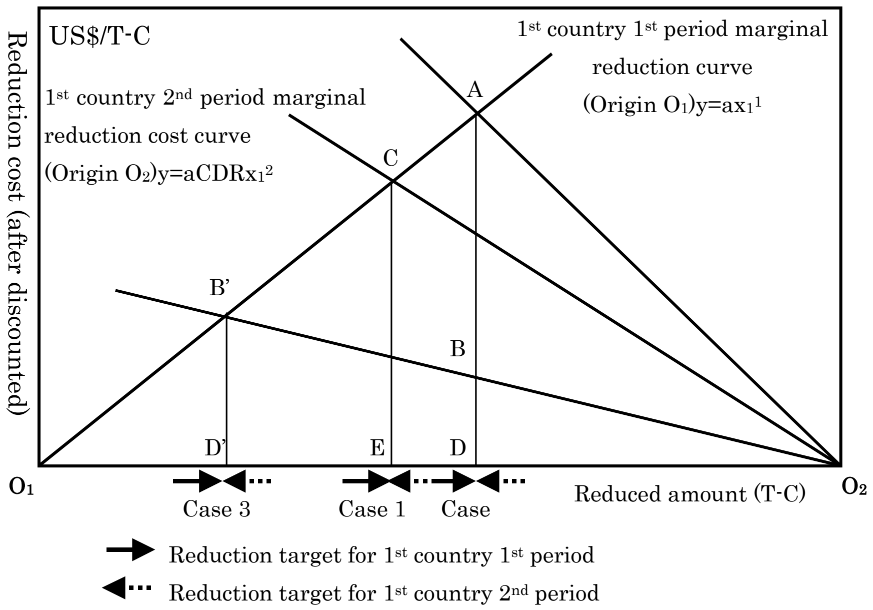
If the world has the only one energy industry trading emissions permits, the industry is expected to cut emissions and trade emissions permits in a way that such activities yield maximum economic surpluses = maximum profits. When a future is expressed as "total sales of emissions permits (permits price x reduced amount) – total reduction cost (cost/T-C x reduced amount) = profits (economic surpluses)," the industry should bank when the equations are read now as the right side (RS) > the left side (LS). Similarly, the industry should prefer borrowing when RS < LS is more likely. What affects total sales in the future is $Bn=(1+p)^n \times (1+s)n$(p determines the price, and s does the size of trade), while what affects total cost in the future is $Cn=(1+r)^n \times (1+t)^n$ (r determines cost increases, and t does cost decreases and the magnitude of cost). Accordingly, the world energy industry tries to maximize profits (economic surpluses) (or minimize costs) by banking when the composite discount rate =CDRn=Bn/Cn>1, and by borrowing when Bn/Cn<1. Thus, banking is in progress when CDR=CDRn=Bn/Cn>1, while borrowing is in advance when CDRn=Bn/Cn<1. When CDRn=Bn/Cn= 1, no intertemporal trading (neither banking nor borrowing) takes place.

4. Emissions-Reduction Cost Cutting Effect of Intertemporal Trading

By taking advantage of analogy between intertemporal and spatial trading effects, Fig. 2 shows examples of cost cutting by intertemporal trading. All of the questions, including CDR > 1, or <1, or = 1, and if trading, regardless of banking or borrowing, takes place or not, are shown in this single chart. It should be noted Fig. 2 illustrates intertemporal trading, not between different economic units (areas), but within a single economic unit (area). Intertemporal trading between different areas will be shown separately. While optimal solutions and roles of emissions trading were already explained in relation to the bilateral two-period trading model, the explanations also covered bilateral trading over a single period, which involved not intertemporal trading but inter-area trading alone. Intertemporal trading in the bilateral two-period style takes the form of either trading between the first and second periods within a single economic unit (country) or intertemporal trading between different economic units (countries). Here, given case-specific optimal solutions and their "gaps" from a given target to be adjusted by intertemporal trading, the conditions leading to an optimal reduced amount, an equilibrium marginal reduction cost, banking or borrowing, and an equilibrium are described in terms of total CO_2 reductions (α), composite discount rate (CDR), and gradients of marginal reduction cost (a, b), which are all postulates.

An example of bilateral two-period trading: 1st country 1st period x 1st country 2nd period (see Fig. 2): The marginal reduction cost curve of 1st country 1st period is taken as y=ax, and that of 1st country 2nd period as y=CDRax. Here, in the absence of intertemporal trading, an optimal reduced amount is expected when $x_1^1=\alpha/a(1+a/b)(1+1/CDR)$, $x_1^2=\alpha/(1+a/b)(1+CDR)$. When y=ax=CDRax, no emissions trading takes place. Hence, it is when CDR=1. In this case, an equilibrium marginal reduction cost is expressed as $\lambda=\alpha/(1*a+1/b)(1+1/CDR)$. When the 1st country 1st period is taken as a unit (referred to as "unit" so as to judge if resultant trading should be called banking or borrowing), banking takes place when its marginal reduction cost ($=ax_1^1$)<trading partner's marginal reduction cost ($=CDRax_1^2$), which occurs when CDR>1. In this case, Fig. 2 shows the cost can be trimmed as much as AB×ED×1/2. On the other hand, borrowing takes place when $ax_1^1>CDRax_1^2$, that is, when CDR<1. This case results in a cost reduction of AB' ×FD' ×1/2.

Fig.2 Examples of Cost Cutting by Intertemporal Trading (Bilateral Two-period): 1st Country 1st Period x 1st Country 2nd Period



Trading unit: 1st country 1st period

- Case 1: When **CDR=1**, it is found that emissions reduction cost = ΔCO_1E + ΔCO_2E, whereby no intertemporal trading takes place.
- Case 2: When **CDR>1**, it is found that emissions reduction cost = ΔAO_1D + ΔBO_2D. Then, **banking**, if made under this condition, with DE taken as emissions permits, would result in emissions reduction cost = ΔCO_1E + ΔCO_2E, thus allowing cost-saving equivalent to ΔABC.
- Case 3: When **CDR<1**, it is found that emissions reduction cost = $\Delta A'O_2D'$ + $\Delta B'O_1D'$. Then, **borrowing**, if made under this condition, with D'E taken as emissions permits, would result in emissions reduction cost = ΔCO_1E + ΔCO_2E, thus allowing cost-saving equivalent to $\Delta A'B'C'$.

5. World Energy Industry Model and Simulation Results

The World Energy Industry Model is an LP model that is given a structure as shown in Fig. 3.

Fig. 3 Energy Flow and Flow of Emissions Reduction Cost Calculations of World Energy Industry Emissions Trading Model

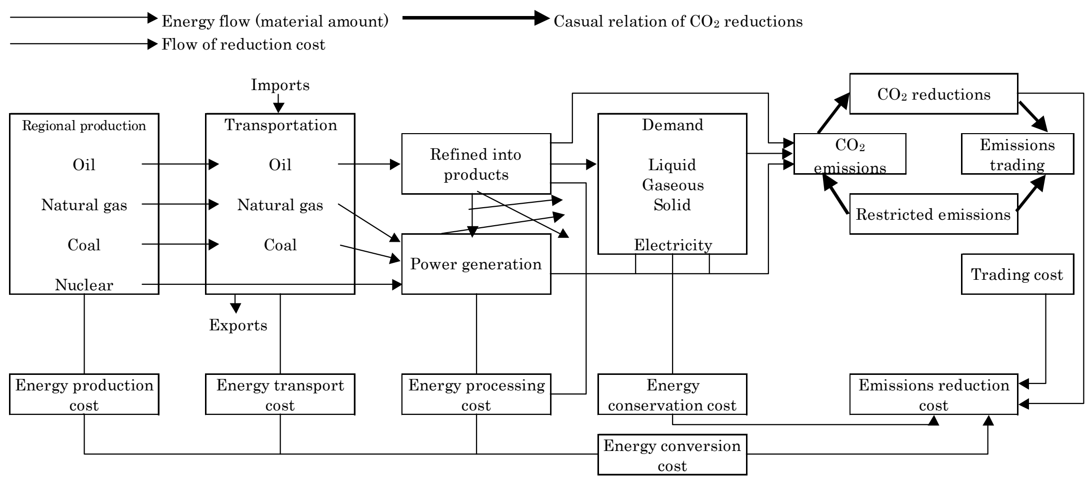


Fig. 3 illustrates the relations among energy flow from production to marketing, the amounts of CO_2 reduced and the emissions reduction costs involved in the world energy industry.

With this model, the six cases described below are simulated, then Tests A to F were made.

(1) Base: BAU case: Assumes no restraints on emissions.

(2) Case 0: Assumes certain restraints on emissions but no emissions trading.

(3) Cases 1~4: Restraints on intertemporal trading are assumed to be gradually lessened in each case.

Assumptions of Four Major Factors Influential on Intertemporal Trading

In Tests A~F, combinations of the four factors and the composite discount rate were employed as shown in Table 1.

Table 1 Four Major Variables and CDR Influential on Intertemporal Trading

4 Variables	Interest rate (r)	Technology advance (t)	Emissions -permit price increases (p)	Aggravating capacity of sinks (s)	Composite discount rate (CDRn)
Test A	5%	1%	7%	0.4%	1<CDRn
Test B	7%	1%	2%	0.4%	1>CDRn
Test C	5%	1%	7%	0.4%	1<CDRn
Test D	5%	1%	2%	0.4%	1>CDRn
Test E	5%	2%	-2%	0.4%	1>CDRn
Test F	5%	2%	-2%	0.4%	1>CDRn

The model was run in a total of 36 cases, and simulation results showed emissions trading was effective in cutting CO_2 reduction costs as much as shown in Table 2.

Table 2 CO_2 Reduction Cost Cuts by Emissions Trading Verified by Model Simulation
(Case 0/Cost-cutting rate from no emissions trading case)

	Case 1 Inter-area trading alone	Case 2 Intertemporal trading in form of banking over a single period alone	Case 3 (current conditions) Intertemporal trading in form of banking over a single period alone and in form of borrowing from different areas over a single period alone	Case 4 Intertemporal trading in form of banking and borrowing, both unlimited
Test A	Δ41.9%	Δ 4.3%	Δ 4.3%	Δ 7.8%
Test B	Δ37.1%	Δ0.01%	Δ 3.8%	Δ 4.0%
Test C	Δ28.5%	Δ 2.0%	Δ 2.0%	Δ 2.9%
Test D	Δ50.2%	0%	Δ12.6%	Δ22.5%
Test E	Δ46.8%	0%	Δ14.5%	Δ25.6%
Test F	Δ37.8%	0%	Δ10.1%	Δ20.5%

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