Environment and Development Economics 8: 247–260 © 2003 Cambridge University Press
DOI:10.1017/S1355770X03000135 Printed in the United Kingdom

Flexibility mechanisms and credit discounting

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ABSTRACT. We consider the international treaties on climate change as self-enforcing agreements. Applying non-cooperative game theory, we interpret the UN framework Convention on Climate Change as a Nash equilibrium outcome of an international abatement game where only domestic abatement is allowed. The Kyoto Protocol is a Nash equilibrium outcome of the game where flexibility mechanisms are introduced. We also show that credit discounting on foreign abatement can Pareto improve the welfare of all countries.

1. Introduction

Climate change is one of the major issues in discussions about the global environment. This is due to the fact that the current climate shows a high degree of variability and threatens unexpected disastrous climate events.

Countries around the world have realized that current climate change is not desirable and may cause serious damage to eco-systems. The United Nations has arranged international regulations such as the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP).

The UN Framework Convention on Climate Change (UNFCCC) was adopted on 9 May 1992 at the UN Headquarters in New York. The UNFCCC classified the involved countries into two groups, namely

We gratefully acknowledge the financial support of the University of Seoul Research Fund of the year 1999 and the BK 21 project. Sang-Chul Suh gratefully acknowledges the financial support of the SSHRCC. We thank the participants of the related sessions of the year 2000 Western Economic Association Meeting at Vancouver, Applied Microeconomic Workshop in Korea, and the year 2000 Korea International Economic Association Meeting for their comments. We are also grateful to Janghyung Cho and Jongjin Kim for their research assistance. We also thank anonymous referees for useful comments. All remaining errors are our own.

https://doi.org/10.1017/S1355770X0300135 Published online by Cambridge University Press

groups of developed and developing countries respectively. And it asked the group of developed countries to take policies and measures to restrain greenhouse gas (GHG) emissions to the level of 1990 by the year 2000. Meanwhile the group of developing countries were exempted from the specific abatement obligation.

The Kyoto Protocol was adopted in December of 1997 in Kyoto. It established a legally binding target of GHG abatement for developed countries. At the same time, it introduced several flexibility mechanisms such as the clean development mechanism, joint implementation, and emissions trading, which can reduce abatement costs.[1] And, in order to prevent the abuse of these mechanisms, their use was restricted by the so-called supplementarity condition. The supplementarity condition requires that the emissions reductions through these mechanisms be only supplementary to domestic emissions reductions.[2]

The flexibility mechanisms were originally introduced in the USA to give flexibility to firms and thereby reduce the costs of abating pollution while keeping the environmental quality. For instance, the 'netting' of emissions, which authorizes internal trading, was introduced to allow modifying or expanding sources to escape from the need to meet the requirements of the rather stringent 'New Source Review Process' in 1974. The 'Offset Policy', which authorizes internal/external trading, was introduced to allow for location in an area with air quality worse than the ambient standard. This was followed by the Bubble policy in 1979 and the Banking concept in 1980. These concepts are based on the internal and external trading of credits. Both the 'Lead Trading' program (1982–1987) and the 'Program for Trading of Ozone Depleting Chemicals' (1988) in the USA used the credit trading concept. These programs are often called credit systems or open systems since the total amount of emissions is not fixed. On the other hand, there are programs called cap-and-trade systems or closed systems since the total amount of emissions is fixed. The most well-known one is the 'SO_2 Allowance Trading Program', initiated in 1990 for addressing acid rain problems in the US. Among others are the 'Ozone Transport Commission No_x Budget Program' (1999) and the 'Regional Clean Air Incentive Market Program' (1994).

As we notice from the experience of the USA, historically, the flexibility mechanism evolved from credit systems such as Offsetting and Bubble Programs to the cap-and-trade systems such as the SO_2 allowance trading system. The credit system is operated by designating source-specific

[1] The clean development mechanism is a system where a developed country abates greenhouse gases in a developing country and obtains the credit of the GHGs' abatement. Joint implementation is a system where a developed country abates GHGs in other developed countries and obtains the credit of the GHGs' abatement. Emissions trading is a system of allowance trading where the total allowances of emissions are fixed for each developed country and developed countries trade allowances with one another.

[2] In the recent Bonn Agreement (2001), the supplementarity condition was somewhat neutralized by agreeing to specify no quantitative limits on the amount. Note that this does not affect our result on credit discounting in section 4.

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emission limits, case-by-case review, and approval of each trade. Thus it does not require the participation of all relevant firms in trading and does not involve establishing a large trading system. In allowances trading, all the relevant parties participate and the administration and monitoring is done through a central agency. In short, the credit system is a partial approach to emissions reduction while the cap-and-trade system is a total approach (for a detailed explanation, see EPA, 2001; Aslam, 1998; and Kosobud, 2000).

The clean development mechanism (CDM) and joint implementation (JI) are similar to the credit system, and emissions trading is similar to the cap-and-trade system.

In this paper, we model international negotiations for the abatement of GHG emissions with a non-cooperative game framework. In the literature on the non-cooperative game theoretic analysis of international environmental agreements, both static and dynamic games were used.[3] For instance, static games were used in Hoel (1991) and Welsch (1993). Dynamic games were used, among others, by Dockner and Long (1993), Martin, Patrick, and Tolwinski (1993). The equilibrium outcomes from static games and dynamic games are different in that, in the dynamic games, a cooperative outcome can be supported as an equilibrium through credible punishments. However, it is quite difficult to solve the equilibrium in dynamic games.

We adopt a one-shot game framework. This not only makes the analysis tractable but has its own relevance. The effect of abatement on the climate cannot be determined immediately, and will be seen in the remote future, such as the year 2100. This implies that the payoff of the game is realized in the remote future while the actions are taken at present. Thus the situation is essentially static and punishments cannot be applied.

We interpret the UNFCCC and the Kyoto Protocol as the Nash equilibrium outcomes of the corresponding games. We also show that credit discounting on foreign abatement can increase the total abatement of GHGs and improve the welfare of participating countries. In some cases, it even does better in improving efficiency than the simple lifting of the supplementarity condition.

Section 2 presents a simple model. Section 3 deals with the states of Nash equilibrium with and without the flexibility mechanisms respectively. They correspond to the states under the UNFCCC and the Kyoto Protocol. Section 4 examines the effect of introducing credit discounting on foreign abatement. Section 5 concludes with some remarks.

2. A simple model

We regard the abatement of GHG emissions as a production of a public good, denoted by y. Suppose that there is only one private good, the amount of which is denoted by x. The production of the public good, y, entails reduction of productive activity or consumption of

[3] For a detailed literature survey, see Carraro and Filar (1995), Folmer, Hanley, and Miβfeldt (1998), and Wagner (2001).

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the private good. We can express this with a cost function mapping the amount of GHG abatement into the required loss of private good. This approach is rather common in the literature (Hoel, 1991; Welsch, 1993; Barrett, 1994).

For simplicity, we consider a world economy consisting of two developed countries, denoted by 1 and 2, and one developing country, denoted by 0.[4] We may think of the two developed countries as representing the Umbrella Group[5] and the European Union (EU) group. Each country i is endowed with an endowment, w_i, and has its own cost and benefit function for the abatement of GHG emissions.

We assume that the cost per unit abatement is constant for each country i, i.e., the cost function is linear in y, $C_i(y) = c_i y$. We assume that the marginal costs for the two developed countries are higher than those for the developing country. Without loss of generality, we assume that $0 < c_0 < c_1 < c_2$.

The net benefit, $B_i(y,x_i)$, is a function of not only the total abatement but also the amount of available private good.

We assume that the marginal net benefit of abatement for the developing country is negative so that it does not abate. This can be justified by the fact that, in the UN Framework Convention on Climate Change, the group of developing countries does not bear specific abatement commitments. And, in the case of implementing abatement policies, the developing country is provided with the costs by the developed countries (UNFCCC, article 4.1 and 4.3). Indeed, for most of the developing countries, the priority needs are for the eradication of poverty and the achievement of economic development.

We denote by y the amount of total abatement in the world, by y_i the amount of abatement by country i, by y_{ij} the amount of abatement in j by i, by y_{-i} the amount of abatement by countries other than i, and by $y_{i,-j}$ the abatement by i in countries other than j. Also B_i^x and B_i^{xy} denote $\frac{\partial B_i}{\partial x}$ and $\frac{\partial^2 B_i}{\partial x \partial y}$ respectively. The following are assumptions about the net benefit functions, $B_i(y, x_i)$, for developed countries.

For $i = 1, 2$:

(B–1) B_i is continuous for all $(y, x_i) \in \mathrm{IR}^2_+$ and strictly concave and twice continuously differentiable for the interior points.

(B–2) $B_i^{xy} \geq 0$ for all $(y, x_i) \in \mathrm{IR}^2_+$.

(B–3) $B_i^y(y, w_i - c_0 y_i) - c_0 B_i^x(y, w_i - c_0 y_i) < 0$ for sufficiently small value of $w_i - c_0 y_i \in \mathrm{IR}_+$.

(B–4) $B_i^y(0, w_i) - c_i B_i^x(0, w_i) > 0$.

[4] Our model can be extended to incorporate many developed countries and developing countries.

[5] The Umbrella Group represents the group of developed countries including Japan, the United States, Canada, Australia, and New Zealand which have different views from the countries in the European Union.

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Assumption (B–2) implies that the private good and the abatement are complementary to each other. Assumption (B–3) requires that, as the amount of domestic abatement approaches the endowment, the marginal net benefit of the abatement becomes negative. Assumption (B–4) requires that the initial marginal net benefit of domestic abatement be larger than 0. The Cobb–Douglas type benefit function satisfies the above assumptions.

3. International agreements on climate change

3.1. Nash equilibrium with domestic abatement: the UNFCCC

We consider the negotiations on the abatement of GHG emissions as a non-cooperative game where each country chooses its own amount of abatement. As a solution concept, we use Nash equilibrium. This may be justified by the fact that there is no central authority to rule over this global climate change. Moreover the exact verification of the cost and benefit is quite difficult. Therefore, the equilibrium outcome of negotiations can be interpreted as a self-enforcing agreement. The self-enforcing agreement is the major characteristic of the concept of Nash equilibrium. Indeed, the climate negotiations are based on the consensus. Each country tries to find out its best position taking into account the other countries' positions. After some time-consuming negotiations, the consensus is documented as a Convention or Protocol. This seems to be literally a self-enforcing agreement. We think of international arrangements such as the Conference of the Parties of the UNFCCC as working not for imposing environmental regulations but for facilitating communication among the participating countries.

Under the condition that each country can abate GHGs in their own territory, each country i solves the following optimization problem given the other countries' abatements

$$\max_{y_i} B_i(y, w_i - c_i y_i) \text{ subject to } 0 \leq c_i y_i \leq w_i$$

Note that, in the first constraint, $c_i y_i \leq w_i$ does not bind due to our assumption (B–3). Thus the first constraint reduces to the non-negativity condition of y_i. The necessary and sufficient condition for the optimum is the following Kuhn–Tucker condition

$$B_i^y - B_i^x c_i \leq 0, (B_i^y - B_i^x c_i) y_i = 0, y_i \geq 0 \text{ where } i = 1, 2$$

From the above condition, we can derive the best response function for i, $R_i(y_j)$, where $i \neq j$. For the interior solution,

$$\frac{dy_i}{dy_j} \mid R_i = - \frac{B_i^{yy} - B_i^{xy} c_i}{B_i^{yy} - 2B_i^{xy} c_i + B_i^{xx} c_i^2}.$$

By assumptions (B–1) and (B–2), it follows that the slope of the best response function of i is negative and its absolute value is less than one. This implies that, if there is an interior equilibrium, it is unique and stable in a Cournot adaptive process. We denote the equilibrium abatement for the above problem as y_i^{FC} where $i = 1, 2$.

This equilibrium is not Pareto efficient. Pareto efficiency requires that the sum of the weighted marginal benefits of abatements equals the lowest marginal cost of abatements: for all i,

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$$\sum_j \frac{\delta_j}{\delta_i} B_j^y = B_i^x c_0$$

where δ_j is a positive number for all j. However, in the above equilibrium, the marginal benefits of abatements are equal to the marginal costs of abatements: $B_i^y = B_i^x c_i$ for all i. There is underabatement of greenhouse gases due to the positive externality of abatement.

The above argument can be summarized in the following proposition (see Hoel, 1991 for a similar result).

Proposition 1. *When only domestic abatement is allowed, there is a unique equilibrium which is not Pareto efficient.*

3.2. Nash equilibrium with flexibility mechanisms under the supplementarity condition: the Kyoto Protocol

After the establishment of the UNFCCC, which refers only to the abatement commitments until the year 2000, the necessity for additional commitments by developed countries after the year 2000 was raised in the first Conference of the Parties (COP) held in Berlin in 1995. In the COP 3 held in Kyoto during December, 1997, the strengthening of the commitments of developed countries after the year 2000 was negotiated. The main result is that the group of developed countries is burdened with more strict abatement commitments while flexibility mechanisms such as joint implementation, the clean development mechanism, and emissions trading are allowed so that the abatement costs may be lowered. The use of flexibility mechanisms is restricted to being supplemental to the domestic abatement. This is the so-called supplementarity condition.

The flexibility mechanisms have been criticized by developing countries who are concerned about the possibility that developed countries may overly exploit them to avoid domestic actions. The supplementarity condition is claimed to give impetus to the development of new technologies and structural adjustment in the developed countries, thereby lowering the overall abatement costs in the long run.

Let $\alpha \in \mathrm{IR}_{++}$ be a positive parameter that represents the degree of supplementarity. As a supplementarity condition, we introduce an inequality that requires the ratio of the domestic abatement to the foreign abatement to be larger than α.

When the marginal cost of abatement is constant, emissions trading and joint implementation among the developed countries will not be conducted since the clean development mechanism provides cheaper abatement opportunities. Thus, without loss of generality, we analyze only the introduction of the clean development mechanism.

We regard the commitments specified in the Kyoto Protocol as the Nash equilibrium outcome of the following abatement game. Each developed country i faces the following optimization problem given the other countries' abatements

$$\max_{y_{ij}} B_i\left(y, w_i - \sum_j c_j y_{ij}\right)$$

$$\text{subject to } 0 \le \sum_j c_j y_{ij} \le w_i,\ y_{ii} \ge \alpha y_{i,-i}, \text{ where } j = 0, 1, 2$$

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The first constraint is a resource constraint. The second constraint is the supplementarity condition. Since $c_0 < c_1 < c_2$, we only need to consider y_{i0}, y_{ii}. Note also that, in the first constraint, $\sum_j c_j y_{ij} \leq w_i$ does not bind due to our assumption (B–3). Thus the first constraint reduces to the non-negativity condition on y_{ij}. Thus the necessary and sufficient condition for the optimum is the following Kuhn–Tucker condition

$$B_i^y - B_i^x c_i + \lambda_i \leq 0,\ (B_i^y - B_i^x c_i + \lambda_i) y_{ii} = 0,\ y_{ii} \geq 0$$
$$B_i^y - B_i^x c_0 + \alpha\lambda_i \leq 0,\ (B_i^y - B_i^x c_0 - \alpha\lambda_i) y_{i0} = 0,\ y_{i0} \geq 0$$
$$y_{ii} - \alpha y_{i0} \geq 0,\ \lambda_i (y_{ii} - \alpha y_{i0}) = 0,\ \lambda_i \geq 0 \text{ where } i = 1, 2$$

Note that, at interior equilibrium, $y_{ii} = \alpha y_{i0}$. This is so since, otherwise, we can increase country i's net benefit by replacing a small amount of y_{ii} with y_{i0}. We denote the solution for the above problem as y_{ij}^{KP} where $i = 1, 2$ and $j = 0, 1, 2$.

The following figure 1 shows the equilibrium state of each country under the Kyoto Protocol. The horizontal axis measures the amount of foreign abatement and the vertical axis measures the domestic abatement. The line eminating from the origin represents the supplementarity condition where $\alpha = 1$. The arcs represent the indifference curves of the country i.

From the Kuhn–Tucker condition and the positivity of y_{ii}, y_{i0}, and λ, we can characterize the interior equilibrium by the following equation

$$B_i^y(y, w_i - \hat{c}_i y_i^{KP}) - B_i^x \hat{c}_i = 0 \text{ where } \hat{c}_i = \frac{\alpha}{1+\alpha} c_i + \frac{1}{1+\alpha} c_0 \text{ and } i = 1, 2$$

By a similar analysis to that in subsection 3.1, we can derive the best response of each country i, $R_i(y_i)$. The best response curve of country i under the Kyoto Protocol is located on the upper part of that under the

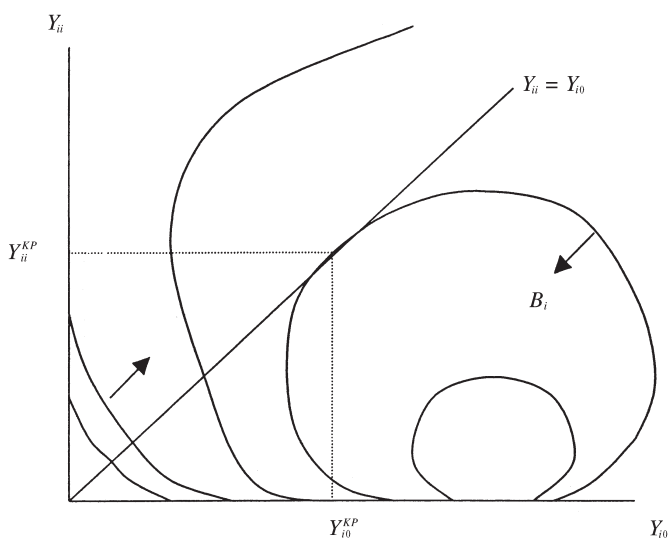


Figure 1. *Equilibrium under Kyoto Protocol* ($\alpha = 1$)

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UNFCCC. Therefore, the total equilibrium abatement under the Kyoto Protocol is larger than that under the UNFCCC. If each country's abatement under the Kyoto Protocol is larger than that under the UNFCCC, we can show that each country's net benefit improves as well. The developing countries gain from the increased abatement. The developed countries also gain from the opportunity for cheaper abatement. Suppose to the contrary that a developed country's welfare level decreases. And suppose that the country changed the amount of abatement to the level of the UNFCCC, y_i^{FC} and divided it into the amounts of domestic and foreign abatement satisfying the supplementarity condition, that is,

$$y_{ii} = \alpha y_{i0} = \frac{\alpha}{1+\alpha} y_i^{FC}.$$

Then, since the other countries abate larger amounts of greenhouse gases in the equilibrium and the abatement costs become cheaper, the country i's welfare improves in comparison to that under the UNFCCC. This is a contradiction.

The above argument can be summarized in the following proposition.

Proposition 2. *Assuming interior equilibrium*:

(a) The total abatement level under the Kyoto Protocol, y^{KP}, is strictly larger than that under the UN Framework Convention on Climate Change, y^{FC}.

(b) If each country's abatement under the Kyoto Protocol is larger than that under the UNFCCC, then each country's welfare level under the Kyoto Protocol improves in comparison to that under the UNFCCC.

4. Credit discounting: a Pareto improving design

4.1. Basic result

Under the Kyoto Protocol, the developed countries still under-abate the GHG emissions in comparison to the Pareto efficient state due to the positive externality of the abatement.

In this section we propose the introduction of credit discounting on the foreign abatement and the supplementarity condition. Namely, we propose that the amount of foreign abatement be discounted by the discounting factor β and the supplementarity condition be modified to apply to the discounted foreign abatement.

When credit discounting is introduced with the minimum required abatement specified by the Kyoto Protocol, each developed country faces the following optimization problem given the other countries' abatements

$$\max_{\{y_{ij}\geq 0\}_{j\in N}} B_i(y, w_i - \sum_j c_j y_{ij})$$
$$\text{subject to } 0 \leq \sum_j c_j y_{ij} \leq w_i$$
$$y_{ii} \geq \alpha\beta y_{i,-i,}\ y_{ii} + \beta y_{i,-i} \geq y_i^{KP}$$

The first constraint is a resource constraint. It reduces to the non-negativity condition of y_{ij}. The second condition is the supplementarity condition

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with credit discounting. The third one denotes the minimum required abatement with credit discounting. In the above problem, the Kuhn–Tucker condition is both necessary and sufficient for the optimum by the concavity of the net benefit function and the linearity of the constraints. The Kuhn–Tucker condition is as follows

$$\frac{\partial L}{\partial y_{i0}} = B_i^y - B_i^x c_0 - \alpha\beta\lambda_i + \beta\mu_i \leq 0,\ y_{i0} \geq 0,\ \frac{\partial L}{\partial y_{ii}} y_{i0} = 0 \tag{1}$$

$$\frac{\partial L}{\partial y_{ii}} = B_i^y - B_i^x c_i + \lambda_i + \mu_i \leq 0,\ y_{ii} \geq 0,\ \frac{\partial L}{\partial y_{ii}} y_{ii} = 0 \tag{2}$$

$$y_{ii} - \alpha\beta y_{i0} \geq 0,\ \lambda_i \geq 0,\ (y_{ii} - \alpha\beta y_{i0})\lambda_i = 0 \tag{3}$$

$$y_{ii} + \beta y_{i0} - y_i^{KP} \geq 0,\ \mu_i \geq 0,\ (y_{ii} + \beta y_{i0} - y_i^{KP})\mu_i = 0 \tag{4}$$

It is difficult to calculate the exact comparative static results as the discounting parameter β decreases from 1 to 0. However, we can figure out the general features from figure 2. Indeed, when the net benefit function is quasi-linear ($B_i(y,x_i) = F(y) + x_i$), we can show that the equilibrium follows the following loci as β decreases.

In figure 2, the line originating from the origin represents the supplementarity condition when $\alpha = 1$. The other line originating from the point $(0, y_i^{KP})$ represents the minimum abatement requirements. The arcs represent the indifference curves of country *i*.

When $\beta = 1$, we obtain the result that $y_{ii}^* = \alpha y_{i0}^*$ assuming interior equilibrium. In this case, since the abatement level y_i^{KP} is just determined to satisfy the third constraint while the first constraint is strictly binding, it follows that $\mu_i = 0$ and $\lambda_i > 0$.

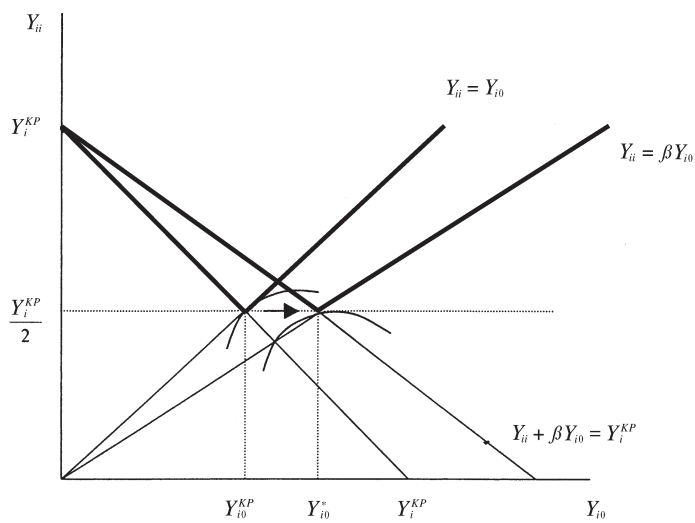


Figure 2. *Equilibrium under the credit discounting* ($\alpha = 1$)

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As β decreases further, both the lines representing the supplementarity condition and the total abatement constraint shift to the right as shown in the figure 2. However, the indifference map moves toward the left since the other country's abatement increases.

Intuitively, credit discounting increases both the virtual amount of foreign abatement and the virtual cost of foreign abatement per credit up to $\frac{1}{\beta}$ and $\frac{1}{\beta}c_0$ respectively, while increasing the required virtual total abatement.

When the discounting parameter β is close enough to 1 so that the net benefit $\frac{1}{\beta}(B_i^y - c_0 B_i^x)$ of a unit of discounted foreign abatement through the flexibility mechanisms is larger than that $B_i^y - c_i B_i^x$ of domestic abatement, then the additional abatement will be implemented in the developing countries. For instance, for $\beta \geq c_0/c_i$, the country i always prefers foreign abatement. Note that, at the optimum, $y_{ii}^* = \alpha\beta y_{i0}^*$ in the supplementarity condition (the second constraint). Except for a case where the domestic abatement becomes larger than the discounted foreign abatement, the total abatement constraint (the third constraint) continues to be binding. When both constraints are binding, it follows that

$$y_{ii}^* = \frac{\alpha}{(1+\alpha)} y_i^{KP}$$

and

$$y_{i0}^* = \frac{1}{\beta(1+\alpha)} y_i^{KP}.$$

At any rate, the equilibrium abatement increases as the discount factor β decreases in the neighborhood of c_0/c_i.

As β decreases further, the marginal cost of a unit of discounted foreign abatement becomes quite large. This makes the domestic abatement more attractive. In this case, at equilibrium, only the total abatement constraint is binding. When β is close to 0, all countries will conduct only the domestic abatement.

The welfare level also improves as β decreases from 1. Let $V_i(\beta)$ denote the welfare level of country i: $V_i(\beta) \equiv B_i(y_i^* + y_{-1}^*, w_i - \sum_j c_j y_{ij}^*)$. By applying the envelope theorem and incorporating the increase in the GHG abatement by other countries, we obtain the following

$$\frac{\partial V_i(\beta)}{\partial \beta} = \frac{\partial L(\beta)}{\partial \beta} = B_i^y \frac{\partial y^*_{-i}}{\partial \beta} - y_{i,-i}(\alpha\lambda_i - \mu_i)$$

From the Kuhn–Tucker condition, $\beta(\alpha\lambda_i - \mu_i) = B_i^y - B_i^x c_0$, and from the above, we have seen that, for the value of β sufficiently close to 1, $\frac{\partial y^*_{-i}}{\partial \beta} < 0$ and μ_i is close to 0. Thus, for a value of β sufficiently close to 1, it follows that $\frac{\partial V_i(\beta)}{\partial \beta} < 0$.

The first term in the above equation represents the welfare increase from the increase of other countries' GHG abatements. The second term repre-

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sents the welfare increase from the relaxed supplementarity condition. Therefore, for a value of β where $B_i^y - B_i^x c_0 \geq 0$ for all $i = 1, 2$, the decrease of β increases each country's welfare.

The following is a numerical example computed by the GAMS/MILES solver. Let $B_1(y, x_1) = x_1^{0.5} y^{0.5}$, $B_2(y, x_2) = x_2^{0.5} y^{0.5}$, $w_i = 1{,}000$ for $i = 1, 2$, $c_0 = 1.0$, $c_1 = 1.1$, $c_2 = 1.15$ and $\alpha = 1$. Then the agreed amount of abatement under the Kyoto Protocol is $y_1^{KP} = 324.8$ and $y_2^{KP} = 302.6$. As β decreases from 1 to 0.7, y_{10}^* increases from 162.4 to 232.0 while y_{11}^* stays constant at 162.4. The net benefit of country 1 increases from 643.0 to 670.1. The net benefit of country 2 increases from 650.6 to 681.6. Table 1 lists the result of a comparative static analysis for this example along with the result for the case of no supplementarity condition.

We can summarize the above discussion by the following proposition.

Proposition 3. *There exists a region [β*, 1] for the value of credit discounting factor* β *such that each country's welfare and its abatement of GHGs increase as* β *decreases*.

Note that the above result extends directly to the case of more than two countries. Note also that the above result remains true when the supplementarity condition is not imposed. This is easily verified in the equation denoting the changes in net benefits by letting $\lambda_i = \alpha = 0$.

The introduction of credit discounting is Pareto improving. Moreover, in the above example, credit discounting is better than the simple removal of the supplementarity condition. Without the supplementarity condition, the net benefits of countries 1 and 2 are equal to 666.7. With the supplementarity condition and credit discount of $\beta = 0.7$, the net benefit of country 1 is equal to 670.1 and the net benefit of country 2 is equal to 681.6.

Credit discounting increases the net benefit through two routes. One is by increasing the required GHG abatements. The other is by relaxing the supplementarity condition. On the other hand, the removal of the supplementarity condition improves the welfare by allowing cheaper foreign abatement. Thus, when the cost differential is small and the benefit of GHG abatement is large, credit discounting can be a more effective measure in improving welfare than the elimination of the supplementarity condition.

Table 1. *A numerical example: credit discount, GHG abatement, and net benefits*

β	y_{11}	y_{10}	B_1	y_{22}	y_{20}	B_2
			With supplementarity condition			
1.0	162.4	162.4	643.0	151.3	151.3	650.6
0.9	162.4	180.5	651.5	151.3	168.2	660.1
0.8	162.4	203.0	660.7	151.3	189.2	670.5
0.7	162.4	232.0	670.1	151.3	216.2	681.6
0.6	303.1	36.2	683.7	153.3	248.9	652.9
0.5	313.6	22.5	666.8	238.6	128.2	648.0
0.4	319.2	14.0	657.1	273.2	73.6	645.2
			Without supplementarity condition			
1.0	0.0	333.3	666.7	0.0	333.3	666.7

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4.2. Discussion

In this subsection, we discuss two issues. One is the comparison of credit discounting with the taxation on the clean development mechanism. The other is the consideration of the case of variable marginal cost.

In the 7th session of the Conference of the Parties in November of 2001, it was determined that 2 per cent of the certified emission reductions issued for a CDM project activity would be used to assist developing country parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation. This is a kind of charge or taxation on the CDM project activity. In terms of our model, this has the effect of raising the virtual cost of the foreign abatement by 2 per cent. This has the effect of reducing the amount of abatement and net benefit of each country. The taxation accompanies only an income transfer from the developed countries to the developing countries with no efficiency gain. Therefore, it would be more desirable to introduce credit discounting and create a separate fund to assist the adaptation of developing countries.

When the marginal cost of abatement is variable, the determination of the costs of CDM projects is difficult to model in a specific form. For instance, when more than two countries implement a clean development mechanism project in a third developing country, the marginal cost attributed to each country varies as both the order and magnitude of investment changes. Furthermore, when the marginal cost of abatement is variable, emissions trading and joint implementation cannot be ignored. These aspects make the analysis quite difficult. For simplicity of analysis, we consider the case where only the clean development mechanism is used and the marginal cost of abatement is linear. To determine the costs of CDM projects in a specific form, we also assume that the costs of CDM projects in a country are shared in proportion to the amount of abatement. Namely, when the amount of abatements by countries i and j is y_{i0} and y_{j0} respectively, the cost of abatement by country i is $\frac{y_{i0}}{y_{i0}+y_{j0}}$ of the total cost. We also assume that the net benefits function of each country is quasi-linear: $B_i(y, x_i) = F(y) + x_i$.

The problem for each country i given the other countries' abatements is as follows

$$\max_{y_{i0}, y_{ii} \geq 0} F_i(y) + w_i - \frac{1}{2}c_0 y_{i0}^2 - \frac{1}{2}c_i y_{ii}^2$$

$$\text{subject to } 0 \leq w_i - \frac{1}{2}c_0 y_{i0}^2 - \frac{1}{2}c_i y_{ii}^2 \leq w_i$$

$$y_{ii} \geq \alpha\beta y_{i0}, \; y_{ii} + \beta y_{i0} \geq y_i^{KP}$$

Following an analysis similar to that in subsection 4.1, assuming interior equilibrium, we obtain the following conditions

$$F_i' - c_i y_{ii} + \lambda_i + \mu_i = 0$$

$$F_i' - c_0\left(y_{i0} + \frac{1}{2}y_{j0}\right) - \alpha\beta\lambda_i + \beta\mu_i = 0$$

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Assuming an interior solution, we find that $y_{ii} = \frac{\alpha}{1+\alpha} y_i^{KP}$, and $y_{i0} = \frac{1}{\beta(1+\alpha)} y_i^{KP}$. The change in net benefit is expressed as follows

$$\frac{\partial V_i(\beta)}{\partial \beta} = -F_i'\left(\frac{y_i^{KP}+y_j^{KP}}{\beta^2(1+\alpha)}\right) + \frac{1}{2}c_0\left\{2y_{i0}\frac{y_i^{KP}}{\beta^2(1+\alpha)} + y_{i0}\frac{y_j^{KP}}{\beta^2(1+\alpha)} + y_{j0}\frac{y_i^{KP}}{\beta^2(1+\alpha)}\right\}$$
$$= -\frac{y_i^{KP}+y_j^{KP}}{\beta^2(1+\alpha)}(F_i' - c_0 y_{i0})$$

When the discount factor β is close to 1, μ_i is close to 1. Thus, from the first-order condition, we find that $(F_i' - c_0 y_{i0}) > 0$. Therefore for a discount factor β close to one, $\frac{\partial V_i(\beta)}{\partial \beta} < 0$. That is, the discounting increases the welfare level of each country as we have seen in the previous section for the case of constant marginal cost.

5. Concluding remarks

The negotiations for combating climate change involve the commons problem. This causes the outcome of the international agreements to be suboptimal. Although the flexibility mechanisms introduced by the Kyoto Protocol alleviate the suboptimality, the state is still far from Pareto optimum.

The introduction of credit discounting improves efficiency. It has the effect of increasing the amount of the required abatement. It also has the effect of relaxing the supplementarity condition by implicitly allowing the foreign abatement to be larger than the domestic abatement. Through these two effects, credit discounting can improve the welfare of participating countries. Moreover, in some cases, credit discounting can be more effective than the simple removal of the supplementarity condition in improving efficiency.

Many developing countries have difficulties in adapting to climate change and implementing policies geared to GHG emissions reduction. They have requested financial assistance and technology transfer. In the recent Bonn Agreement, a tax on the CDM project activities was introduced and it was supposed to be used for the financial assistance to the developing countries. We think that credit discounting is more appropriate than taxation on the flexibility mechanisms. The issue of financial assistance needs to be addressed independently of the flexibility mechanisms.

Our analysis also implies the limited ability of international agreements such as the UN Framework Convention on Climate Change and the Kyoto Protocol to prevent climate change. They may seem to be intended to be mechanisms of international environmental regulation. But, in fact, they just serve as a communication device that helps the participating countries to find a laissez-faire equilibrium.

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References

Aslim, M.A. (1998), 'Emissions trading: path of prospective "AIJ" development (a developing country viewpoint)', in P.W.F. Riemer, A.Y. Smith, and K.V. Thambimuthu (eds), *Greenhouse Gas Mitigation: Technologies for Activities Implemented Jointly*, Elsevier.

Barrett, S. (1994), 'Self-enforcing international environmental agreements', *Oxford Economic Papers* **46**: 878–894.

Bodansky, D. (1993), 'The United Nations Framework Convention on Climate Change: a commentary', *Yale Journal of International Law* **18**: 451, 453–558.

Carraro, C. and J.A. Filar (eds) (1995), *Control and Game-Theoretic Models of the Environment*, Birkhäuser.

Dockner, E. and N.V. Long (1993), 'International pollution control: cooperative versus noncooperative strategies', *Journal of Environmental Economics and Management* **24**: 13–29.

US EPA (2001), 'The United States experience with economic incentives to protect the environment', Office of the Administrator.

Folmer, H., N. Hanley, and F. Miβfeldt (1998), 'Game-theoretic modelling of environmental and resource problems: an introduction', in N. Hanley and H. Folmer (eds), *Game Theory and the Environment*, Edward Elgar.

Hoel, M. (1991), 'Global environmental problems: the effects of unilateral actions taken by one country', *Journal of Environmental Economics and Management* **20**: 55–70.

Hamway, R. and F. Szekely (1999), 'Practical approaches in the energy sector', in J. Goldemberg (ed.), *Issues and Options: The Clean Development Mechanism*, United Nations Development Programme, chapter 10.

Kosobud, R.F. (eds) (2000), *Emissions Trading*, John Wiley & Sons.

Martin, W.E., R.H. Patrick, and B. Tolwinski (1993), 'A dynamic game of a trans-boundary pollutant with asymmetric players', *Journal of Environmental Economics and Management* **24**: 1–12.

Shin, S. (1998), 'Developing country's perspective on COP 3 development (Kyoto Protocol)', *Energy Policy* **26**: 519–526.

Tattenbach, F. (1997), AIJ lower GHG emissions: a double or nothing approach', mimeo, presented in the *International Conference on Technologies for Activities Implemented Jointly*, organized by IEA Greenhouse Gas R & D Programme in 26–29 May, Vancouver, BC, Canada.

Wagner, U.J. (2001), 'The design of stable international environmental agreements: economic theory and political economy', *Journal of Economic Surveys* **15**: 377–411.

Welsch, H. (1993), 'An equilibrium framework for global pollution problems', *Journal of Environmental Economics and Management* **25**: S64–S79.

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