Devising an International Regime of Emission Rights to Moderate Global Warming : A Planning Theoretical Approach†

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ABSTRACT : This paper proposes a possible theoretical solution to moderate it by devising an international regime of emission-right certificates. More precisely, we present a discrete non-tâtonnement procedure for determining the sum of emission-right certificates (ERC) assigned to the nations in order to curb greenhouse gases such as carbon dioxide in the global atmosphere. The task to be undertaken under uncertainty by the procedure is to find a “livable” combination of global optimal levels of greenhouse gas emissions and atmospheric air quality. For that purpose, the procedure determines and revises the ERC supply and adjusts the step-size according to information from the whole earth. Finally, we prove that this procedure simultaneously achieves efficiency and local strategy proofness in the sense that it converges to a Pareto optimum, and sincere revelation of preferences for global atmospheric air quality is a dominant strategy for any nation on the earth. Aided by the “Visible Hand,” in the form of an international regime with both a discrete non-tâtonnement planning procedure and the market for emission rights, we attempt to give a market-oriented solution to the global market failure.

Key Words : emission rights, non-tâtonnement process, planning thery.

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Ⅰ INTRODUCTION

1. Global warming may be considered a "chronic disease" caused by the accumulation of 185 thousand million tons of carbon dioxide since the Industrial Revolution.[(1), (2)] As there is no surgical operation for our planet, and thus perfect recovery cannot be expected, we have no choice but to accept this incurable disease. Human beings are unable to have "zero emission solution," because they emit CO_2 when breathing. CO_2 is also a by-product in numerous manufactuaring procedures. Thus, we aim to find a "livable" combination of global optimal level of the ambient air quality and greenhouse gas emissions.

The environmental managers of many countries have been utilizing the command and control as well as the tax and subsidy systems. Efficiency of the systems, however, is likely to be lost, because they cannot be made cost-effective. Furthermore, the systems cannot confront the incentive problem because relevant information is privately held. Thus, very often, they can be neither informationally efficient nor incentive compatible.

Because global warming has become an internationally significant issue in recent years, increasing attention has been paid to other economic instruments which are considered more immediate and powerful remedies than the technological ones such as a method to fix the carbon dioxide, now being studied in several countries.

In the case of a single and homogeneous pollutant, a lump-sum effluent charge posed on each unit of the emitted pollutant leads firms to reduce their pollution. They independently choose a level of abatement cost that corresponds to the equality of their marginal costs, a condition leading to an efficient allocation. Of course, without knowledge of these costs, it is impossible to establish directly the rate of effluent charge associated with a socially optimal residual pollution level.

2. As has been demonstrated by Claude Henry (1989), however, the adjustment of this rate can be socially acceptable. He tries to answer the question; "Is it possible for the public authority overseeing the pollution problem to find a cost-effective allocation without an exact knowledge of the abatement costs privately held by the emitters as well as the marginal social damage suffered by the people affected by the pollution?" His answer is in the affirmative when the system of rights, or transferable permits

to pollute, is carried out by the public authority. He models the functioning of the sophisticated market of rights in the case where the public authority seeks to optimize the abatement when it knows only certain points of the marginal social damage function, which therefore plays an important role as the supply function of rights to pollute.

Henry's model deals with a lake as a public good in a country and considers its quality to be optimized by surrounding factories' not emptying discharge into the lake. The present paper attempts to apply and generalize his model to the global ambient air quality as a transfrontier public good in a dynamic setting when the rights are adjusted by the public authority and transferable among countries involved.

3. The concept of *emission rights*, originally attributable to J. H. Dales(1968), who was the first to advocate the concept of "pollution rights," moves into the limelight as a most promising and cost-effective way to moderate the greenhouse gas emissions. In this paper I will use the term "Greenhouse Gas Emission-Right Certificate" or the abbreviation "ERC". ERC represents the right to emit warming gases into the atmosphere while considering the need to protect global atmospheric quality.

Three important issues concerning ERC are in order: i) its sum, ii) its assignment, and iii) its monitoring. More precisely, these problems are: i) how to determine the sum of ERC to permit the countries to emit CO_2, ii) how to assign ERC to each country, and iii) how to monitor the emitting behavior of each country to assure compliance; i. e. to ascertain if any nation has exceeded the emission level permitted by ERC it possesses. In this paper we will deal with issues i) and ii) by devising an international regime of emission rights: i.e. by use of the planning method and the market for ERC. We will leave issue iii), which may be beyond the scope of economics, for future research.

4. It has been hitherto a general case that there is no public good at the beginning of the model, and the issue is how to decide an optimal quantity of the public good by using the private numéraire. Our case in the present paper is, however, that our planet exists already as the very pure public good, and the issue is how to choose both an acceptable quality of the global environment and a globally acceptable emission level. Thus we have to construct a model in a non-tâtonnement setting where both the current pollution level and global ambient air quality vary over time, instead

of providing an optimal amount of the public good as the result of the quantity adjustment by the tâtonnement. Moreover, in order that this model may be operational, it may as well be discrete, so that necessity compels us to devise a discrete non-tâtonnement procedure for determining the sum of rights to emit the greenhouse gases into the global atmosphere.

5. The remainder of the paper is organized as follows. The next section outlines the general framework, and Section III introduces Claude Henry's study to show the working of the markets to determine the international price of ERC. In Section IV we present a discrete non-tâtonnement procedure for determining and revising the sum of ERC and then examine the properties of our procedure. Section V explores nations' strategic manipulability in the procedure and presentes our main theorem on incentives of nations as to atmospheric air quality as a global common patrimonial good. The last section provides some final remarks.

II General Framework

1. *Notation*

In the beginning Earth had completely unpolluted ambient air quality, x^{**}. The global environment is now perceived to be a pure transboundary public good x which we have to protect. Let $\boldsymbol{N} = \{1, \ldots, N\}$ be the set of nations involved in the fatal problem of the global warming which may be caused by the greenhouse gases(3); viz. the whole earth, as polluters as well as victims of polluted air and gradually warming climate. Let G be an intergovernmental organizer named the "Global Environmental Organization (GEO)" that is in charge of determining the total amount of ERC, issuing and assigning it among nations, and monitoring those nations to check whether they release gases no more than the emission level permitted. In order to mitigate global warming, the GEO has to observe all the geographical areas in the world, inland or on the sea surface, where greenhouse gases are emitted. The GEO sets several geographical points inland or on the sea surface where air is observed and sampled, and air quality is technically evaluated by an observatory, such as the "laser radars" in operation in the northern hemisphere, so that there is a basis for determining the supply of ERC.

Each nation $i \in \boldsymbol{N}$ has a collective utility function $u^i(x, y^i)$ defined on its consumption set R^2_+, and owns an initial endowment of private good ω^i. Let $\boldsymbol{M} = \{1,\ldots,M\}$ be the set of polluting entities all over the world. A polluter/emitter j in each country i is represented by the abatement cost function g^{ij}: $\mathbf{R}_+ \to \mathbf{R}_+$, and $y^{ij} = g^{ij}(q^{ij})$ signifies the private good quantities needed to reduce greenhouse gas emissions in order not to further deteriorate global ambient air quality as a public good x. We shall call q^{ij} the emission caused by the firm j in a country i, and q the total emission which degrades the atmospheric air quality of the globe. As stated in Henry (1989), the amount q of air pollutants are assumed to be measured in quality-equivalent: i.e. the resulting ambient air quality becomes $x = x^{**} - q$ (a 'transfer function' in technical terminology), with $q = \sum_i \sum_j q^{ij}$. Any firm in the world must buy the corresponding ERC to emit greenhouse gases.

2. *Assumptions*

The following assumptions will be made throughout the paper.

Assumption 1. $(\forall i \in \boldsymbol{N})(\omega^i > 0)$. $\left(\sum_i \omega^i < \infty\right)$.

Assumption 2. For any $i \in \boldsymbol{N}$,

i) u^i is strictly quasi-concave and twice continuously differentiable,

ii) $\partial u^i(x, y^i)/\partial x \geqq 0$ and $\partial u^i(x, y^i)/\partial y^i > 0$ for any x and for any y^i, and,

iii) $\lim_{y^i \to +0} \partial u^i(x, y^i)/\partial x = 0$ for any x.

Assumption 3. For any $i \in \boldsymbol{N}$, and for any $j \in \boldsymbol{M}$,

i) g^{ij} is strictly convex and twice continuously differentiable, and

ii) $g^{ij}(0) = g'^{ij}(0) = 0$ and $g''^{ij}(q^{ij}) \geqq 0$ for any q^{ij}.

3. *Definitions*

Each producer/emitter's marginal cost of reducing greenhouse gas emissions such as CO_2 and each country's marginal rate of substitution between the public good and the private numéraire are represented respectively by:

$$\gamma^{ij} = dg^{ij}/dq^{ij}, \qquad \forall i \in \boldsymbol{N},\ \forall j \in \boldsymbol{M}$$

and

$$\pi^i = (\partial u^i/\partial x)/(\partial u^i/\partial y^i), \qquad \forall i \in \boldsymbol{N}.$$

An allocation a is an $(N+1)$ vector $(x,\ y^1,\dots,y^N)\in \mathrm{R}_+^{N+1}$.

Definition 1. An allocation a is feasible iff

$$a\in \boldsymbol{A}=\Big\{(x,\ y^1,\dots,y^N)\in \mathrm{R}^{N+1}\mid \sum\nolimits_i\,(y^i+\sum\nolimits_j g^{ij}(q^{ij}))=\sum\nolimits_i \omega^i\Big\}.$$

Definition 2. An allocation a is individually rational iff

$$(\forall\, i\in \boldsymbol{N})[u^i(x,\ y^i)\geqq u^i(0,\ \omega^i)].$$

Definition 3. An allocation a^* is Pareto optimal if there exists no allocation $a\in \boldsymbol{A}$

$$u^i(a)\geqq u^i(a^*),\qquad \forall\, i\in \boldsymbol{N}$$

and

$$u^k(a)>u^k(a^*),\qquad \exists\, k\in \boldsymbol{N}.$$

The assumptions and definitions altogether give us a condition for Pareto optimality in our global economy.

Lemma 2. 1. *Under Assumptions 1–3. a necessary and sufficient condition for an allocation $a^*\in \boldsymbol{A}$ to be Pareto optimal is*

$$\sum\nolimits_i \pi^i(x^*)\leqq \gamma^{ij}(q^*)\quad \text{and}\quad x^*>0\qquad \Rightarrow\qquad \sum\nolimits_i \pi^i(x^*)=\gamma^{ij}(q^*).$$

Efficiency requires the equality of marginal costs.

$$\gamma^{11}(q^{11*})=\cdots=\gamma^{\boldsymbol{NM}}(q^{\boldsymbol{NM}*}),$$

and

$$q^*=\sum\nolimits_i\sum\nolimits_j q^{ij*}.$$

Remark 1. Since $\gamma^{ij}(q^{ij*})$ is the same for any $i\in \boldsymbol{N}$ and for any $j\in \boldsymbol{M}$, let $\gamma(q^{ij*})$ be a common value. As in Henry(1989). let us assume no income effect on the atmospheric air quality as a transboundary public good, so we can write $\pi^i(x)$.

Generalization to many public goods, including the global ambient air quality, is straightforward. We shall focus only on an intergenerational public good: i.e. the atmosphere of the earth.

Ⅲ Markets for the Greenhouse Gas Emission-Right Certificates

In this section let us briefly introduce Claude Henry's superb results so as to establish our point of departure to the analysis of emission-right certificates. We shall consider the problem of determining the price of ERC by the international market that the GEO organizes by resorting to Henry's analysis with the demand-supply diagram in (1989) and (1990a).

Henry has gone beyond the results by Roberts and Spence(1976), Kwerel(1977), and Collinge and Bailey(1983). Since he needs no information from polluting firms, he is not faced with the incentive problem from the producers' side. He only requires several points of marginal social damage corresponding to the respective pollution level. We shall specify in Ⅳ. 2. the method of measuring or estimating damage by making use of the sampling to acquire the relevant information which can approximate the international supply correspondence Q of emission-right certificates as a step function as represented in Henry(1989) and (1990a).

We shall hereafter call an international market for ERC the "Eco-Mart," where trade occurs among nations. Either country i can sell the amount corresponding to $z^i - \sum_j q^{ij}$ at price τ if $z^i > \sum_i q^{ij}$; or it must buy the quantity equal to $\sum_j q^{ij} - z^i$ at price τ if $z^i < \sum_j q^{ij}$, where z^i is a supply of ERC assigned to country i. Any firm should buy a necessary amount of ERC at price τ to emit warming gases. This may be called the *Principle of Emission Rights* based on the Polluter Pays Principle.

According to Henry, we can have the following definition: i.e. international Eco-Mart equilibrium for ERC under uncertainty.

Definition 4. International Eco-Mart Equilibrium is a non-negative $(NM+1)$ vector $(\tau^e, q^{11e}, \ldots, q^{NMe})$ under uncertainty is defined as:

i) $\gamma^{ij}(q^{ije}) = \tau^e, \qquad \forall i \in \boldsymbol{N}, \ \forall j \in \boldsymbol{M}$

ii) $q(\tau^e) \in Q(\tau^e)$, where $q(\tau^e) = \sum_i \sum_j q^{ije}$.

where 'e' signifies the value at an equilibrium.

Remark 2. i) results from the standard cost-minimizing behavior of the firms all over the world, and ii) implies the equality of demand and supply for ERC. Obviously, it is likely that $q^{ije} = \gamma^{ij-1}(\tau^e) \neq q^{ike} = \gamma^{ik-1}(\tau^e)$ holds; however, $\gamma^{ij}, \ \forall i \in \boldsymbol{N}, \ \forall j \in \boldsymbol{M}$ is the same at the international Eco-Mart equilibrium.

Claude Henry has demonstrated the following theorems under the startling uncertainties associated with the information as to the mar-ginal social damage privately held by the residents around the lake polluted by the surrounding factories. :

Theorem 3. 1 [Henry (1989) and (1990a)]. *There exists an equilibrium price of rights to pollute such that*

i) *the demand does not exceed the maximum supply:*

$$q(\tau^e) \leqq z(\tau^e)$$

ii) *the excess demand prevails at any price* τ *less than the* τ^e

$$\forall \tau < \tau^e,\ q(\tau) > z(\tau).$$

From i) we can be assured that there is no excess demand at the equilibrium price of ERC, and this fact is very important from the viewpoint of actual emissions reduction. At any rate, adjustment of demand and supply for ERC can be ingeniously done by the price τ in the International Eco-Mart to allocate ERC among nations as well as emitting firms. The revenue τq is attributed to the GEO, which does not necessarily distribute it; instead, the GEO may well preserve revenue to donate to countries in need, such as the small island states in the Oceania, to support forestation or to fund preservation of tropical rainforests.

Let q^* denote the equilibrium amounts of rights determined at the intersection of demand and supply functions under complete information. Let $[q^k, q^{k+1}]$ be the interval for any $k = 1,\ldots, K$.

Theorem 3. 2 [Henry (1989) and (1990a)]. *There exists an integer* k *such that*

$$q^* \in [q^k, q^{k+1}] \quad \Rightarrow \quad q(\tau^e) \in [q^k, q^{k+1}].$$

This remarkable theorem says that both q^* and $q(\tau^e)$ exist in the same interval, even if neither k nor q^* is known. Despite this ignorance, the public authority can find $q(\tau^e)$ close to q^*. The distance between q^* and $q(\tau^e)$ can be as small as possible if the interval $[q^k, q^{k+1}]$ approaches zero.

It will be shown that the maximum supply of ERC is controlled by the GEO via the use of the procedure to be defined in the next section.

Ⅳ A Discrete Non-Tâtonnement Procedure for Greenhouse Gas Emission-Right Certificates

A Discussion of Discrete Non-Tatonnement Procedures

This section will deal with the issue cited in the Introduction: i.e. how the GEO will determine the total sum of ERC at the beginning of each year by making use of a discrete non-tatonnement procedure.

Casual observations suggest that discrete procedures are more realistic than continuous ones. Discrete versions of the MDP procedure(4) have been presented by several authors, and there are three different strains of related literature. The first strain—taken by Champsaur, Drèze, and Henry (1977)— is characterized by a decreasing adjustment pitch (or step-size) as a parameter, with which they could overcome a dilemma associated with a discrete formulation by keeping the pitch constant, as long as it allows progress in efficiency, and by halving it as soon as that progress is impossible. See Henry and Zylberberg(1978) for the graphical representation of how the decreasing pitch works.

As indicated by Malinvaud(1967) and others, this dilemma concerns a traditional technical difficulty and is summarized in such a way that if one selects a pitch large enough to get a rapid convergence, one runs the risk of no convergence. On the other hand, if one chooses a pitch small enough to expect an exact convergence, there is a possibility of delay.

Discussions on incentives in discrete-time MDP procedures are also given in Henry(1979) and Schoumaker(1977) and (1979), who analyzed strategic behavior by ruling out the assumption of truthful revelation. The result they achieved is that the process does still converge to a Pareto optimum even under strategic preference revelation à la Nash.

Secondly, Otsuki (1978) presented a view of using feasible direction methods to unify discrete procedures such as the MDP as well as the Heal Procedure, dealing with increasing returns to scale.

Thirdly, approaching the same issue from another angle, Green and Schoumaker (1980) presented a discrete MDP process with a flexible step-size at each iteration, and studied its incentive properties in the game theoretical framework. Although their ideas are interesting, the informational burden in their model is much greater than that in the former approach.

1. *Relevant Information Needed to Operate the Discrete Procedure*

Non-tatonnement procedures are of concern in real economic life as well as in our environmental issue, since greenhouse gas emissions and the resulting ambient air quality vary over time. Hence, in view of obvious practical relevance, we must construct our discrete process in a non-tatonnement setting. We shall show how it works to determine the sum of emission rights among nations.

Let each inhabitant $h \in \boldsymbol{H}$ in a country $i \in \boldsymbol{N}$ have a utility function $u^{ih}(x, y^{ih})$ defined on its consumption set $\mathbf{R}^2_+$, and own an initial endowment of private good ω^{ih}. Denote

$$\pi^{ih} = (\partial u^{ih}/\partial x)/(\partial u^{ih}/\partial y^{ih}), \qquad \forall i \in \boldsymbol{N},\ \forall h \in \boldsymbol{H}$$

as a marginal rate of substitution of an inhabitant in a nation.

In order to obtain national aggregate values π^i, for any i, we shall follow Nakatani(1979) to adopt a sampling approach so as to show that they are available as uniformly unbiased minimum variance estimators, respectively. This method can reduce the information gathering cost from the entire population of the world.

Suppose in each country that one can classify the population into areas according to some environmental features related to climatic conditions. Let $k^i = \{1,\ldots, K^i\}$ be the set of areas in nation i. In each area is an observatory where some observers reside as representative individuals. The number of observers is n^{ik}, $1 \leqq n^{ik} \leqq N^{ik}$, $\forall i \in \boldsymbol{N}$, $\forall k \in K^i$ and N^{ik} is all the inhabitants in area k in a country i. Here we have:

Theorem 4. 1 [Nakatani (1979)]. *π^i is the uniformly unbiased minimum variance estimator of $\sum_h \pi^{ih}$.*

Proof: By applying the proof in the Appendix in Nakatani (1979), we can easily get

$$\pi^i = \sum_h \sum_{k \in \boldsymbol{n}} (N^{ik}\pi^{ih}/n^{ik})$$

as the uniformly unbiased minimum variance estimator. ||

In what follows, we shall use π^i as the uniformly unbiased minimum variance estimator of $\sum_h \pi^{ih}$, which is involved in country i's willingness-to-pay functions. Analysis of incentives to report truthfully these values will be the main concern in Section V. Sincere revelation is assumed in this section. We will focus on the revelation of π^i, and as will be shown in V, π^i can be correctly revealed by every nation as a dominant strategy.

Let us also redefine a country i's minimum additional abatement cost to reduce worldwide greenhouse gas emission or maximum saving in abatement cost when releasing global emission as γ^i, expressed in terms of private numéraire, resulting from an increment or a reduction α,

$$\gamma^i = \sum_j \gamma^{ij} = \sum_j \{g^{ij}(q^{ij}-\alpha)-g^{ij}(q^{ij})\}, \text{ for any } i.$$

Let us denote $\gamma = (1/N)\sum_i \gamma^i$ hereafter.

At the beginning of each year, the GEO, as a planner, announces that it intends to improve the current ambient air quality x as a transnational public good by a feasible amount $\alpha(0)$ that the GEO chooses at the initial time on scientific grounds.

Let us introduce additional function: for any date $t \in \{0, 1, 2, \ldots\}$

$$\Pi^t = \sum_i \pi^{it}(x^t, \alpha^t)-\gamma^t(x^t, \alpha^t).$$

Generally, a step-size is determined as

$$\alpha^t = \beta^t \Pi^t |\Pi^t|^{N-2}, \qquad \beta^t \in \mathbf{R}_{++},$$

where β^t is a policy parameter concerning an adjustment speed the GEO decided at each iteration t.

Then the GEO asks every country i its willingness to pay function ϕ^{it} defined as

$$\phi^{it} = \pi^{it}\beta^t \Pi^t |\Pi^t|^{N-2}$$

such that

$$u^i(x^t+\alpha^t, y^{it}-\phi^{it}) = u^i(x^t, y^{it}).$$

The problem is to decide whether and in what direction to change the allocation to achieve a globally optimal pair of the environmental quality and the amount of gases to be emitted.

2. *Statement of the Discrete Non-Tatonnement Procedure for Emission-Right Certificates*

This subsection will formalize a discrete non-tatonnement version of the continuous-time process devised by Fujigaki and Sato(1981), so as to explain how to determine the sum of rights to emit warming gases.

The original Generalized MDP Procedures are characterized by the nonlinear rule for adjusting the amounts of public goods to be provided. In the discrete version, however, there must be modification of the public good revision rule as well as that of the information to be transmitted from the nations to the GEO, as will be shown soon.

We shall propose a discrete algorithm with variable endogenous step-size, which is both efficient and locally strategy proof. That is to say, it converges to a Pareto optimum, and revealing sincere preference for ambient air quality as a transboundary public good is a dominant strategy for any nation on the earth.

In our procedure originally due to Sato(1991), the GEO chooses a trajectory (or solution path) that matters in non-tâtonnement formulations. The GEO revises the sum of ERC according to the following rules: formally, our discrete non-tâtonnement procedure for ERC, termed the *Eco-Process*(5), reads for any $t \in \{0, 1, 2, \ldots\}$:

Revision of Supply of the Greenhouse Gas Emission-Right Certificates

$$z^{t+1} = z^t - \alpha^t$$

Global Ambient Air Quality Change

$$x^{t+1} = x^t - \alpha^t$$

Step-Size Adjustment

$$\alpha^t = \beta^t \Pi^t |\Pi^t|^{N-2}, \quad \beta^t \in \mathbf{R}_{++}$$

Revision of Endowments

$$y^{i,\, t+1} = y^{it} - \{\pi^{it} - (1/N)\Pi^t\} \beta^t \Pi^t |\Pi^t|^{N-2}, \quad \beta^t \in \mathbf{R}_{++}, \ \forall i \in \boldsymbol{N}, \text{ and } y^{i0} = \omega^i.$$

With our process, one of the following cases will be realized.

Case A: The public good quantity will be increased to $x^t + \alpha^t$: i.e. the global ambient air quality is ameliorated by α^t, for which each nation is asked to pay its contribution and the private numéraire will be adjusted accordingly. In other words, the supply of ERC is diminished, so that the worldwide gas emissions are lessened by the amount α^t.

Case B: The public good amount is decreased to $x^t - \alpha^t$: i.e. the global atmosphere is contaminated by α^t, so that each nation is paid the compensation for the degradation.

Stated differently, the supply of ERC is increased, hence the greenhouse gas emissions are increased by the amount α^t.

Case C: If neither an increase nor a decrease is possible, the GEO does not revise the allocation.

3. *Properties of the Discrete Non-Tatonnement Eco-Process*

The procedure is determined by the mapping $a = (x, y^1, \ldots, y^N)$ from $\mathbf{R}^N$ into $\mathbf{R}^{N+1}$. It associates with every indicator at iteration t, $(x^t, \alpha^t) \in \boldsymbol{A} \times (0, \infty)$, a correspondence $\xi(x^t, \alpha^t)$ of possible values for the indicator (x^{t+1}, α^{t+1}) at iteration t, which will be called an "admissible sequence," as in Champsaur, Drèze, and Henry (1977). Let $u^i(a) = \sum_h u^{ih}(a)$. We use the same notation as theirs.

Now we will examine the properties of the procedure just defined. We can easily show that it satisfies feasibility, monotonicity, and convergence, leaving the incentive properties for the next section.

Let us introduce additional function:

$$\Phi(x^t, \alpha^t) = \max\{0, \Pi(x^t, \alpha^t)\}.$$

Theorem 4. 2 (feasibility). $y^{it} > 0, \ \forall i \in \boldsymbol{N}$, and $(x^t, \alpha^t) \in \xi(x^t, \alpha^t) \Rightarrow a \in \boldsymbol{A}$.

Proof: It can be easily checked by summing $y^{i,\,t+1}$: i.e.

$$\sum_i y^{i,\,t+1} = \sum_i y^{it} - \gamma^t \text{ or } \sum_i y^{i,\,t+1} = \sum_i y^{it} + \gamma^t.$$

Theorem 4. 3 (monotoniciby). *For any admissible sequence one has for any* $i \in \boldsymbol{N}$:

$$\Phi(x^t, \alpha^t) = 0 \quad \Rightarrow \quad u^i(a^{t+1}) = u^i(a^t)$$
$$\Phi(x^t, \alpha^t) > 0 \quad \Rightarrow \quad u^i(a^{t+1}) > u^i(a^t).$$

Proof: The first statement is obvious. For the second, we must consider two cases: i) $\Pi^t > 0$ and ii) $\Pi^t < 0$.

Case i) $\Pi^t > 0$. This means that $\alpha^t > 0$ and then

$$u^i(x^{t+1} + \alpha^{t+1}, y^{i,\,t+1} - \pi^{i,\,t+1})$$
$$> u^i(x^t + \alpha^t, y^{it} - \pi^{it})$$
$$= u^i(x^t, y^{it}).$$

Case ii) $\Pi^t < 0$. Analogous to the case *i*).

Hence the Eco-Process is monotonic for any participating country i which can at least assure individual rationality. Moreover, it may get utility increment at the next iteration. Incentive to participate in the procedure, one of the most important issues concerning ERC, is thus assured, and our Eco-Process will resolve this problem.

Lemma 4. 1 (finiteness). *For any admissible sequence there exists an iteration s such that*

$$\Phi(x^s, \alpha^s) = 0.$$

Proof: See for example Henry and Zylberberg(1978).

Theorem 4. 4 (convergence). *Under Assumptions 2 and 3, every limit point of anv admissible sequence corresponds to a Pareto optimum.*

Proof: The proof is already provided in Champsaur, Drèze, and Henry(1977). Here we present a brief sketch of the proof. It is based on the fact that if a limit point of any admissible sequence were not a Pareto optimum, all other limit points of the same sequence could no longer be an optimum. Consequently, starting from an iteration t sufficiently large, one could always have $\Phi(x^t, \alpha^t) > \varepsilon > 0$, for a positive constant ε. This contradicts Lemma 4. 1 and the revision rule of step-size in our Eco-Process.

V Strategic Manipulability in the Eco-Process

We consider the international free rider problem in our discrete non-tâtonnement procedure described in the preceding section and examine its incentive properties in detail. Now the assumption of truthful revelation of preferences is relaxed. In what follows, each nation's announcement, ψ^i, need not be equal to its true value: i.e. its MRS, π^i.

Following Schoumaker(1979), we shall consider a local incentive game in which each country is now considered to be a player whose strategy set is $\mathbf{R}_+$, and whose payoff is its utility at the next iteration of the procedure.

Since the GEO can calculate the sum of messages from the agents:

$$\Psi^t = \sum_k \phi^{kt} - \gamma^t, \qquad i \in \boldsymbol{N},$$

one of the following cases is realized.

Case A′: $\Psi^t > 0$

The global air quality is ameliorated to be $x^t + \alpha^t$, and each country is asked to pay its contribution ϕ^{i+}. Its private numéraire in this case is:

$$y^{i,\, t+1} = y^{it} - \{\phi^{it} - (1/N)\Psi^t\}\beta^t \Psi^t |\Psi^t|^{n-2}$$
$$\beta^t \in \mathbf{R}_{++},\ \forall i \in \boldsymbol{N}, \text{ and } y^{i0} = \omega^i.$$

The payoff at the next iteration is obtained by

$$u^i(x^t,\ y^{it} - \{\phi^{it} - (1/N)\Psi^t\}\beta^t \Psi^t |\Psi^t|^{n-2}).$$

Case B′: $\Psi^t < 0$

The atmospheric quality is deteriorated to $x^t - \alpha^t$, and each country is paid the compensation ϕ^i for this reduction. Each nation therefore has $y^{i,\, t+1}$ and u^i as above, but with the inverse sign of Ψ^t.

Case C′: $\Psi^t = 0$

Every player remains at the *status quo*: i.e. for any $i \in \boldsymbol{N}$, we have

$$u^i(x^t,\ y^{it}).$$

Here we introduce two behavioral assumptions and a definition.

Assumption 4. Every country behaves myopically. Namely, when it determines its answer ϕ^i, it only allows for the utility it can get at the next iteration.

Remark 3. This behavioral hypothesis may be justified by considering that causality between global warming and emissions of greenhouse gases is now certain at this stage of the development of sciences, but that climate change in the future and its impact on global warming cannot be predicted for exactly. Hence, every country has to make a decision under gloomy uncertainty. Assumption 4 is common in local games associated with both continuous and discrete planning procedures such as the MDP and the CDH. Sec Henry(1979) and Schoumaker(1977) and (1979) for the details of this point.

Definition 5. A strategy ϕ^{i*} is said to be dominant for the game if

$$u^i(\phi^{i*}, \phi^{-i}) \geqq u^i(\phi^i, \phi^{-i})$$

for all ϕ^j, $j \neq i$, and for all ϕ^i.

Definition 6. A process is locally strategy proof if and only if for any $t \in \{0, 1, 2, \ldots\}$

$$(\forall i \in \boldsymbol{N})[u^i(\pi^{it}, \phi^{-it}) \geqq u^i(\phi^{it}, \phi^{-it})]$$

for all ϕ^{jt}, $j \neq i$, and for all ϕ^{it}.

We are now in a position to present our main theorem.

Theorem 5. 1. *Under Assumption 4. sincere revelation of preferences for global atmospheric air quality at any iteration of the Eco-Process is a dominant strategy for each nation.*

Proof: Immediately follows from the Theorem 4. 1. in Sato(2007).

Ⅵ A Discrete Non-Tâtonnement Procedure for Greenhouse Gas Emission-Eight Certificates

1. An alternative version of the Eco-Process as a Pivotal Procedure

At the beginning of each year, the GEO, as a planner, announces that it intends to improve the current ambient air quality x as a transnational public good by a feasible amount $\alpha > 0$ that the GEO chooses on scientific grounds. Then the GEO asks every country i its contribution: $\pi^{i+}(x, \alpha)$ if it will be able to enjoy a better global environment, $x^{+} = x+\alpha$, as well as its compensation: $\pi^{i-}(x, \alpha)$ it requires if x will be deteriorated by the amount α: i.e. $x^{-} = x-\alpha$, where $\pi^{i+}(x, \alpha)$ and $\pi^{i-}(x, \alpha)$ will be defined below. The problem is to decide whether or not the allocation should be changed in what direction to achieve a globally optimal pair of the environmental quality and the amount of gases to be emitted.

The following equalities define π^{i+} and π^{i-}, respectively:

$$u^{i}(x, y^{i}) = u^{i}(x^{+}, y^{i}-\pi^{i+}) \text{ for any } i,$$
$$u^{i}(x, y^{i}) = u^{i}(x^{-}, y^{i}+\pi^{i-}) \text{ for any } i.$$

We will also denote the country i's minimum additional abatement cost to reduce worldwide greenhouse gas emission as γ^{i+} and the maximum saving in abatement cost when releasing global emission as γ^{i-}, expressed in terms of private numéraire, resulting from an increment or a reduction α, respectively:

$$\gamma^{i+} = \sum_{j} \gamma^{ij+} = \sum_{j} \left\{ g^{ij}(q^{ij}-\alpha) - g^{ij}(q^{ij}) \right\} \text{ for any } i,$$
$$\gamma^{i-} = \sum_{j} \gamma^{ij-} = \sum_{j} \left\{ g^{ij}(q^{ij}) - g^{ij}(q^{ij}+\alpha) \right\} \text{ for any } i.$$

Let me denote $\gamma^{+} = (1/\boldsymbol{N}) \sum_{i} \gamma^{i+}$ and $\gamma^{-} = (1/\boldsymbol{N}) \sum_{i} \gamma^{i-}$ hereafter.

In our procedure, there can be pivots or pivotal states whose decisions can reverse the direction of revising the public good agreed by all other nations. At iteration t of the procedure, we define the set of pivotal countries in our setting, $\mathbf{P}^{t}$, as the union of four sets: those whose statements change the sign of the aggregate net contribution (resp. compensation) belong to $\mathbf{P}^{1t}$ or $\mathbf{P}^{2t}$ (resp. $\mathbf{P}^{3t}$ and $\mathbf{P}^{4t}$).

More formally: for $t \in \{0, 1, 2, \ldots\}$

$$i \in \mathbf{P}^{1t} \quad \Leftrightarrow \quad \left(\sum_{i} \pi^{it+} - \gamma^{t+}\right)\left[\sum_{k \neq i} \left(\pi^{kt+} - \xi^{kt}\gamma^{t+}\right)\right] = 0,$$
$$i \in \mathbf{P}^{2t} \quad \Leftrightarrow \quad \left(\sum_{i} \pi^{it+} - \gamma^{t+}\right)\left[\sum_{k \neq i} \left(\pi^{kt+} - \xi^{kt}\gamma^{t+}\right)\right] < 0,$$
$$i \in \mathbf{P}^{3t} \quad \Leftrightarrow \quad \left(\gamma^{t-} - \sum_{i} \pi^{it-}\right)\left[\sum_{k \neq i} \left(\zeta^{kt}\gamma^{t-} - \pi^{kt-}\right)\right] = 0,$$
$$i \in \mathbf{P}^{4t} \quad \Leftrightarrow \quad \left(\gamma^{t-} - \sum_{i} \pi^{it-}\right)\left[\sum_{k \neq i} \left(\zeta^{kt}\gamma^{t-} - \pi^{kt-}\right)\right] < 0,$$

where $\xi^{it} > 0,\ \forall i \in \boldsymbol{N},\ \sum_{i} \xi^{it} = 1$, and $\zeta^{it} > 0,\ \forall i \in \boldsymbol{N},\ \sum_{i} \zeta^{it} = 1$.

2. *A Discrete Non-Tâtonnement Eco-Process for ERC*

The GEO revises the allocation according to the following rules:

Case A: $x^{+}=x+\alpha$; i.e. the global environment is ameliorated by α, for which each nation is asked to pay its contribution and the private numéraire will be adjusted accordingly. In other words, the supply of ERC is diminished, so that worldwide gas emissions are lessened by the amount α.

Case B: $x^{-}=x-\alpha$; i.e. the global environment is contaminated by α, so that each nation is paid the compensation for the degradation. Stated differently, the supply of ERC is increased, hence the greenhouse gas emissions are increased by the amount α.

Case C: If neither an increase nor a decrease is possible, the GEO does not revise the allocation but halves the step size α.

Case D: If both an increase and a decrease is possible, the GEO does not revise the allocation but halves the step size α.

Remark Cases C and D cannot be resulted at the same time.

Formally, our discrete non-tâtonnement procedure for ERC, termed the *Eco-Process,* reads for any $t \in \{0, 1, 2, \ldots\}$:

Revision of Supply of the Greenhouse Gas Emission-Right Certificates

$$z^{t+1}=z^{t}-\alpha^{t} \text{ if } \sum_{i} \pi^{it+}(x^{t}, \alpha^{t})-\gamma^{t+}(q^{t}, \alpha^{t})>0 \text{ and}$$

$$\sum_{i} \pi^{it-}(x^{t}, \alpha^{t})-\gamma^{t-}(q^{t}, \alpha^{t})>0 \text{ if } A \text{ holds}$$

$$z^{t+1}=z^{t}+\alpha^{t} \text{ if } \sum_{i} \pi^{it-}(x^{t}, \alpha^{t})-\gamma^{t-}(q^{t}, \alpha^{t})<0$$

$$\sum_{i} \pi^{it+}(x^{t}, \alpha^{t})-\gamma^{t+}(q^{t}, \alpha^{t})<0 \text{ if } B \text{ holds}$$

$$z^{t+1}=z^{t} \quad \text{otherwise} \quad C \text{ or } D \text{ holds.}$$

Global Ambient Air Quality Change

$$x^{t+1}=x^{t}+\alpha^{t} \text{ if } A \text{ holds}$$

$x^{t+1} = x^t - \alpha^t$ if B holds

$x^{t+1} = x^t$ otherwise.

Step-Size Adjustment

$\alpha^{t+1} = \alpha^t$ if either A or B holds

$\alpha^{t+1} = \alpha^t/2$ otherwise.

Revision of Endowments

$$y^{i,\,t+1} = y^{it} - \xi^{it}\gamma^{t+}(q^t,\,\alpha^t)$$

$$-2\mu^{it}\sum_{k\neq i}\left\{\xi^{kt}\gamma^{t+}(q^t,\,\alpha^t) - \pi^{kt+}(x^t,\,\alpha^t)\right\} + \Theta^{it+}/N,\ \ \forall\, i \in \boldsymbol{N},\ \text{if } A \text{ holds}$$

with $\xi^{it} > 0,\ \forall\, i \in \boldsymbol{N}$, and $\sum_i \xi^{it} = 1$;

$\mu^{it} = 0$ if $i \notin \boldsymbol{P}^t$; $\mu^{it} = 1$ if $i \in \boldsymbol{P}^t$; $y^{i0} = \omega^i$.

$$y^{i,\,t+1} = y^{it} + \zeta^{it}\gamma^{t-}(x^t,\,\alpha^t)$$

$$-2\mu^{it}\sum_{k\neq i}\left\{\pi^{kt-}(x^t,\,\alpha^t) - \zeta^{kt}\gamma^{t-}(q^t,\,\alpha^t)\right\} + \Theta^{it-}/N,\ \ \forall\, i \in \boldsymbol{N},\ \text{if } B \text{ holds}$$

with $\zeta^{it} > 0,\ \forall\, i \in \boldsymbol{N}$, and $\sum_i \zeta^{it} = 1$;

$\mu^{it} = 0$ if $i \notin \boldsymbol{P}^t$; $\mu^{it} = 1$ if $i \in \boldsymbol{P}^t$; $y^{i0} = \omega^i$.

Distribution of Pivotal Payments

$$\Theta^{it+} = 2\sum_{i\in \mathbf{P}}\sum_{k\neq i}\left\{\xi^{kt}\gamma^{t+}(q^t,\,\alpha^t) - \pi^{kt+}(x^t,\,\alpha^t)\right\} \text{ if } A \text{ holds}$$

$$\Theta^{it-} = 2\sum_{i\in \mathbf{P}}\sum_{k\neq i}\left\{\pi^{kt-}(x^t,\,\alpha^t) - \zeta^{kt}\gamma^{t-}(q^t,\,\alpha^t)\right\} \text{ if } B \text{ holds}$$

with $\eta^{it} > 0,\ \forall\, i \in \boldsymbol{N}$, and $\sum_i \eta^{it} = 1$.

ξ^{it} (cost-sharing coefficient) and ζ^{it} (compensatory coefficient) may be defined respectively by

$$\xi^{it} = \sum_j q^{ijt}/q^t;\ \zeta^{it} = \sum_j \sum_{k\neq i} q^{kjt}/(N-1)q^t.$$

3. *Properties of the Discrete Non-Tatonnement Eco-Process*

The procedure is determined by the mapping $a = (x,\ y^1,\ldots,y^N)$ from $\mathbf{R}^N$ into

$\mathbf{R}^{N+1}$. It associates with every indicator at iteration t, $(x^t, \alpha^t) \in A \times (0, \infty)$, a correspondence $\phi\ (x^t, \alpha^t)$ of possible values for the indicator (x^{t+1}, α^{t+1}) at iteration t, which will be called an "admissible sequence," as in Champsaur, Drèze, and Henry (1977). Define.

$$\Pi^+(x^t, \alpha^t) = \sum_i \pi^{it+} - \gamma^{t+}$$

$$\Pi^-(x^t, \alpha^t) = \gamma^{t-} - \sum_i \pi^{it-}$$

$$\Phi(x^t, \alpha^t) - \max\{0, \Pi^+(x^t, \alpha^t), \Pi^-(x^t, \alpha^t)\}.$$

Theorem 6. 1 (feasibility). $y^{it} > 0$, $\forall i \in \boldsymbol{N}$, and $(x^t, \alpha^t) \in \phi(x^t, \alpha^t) \Rightarrow a \in \boldsymbol{A}$.

Theorem 6. 2 (monotonicity). For any admissible sequence one has for any $i \in \boldsymbol{N}$:

$$\Phi(x^t, \alpha^t) = 0 \quad \Rightarrow \quad u^i(a^{t+1}) = u^i(a^t)$$
$$\Phi(x^t, \alpha^t) > 0 \quad \Rightarrow \quad u^i(a^{t+1}) > u^i(a^t).$$

Lemma 6. 1 (finiteness). For any admissible sequence there exists an iteration s such that

$$\Phi(x^s, \alpha^s) = 0.$$

Theorem 6. 3 (convergence). Under Assumptions 2 and 3, every limit point of any admissible sequence corresponds to a Pareto optimum.

Ⅶ Strategic Manipulability in the Pivotal Eco-Process

In the Local Incentive Game, the set of pivots has to be modified by replacing π^{it+} and π^{it-} with ϕ^{it+} and ϕ^{it-} which are not necessarily true values; $\mathbf{P}^{\,t}$ is the union of four sets:

$$i \in \mathbf{P}^{1\,t} \Leftrightarrow \left[\sum_i \phi^{it+} - \gamma^{t+}\right]\left[\sum_{k \neq i}\left(\phi^{kt+} - \xi^{kt}\gamma^{t+}\right)\right] = 0,$$

$$i \in \mathbf{P}^{2\,t} \Leftrightarrow \left[\sum_i \phi^{it+} - \gamma^{t+}\right]\left[\sum_{k \neq i}\left(\phi^{kt+} - \xi^{kt}\gamma^{t+}\right)\right] < 0,$$

$$i \in \mathbf{P}^{3\,t} \Leftrightarrow \left[\gamma^{t-} - \sum_i \phi^{it-}\right]\left[\sum_{k \neq i}\left(\zeta^{kt}\gamma^{t-} - \phi^{kt-}\right)\right] = 0,$$

$$i \in \mathbf{P}^{4\,t} \Leftrightarrow \left[\gamma^{t-} - \sum_i \phi^{it-}\right]\left[\sum_{k \neq i}\left(\zeta^{kt}\gamma^{t-} - \phi^{kt-}\right)\right] < 0,$$

where $\sum_k \xi^{kt} = 1,\ \xi^{kt} > 0,\ \forall k \in \boldsymbol{N}$, and $\sum_k \zeta^{kt} = 1,\ \zeta^{kt} > 0,\ \forall k \in \boldsymbol{N}$.

$$\Psi^{t+} = \sum_k \phi^{kt+} - \gamma^{t+}, \qquad i \in \boldsymbol{N},$$

$$\Psi^{t-} = \gamma^{t-} - \sum_k \phi^{kt-}, \qquad i \in \boldsymbol{N}.$$

Case A: $\Psi^{t+} > 0$ and $\Psi^{t-} < 0$

The global air quality is ameliorated to $x^{+} = x + \alpha$, and

$$y^{i,\ t+1} = y^{it} - \xi^{it}\gamma^{t+} - 2\mu^{it} \sum_{k \neq i} \left(\xi^{kt}\gamma^{t+} - \phi^{kt+}\right) + \Theta^{it+}/N$$

with $\mu^{it} = 0$ if $i \notin \mathbf{P}^{t}$; $\mu^{it} = 1$ if $i \in \mathbf{P}^{t}$;

$$\Theta^{it+} = 2 \sum_{i \in \mathbf{P}^t} \sum_{k \neq i} \left(\xi^{kt}\gamma^{t+} - \phi^{kt+}\right).$$

(a) $u^i\left(x^{t+},\ y^{it} - \xi^{it}\gamma^{t+} - 2\mu^{it} \sum_{k \neq i} \left(\xi^{kt}\gamma^{t+} - \phi^{kt+}\right) + \Theta^{it}/N\right)$.

Case B: $\Psi^{t+} < 0$ and $\Psi^{t-} > 0$

The atmospheric quality is deteriorated to $x^{-} = x - \alpha$, and

$$y^{i,\ t+1} = y^{it} + \zeta^{it}\gamma^{t-} - 2\mu^{it} \sum_{k \neq i} \left(\phi^{kt-} - \zeta^{kt}\gamma^{t-}\right) + \Theta^{it-}/N$$

with $\mu^{it} = 0$ if $i \notin \mathbf{P}^{t}$, $\mu^{it} = 1$ if $i \in \mathbf{P}^{t}$;

$$\Theta^{it-} = 2 \sum_{i \in \mathbf{P}^t} \sum_{k \neq i} \left(\phi^{kt-} - \zeta^{kt}\gamma^{t-}\right),$$

(b) $u^i\left(x^{t-},\ y^{it} + \zeta^{it}\gamma^{t-} - \mu^{it} \sum_{k \neq i} \left(\zeta^{kt}\gamma^{t-} - \phi^{kt-}\right) + \Theta^{it-}/N\right)$.

Case C: $\Psi^{t+} \leqq 0$ and $\Psi^{t-} \leqq 0$

Every player remains at the *status quo*: i.e. for any $i \in \boldsymbol{N}$,

(c) $u^i(x^t,\ y^{it})$.

Case D: $\Psi^{t+} \geqq 0$ and $\Psi^{t-} \geqq 0$

As in *Case C*, the allocation is not changed, which entails

(d) $u^i(x^t,\ y^{it})$.

Assumption 4. Every country behaves myopically. Namely, when it determines its answers ϕ^{i+} and ϕ^{i-}, it only allows for the utility it can get at the next iteration.

Assumption 5. When country i is indifferent about whether to reveal $\phi^{i+} = \pi^{i+}$ (resp. $\phi^{i-} = \pi^{i-}$) or $\phi^{i+} \neq \pi^{i+}$(resp. $\phi^{i-} \neq \pi^{i-}$), it announces its preferences truthfully.

Assumption 6. When N is large, each country ignores the impact of its announcements on $(1/N)\Theta^{it+}$ or $(1/N)\Theta^{it-}$.

Definition 5. A strategy (ϕ^{i+*}, ϕ^{i-*}) is said to be dominant for the game if $u^i(\phi^{i+*}, \phi^{i-*}) \geqq u^i(\phi^{i+}, \phi^{i-})$ for all ϕ^{j+}, ϕ^{j-}, $j \neq i$, and for all ϕ^{i+}, ϕ^{i-}.

Definition 6. A discrete process is locally strategy proof if and only if for any $t \in \{0, 1, 2, \ldots\}$

$$(\forall i \in \boldsymbol{N})\ [u^i(\pi^{it+}, \pi^{it-}) \geqq u^i(\phi^{it+}, \phi^{it-})]$$

for all ϕ^{jt+}, ϕ^{jt-}, $j \neq i$, and for all ϕ^{it+}, ϕ^{it-}.

Theorem 7. 1 (local strategy proofness). Under Assumptions 4, 5, and 6, sincere revelation of preferences for global atmospheric air quality at any iteration of the Eco-Process is a dominant strategy for each nation.

Ⅷ Final Remarks

This paper has proposed a theoretical possibility to moderate global warming by presenting an international regime of emission rights for determining the sum of rights to emit greenhouse gases via the discrete non-tatonnement Eco-Process, and allocating it to nations via the international Eco-Mart. This procedure can achieve simultaneously efficiency and local strategy proofness in the sense that it converges to a Pareto optimum and that truthful revelation of preference for the ambient air quality is a dominant strategy for each nation, and cost-minimizing behavior leads any polluting firm to choose efficient emission level. Aided by the “Visible Hand”, in the form of international regime with the discrete non-tatonnement planning procedure as well as the market for ERC, we have attempted to give a market-oriented solution to the global market failure. We recognize that the study has just begun, and that much remains to be done in this research(6).

This paper has made five premises which are in order : i) no discrimination of pollutant, ii) no spatial differentiation, iii) competitive market for ERC, iv) no speculation about ERC, and v) no income effect.

i) We may justify a hypothesis of a single and homogeneous pollutant by the conversion of the other greenhouse gases into CO_2. See note (2) for this point.

ii) Since the global environment is regarded to be the very pure public good, we have proceeded our analysis without differentiating where to emit warming gases. Strictly speaking, however, one has to allow for the difference about the concentration of CO_2 between the northern and southern hemispheres. An accumulation of CO_2 is observed much higher in the northern hemisphere than in the southern one.

iii) The Eco-Mart has been considered to be perfectly competitive, because there are many emitters in countries demanding ERC all over the world. Moreover, the public monopsony will not be detrimental to the price of ERC, since its supply is controlled by the GEO.

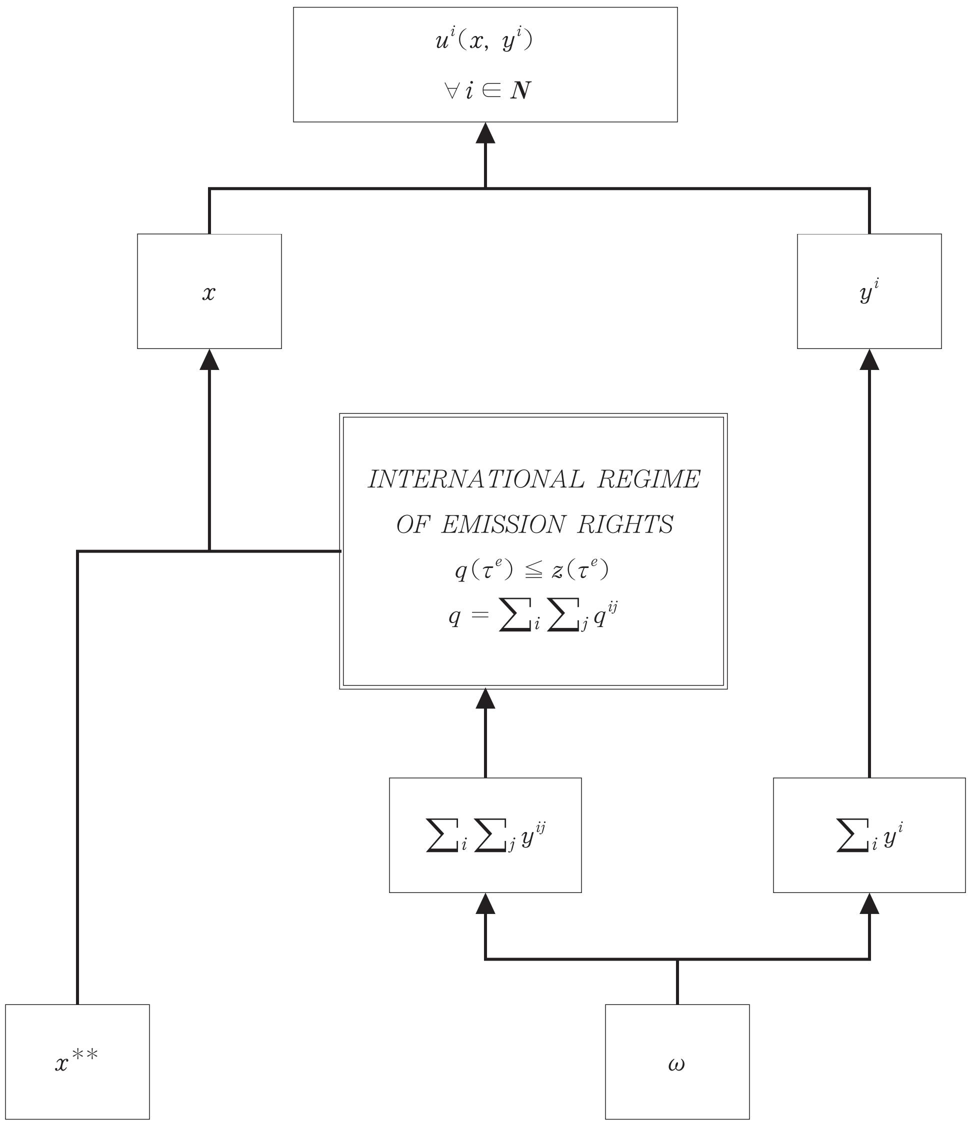
iv) Our Eco-Process revises the supply of ERC every year, which is assumed to hold only within a year, hence anxiety about the speculation is removed.

v) The last premise may not be an innocuous one, since increasing GNP may augment the CO_2 , which entails the degradation of resulting ambient air quality.

The present paper does not claim that economics alone can provide a perfect solution to the warming problem, but it appears that economics offers a possible avenue to limited success in the global environmental issues. If this paper makes other scientists aware of the potential of the international regime of emission rights, its most significant purpose will have been served.

† This is one of papers that are dedicated to the global environmental problems. An earlier draft of this paper was presented at the annual meeting of the Japan Association of Theoretical Economics and Econometrics held at Kwansei Gakuin University, October 13, 1990. Thanks are due to Professor Toru Mori for his discussion at the Meeting. The author is also grateful to Professors Haruo Ogawa and

STRUCTURE OF THE MODEL



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NOTES

(1) See S. Schneider (1989) for a comprehensive study about global warnsing. See also C. Schneider (1989).

(2) CO_2 is now regarded as a "numeraire gas," into which other greenhouse gases such as chlorofluorocarbons(CFCs), and methane are converted. The method is now being devised in the Japanese Industrial Standard(JIS). See *World Resources 1990–91* for the concept of "Global Warming Potential."

(3) For global warming, see, for example, Nowotny(1989) and S. Schneider(1989). There are four types of emission trading to mitigate this phenomenon: i.e. bubbles, netting, offsets, and banking. For this point, see OECD(1989), pp. 89–90. For the various ways of pollution abatement in European countries, see Henry(1990b) and OECD(1989). See also the Clean Air Act just recently amended 1990 in the United States.

(4) The essence of the MDP procedure can be captured in Henry and Zylberberg (1977), who also treated the case of increasing returns to scale. See, in addition, the recent work by Mukherji(1989) for a lucid digest of the MDP procedure. See, of course, their original papers: Drèze and de la Vallée Poussin(1971), and Malinvaud (1971). The MDP procedure can be seen as a "non-tâtonnement process," because of its feasibility, it can be truncated at any time.

(5) The term "Eco-Process" is an abbreviation of an "econo-bionomical" process which intends to establish the compatibility between our economy and ecosystem.

(6) For a relevant research, see Sato(2004) for an idea of introducing the Principle

of Emission Right in the "International Law of the Atmosphere" to curb CO_2 emission which causes a greenhouse warming. See also Sato(2000), (2001), (2002) and (2008) for a hedonic approach to global warming, biodiversity and urban heat island.

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