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Self-enforcing International Environmental Agreement

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Abstract

This paper aims to analyze the stability of self-enforcing International Environmental Agreement (IEA). In this paper the stability of an IEA is studied using a two-stage game. In the first stage each country decides non-cooperatively whether or not to join the IEA, and in the second stage signatories and non-signatories make decision on the levels of their emissions. This study has employed two conjectures for analyzing signatories' and non-signatories' emissions in the second stage. The first conjecture is based on Cournot assumptions, where signatories and non-signatories simultaneously choose their emissions. The second conjecture is based on the Stackelberg assumptions, where signatories are the first players to choose their emissions. The analytical results have shown that non-signatories' emissions are lower than signatories' emissions in both Stackelberg and Cournot cases. Moreover, this study has employed the numerical simulation to explain how the stability conditions operate to select a stable IEA. The results show that the number of signatories in both Stackelberg and Cournot cases are determined by the slope of marginal damage cost. The number of signatories in the case of Stackelberg is always higher than that in the case of Cournot, whereas total pollution in the case of Stackelberg is lower. However, the weakness of Stackelberg case is that the number of countries that sign in the IEA decreases when the slope of marginal damage cost increases. Since signatory's net benefit is lower whereas non-signatory's net benefit is higher when the slope of marginal damage cost rises, non-signatory that looks like a free rider gains from the increase in the slope of marginal damage cost whereas signatory who is the first player to choose her emission loses her net benefit. Thus, the number of signatories decreases when the slope of marginal damage cost rises.

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1. Introduction

The issue of climate change induced by the accumulation of greenhouse gas (GHG) in the atmosphere is an important global environmental problem. The impact of the increase in GHG concentration in each country depends not only on its current GHG emissions, but also on the emissions by other countries as well as the greenhouse gas accumulation. In order to remedy such the problem, the cooperation among countries is necessary. The international environmental agreement, such as the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol[2], formalizes an international commitment to GHG mitigation. Nevertheless, there is a following question about how to design the International Environmental Agreement (IEA) which gives the countries an incentive to both join and abide by such an agreement. The publications have studied the role of IEA to mitigate the environmental problem using the method of non-cooperative game. The concept of the non-cooperative game is that the players make decision independently. Therefore, in the absence of any international authority, the successful agreement must be self-enforcing. For the agreement to be self-enforcing, it must be profitable, that is, there must be potential gains to all signatory countries. In addition, it must be stable, that is, no country has an incentive to revise its participation decision in the sense that signatories have no incentive to withdraw from the agreement while non-signatories have no incentive to join the agreement.

The concept of the self-enforcing IEA was initially proposed by Carraro and Siniscaclo (1993) and Barrett (1994). Carraro and Siniscaclo adopt the concept of cartel stability[3] that is introduced by D'Aspremont, Jacquemin, Gadszeweiz and Weymark (1983)

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[2] The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change (UNFCCC). The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing GHG emissions. These amount to an average of 5% against 1990 levels over the five-year period from 2008-2012 (Kyoto Protocol to the United Nations Framework Convention on Climate Change United Nation, 1988)

[3] Cartel Stability is defined as a cartel for which there is no incentive for any individual members to leave or any outsiders to join.

to construct the concept of a stable IEA[4]. Barrett (1994) has employed the Stackelberg assumptions to analyze the stability of the IEA. Signatories, who act as the Stackelberg leader, choose their abatement effort[5] to maximize the sum of net abatement benefit of all signatories. Each non-signatory, who acts as the follower, then chooses her abatement effort to maximize her own net abatement benefit. That is, signatories have an advantage over non-signatories as signatories choose their emissions based on the reaction function of non-signatories. The main result concludes that the increase in the ratio of marginal abatement cost to marginal abatement benefit reduces the number of signatories to the self-enforcing IEA and global abatement.

Barrett's paper initiates a series of publications about the self-enforcing IEA. In stead of the Stackelberg assumptions, Hoel and Schneider (1997) use the Cournot assumptions that both signatories and non-signatories simultaneously choose their emission levels in the one period. Afterward, Rubio and Casino (2005) apply the self-enforcing IEA model using the Cournot assumptions to a multi-period, stock pollutant case. In this model, non-signatories choose the level of emissions in each period simultaneously and non-cooperatively in order to maximize the discounted present value of the stream of net benefit taking as given the strategy of the other countries. Meanwhile, signatories make their decisions cooperatively among themselves (and non-cooperatively against non-signatories) in order to maximize the discounted present value of the stream of the aggregate net benefits of all signatories. More recently, the survey of Finus (2008) argues that if there is one period, the global emission under a situation in which the coalition acts as a Stackelberg leader is lower than that under a situation in which the coalition acts as a Cournot player.

This research extends the frontier of environmental economics to the dynamic IEA framework. Combining the Stackelberg assumptions of Barrett (1994) and the Cournot assumptions of the self-enforcing IEA model with stock pollutant by Rubio and Casino (2005), this study wishes to investigate the factors affecting signatory's emissions, non-

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[4] Stable IEA means that no individual signatory has an incentive to leave the IEA, and no non-signatory has an incentive to join the IEA, taking the membership decisions of all other countries as given. Moreover, the definition of a self-enforcing IEA is the concept of a stable IEA.

[5] Abatement effort is defined as a reduction in the flow of emissions.

signatory's emissions, and total pollution, as well as to analyze the stability of the IEA. The results under the Stackelberg assumptions will then be compared with those under the Cournot assumptions in the case of two periods. For the self-enforcing IEA model with the Stackelberg assumptions, after a coalition is formed each signatory who acts as the leader is the first player to collectively choose her emissions in order to maximize her aggregate net benefit. Each non-signatory then chooses her emissions in order to maximize her own net benefit. For the self-enforcing IEA model with the Cournot assumptions, signatory and non-signatory simultaneously choose their emissions to maximize the aggregate net benefit and own net benefit, respectively.

This paper thus raises three research questions. First, if there are two periods, what are the factors affecting the total pollution? Second, is the resulting international environmental agreement stable? Third, are the global emissions under a situation in which the coalition acts as the Stackelberg leader lower than those under a situation in which the coalition acts as the Cournot player?

2. Literature Review

The early papers, such as Barrett (1994) and Hoel and Schneider (1992), analyze the stability of International Environmental Agreement (IEA) in a static framework. Barrett has employed the concept of Stackelberg game to analyze the stability of IEA. He assumes that signatories who act as the Stackelberg leaders are the first players to choose their abatement levels. Afterwards non-signatories will choose their abatement levels. Hoel and Schneider, however, have employed the concept of Cournot game to analyze the stability of IEA. They assume that signatories and nonsignatories simultaneously choose their emissions[6]. Barrett's paper has shown that a stable IEA can

[6] The study from Diamantoudi and Sartzetakis (2006) exhibits the different results that are not due to the choice variable. Since the abatement effort is defined as a reduction in the flow of emissions, the abatement is meaningful only in the presence of emissions, and thus the maximum level of abatement is constrained by the maximum uncontrolled flow of emissions. Nevertheless, the difference between two choices variables arises in the case of stock pollutant, whose stock could be technologically and economically viable to reduce. In such a case, it could be possible to abate more than the current flow of emission. That is, it could be possible to have a negative net flow of emissions.

have any number of signatories between two and the grand of coalition of all countries. Hoel and Schneider have shown that if signatories act as the Cournot players with respect to non-signatories, then a stable IEA consists of three signatories when marginal environmental damage cost is constant, and of two signatories when the marginal environmental damage cost is linear. Moreover, both Barrett (1994) and Hoel and Schneider (1992) have employed the numerical simulation to analyze the global abatement and global emissions, respectively. In the study of Barrett, the global abatement depends on the ratio of the slope of marginal abatement cost to the slope of marginal abatement. If this ratio is low (high), then global abatement is high (low). The study of Hoel and Schneider has shown that global emissions are determined by the marginal damage cost. If the marginal damage cost is low (high), then global emissions are high (low).

Rubio and Casino (2005) and Sbragia and Zaccour (2010) have extended the self-enforcing IEA model to a dynamic setting in order to analyze the stability of IEA under the Cournot assumptions. However, two studies have different assumptions. The first assumption is the time variable. Rubio and Casino let the time variable be continuous whereas Sbragia and Zaccour let the time variable be discrete. The second assumption is the pattern of damage cost function. Rubio and Casino let the damage cost function be quadratic whereas Sbragia and Zaccour let the damage cost function be linear. The results of two studies are thus different. The results from Rubio and Casino show that both signatory's emissions and non-signatory's emissions depend on the initial stock pollutant. They are decreasing (increasing) along the optimal path if the initial stock pollution is smaller (larger) than its steady-state value. In addition, accumulated emissions are increasing (decreasing) along the optimal path if the initial stock pollution is smaller (larger) than its steady-state value. However, the study from Sbragia and Zaccour has shown that signatory's emissions are independent of the stock pollution and non-signatory's emissions. Similarly, non-signatory's emissions are also independent of the stock pollution and signatory's emissions.

Furthermore, Barrett (1994) and Rubio and Casino (2005) have employed simulations to solve for the number of signatories. The study of Barrett has shown that the self-enforcing IEA will be signed by several countries when the ratio of marginal abatement cost to marginal abatement benefit is small. The study of Rubio and Casino has shown that the stock of pollution is lower as the ratio of marginal benefit to marginal damage cost rises. The results from simulation show that the number of signatories is equal to 2 when the number of countries in the world is equal to 10, the natural decay rate is equal to 0.005, the intercept of marginal benefit is equal 10, the slope of marginal benefit is equal to 1,650, the slope of marginal damage cost is equal to 0.001, and the discount rate is equal to 0.025.

3. The Self-enforcing IEA Model

This section first explains the assumptions of the self-enforcing IEA model and then describes the structure of coalition formation by using a two-stage game.

3.1 The Model Description

The assumptions of the model in this paper are based on the self-enforcing IEA model with stock pollutant by Rubio and Casino (2005) as follows.

(1) There are N identical countries.

(2) There are two periods.

(3) The Benefit Function:

Denote e_{it} as emissions by country i. These emissions are associated with a natural resource whose consumption provides the utility to the consumers of the country. Thus, each country gets the benefit from its emissions. Each country's quadratic benefit function is

$$B_i\left(e_{it}\right) = ae_{it} - \frac{b}{2}e_{it}^2 \quad , a, b > 0 . \tag{1}$$

(4) The Damage Cost Function:

Since no country can avoid the environmental damage cost, the environmental damage cost function depends on the GHG accumulated emissions $\left(z_t\right)$. Each country's quadratic damage cost function is

$$C_i\left(z_t\right) = \frac{c}{2}z_t^2 \quad , c > 0 . \tag{2}$$

(5) The Net Benefit Function:

Each country i's net benefit function is

$$\pi_i\left(e_{it}, z_t\right) = ae_{it} - \frac{b}{2}e_{it}^2 - \frac{c}{2}z_t^2 . \tag{3}$$

(6) The pollution stock constraints are

$$z_0 = \sum_{i=1}^{N} e_{i0} \tag{4}$$

$$z_1 = \left(1-\delta\right) z_0 + \sum_{i=1}^{N} e_{i1} \tag{5}$$

where δ is the natural decay rate. $\delta \in \left(0,1\right)$.

From the pollution stock constraints, Equation (4) shows that, in the initial period ($t = 0$) accumulated emissions are simply equal to total emissions of all countries in that period. Equation (5) shows that, in period 1 ($t = 1$) accumulated emissions are equal to the sum of the remaining stock of emissions after deterioration from period 0 plus the net aggregate emissions occurring in period 1.

3.2 The Structure of Coalition Formation

This paper has employed a two-stage game to explain the structure of coalition formation.

3.2.1 The First Stage (Membership Game)

In the first stage, each country plays a simultaneous open membership game. The strategies for each country are to sign or not sign, and any player is free to join the agreement. The agreement is formed by all players who choose to sign. Finally, they assume that the signature of the agreement is binding on signatories so that they acquire a commitment to stay in the agreement during the second stage of the game. We now introduce the definition of the equilibrium of the first-stage membership game. The IEA with n signatories is stable or self-enforcing if it satisfies two following properties in Definition 1.

Definition 1: An IEA consisting of n signatories is self-enforcing if $W_i(n) \geq W_j(n-1)$ and $W_j(n) \geq W_i(n+1)$, where $i = 1, \ldots, n$ and $j = 1, \ldots, N-n$.

In this study, we denote the signatories' net benefit and the non-signatories' net benefit by $W_i(\cdot)$ and $W_j(\cdot)$, respectively such that

$$W_i = \left(ae_{i0} - \frac{b}{2} e_{i0}^2 - \frac{c}{2} z_0^2 \right) + \beta \left(ae_{i1} - \frac{b}{2} e_{i1}^2 - \frac{c}{2} z_1^2 \right) \quad (6)$$

$$W_j = \left(ae_{j0} - \frac{b}{2} e_{j0}^2 - \frac{c}{2} z_0^2 \right) + \beta \left(ae_{j1} - \frac{b}{2} e_{j1}^2 - \frac{c}{2} z_1^2 \right) \quad (7)$$

where β is the discount rate, $\beta \in (0,1)$.

From Definition 1, $W_i(n) \geq W_j(n-1)$ is called "Internal Stability", which means that any signatory country is at least as well off staying in the IEA as leaving, assuming that all other countries do not change their membership decisions. $W_j(n) \geq W_i(n+1)$ is called "External Stability", which means that any non-signatory is at least as well off being non-signatory as joining the IEA, assuming that all other countries do not change their membership decision. Then Definition 1 implies that the international environmental agreement consists of n signatories is self-enforcing if no individual signatory country has an incentive to leave the IEA, and no non-signatory country has an incentive to join the IEA, taking the membership decisions of all other countries as given.

3.2.2 The Second Stage (Emissions Game)

Suppose that, as the outcome of the first-stage game, there are n signatories and $N-n$ nonsignatories. The second stage of the game applies the concepts of the Stackelberg and Cournot models, which are rather different. Under the Stackelberg assumptions, each signatory is the first player to choose her emissions, and then each non-signatory will choose her emissions. Under the Cournot assumptions, signatories and non-signatories simultaneously choose their emissions.

4. The Analytical Results

This section presents the analytical results of signatory's and non-signatory's emissions in the two-period self-enforcing IEA model. The first part focuses on the two-period self-enforcing IEA model with the Stackleberg assumptions, while the second part focuses on the two-period self-enforcing IEA model with the Cournot assumptions.

4.1 The Two-period Self-enforcing IEA Model with the Stackelberg Assumptions

In this model, n signatories act as the Stackelberg leaders with respect to $N-n$ non-signatories. That is, signatories are the first players to choose their emissions in both period 0 and period 1. Therefore, we find signatory's emissions and non-signatory's emissions by backward induction method.

4.1.1 Non-signatory's Maximization Problem in Period 1

Each non-signatory chooses her emission in period 1 $\left(e_{j1}\right)$ to maximize her own net benefit in period 1 such that given her expectation of the other non-signatories' emissions in period 1 $\left(\overline{e}_{j1}\right)$. The non-signatory's maximization problem in period 1 is given by

$$\max_{\{e_{j1}\}} \ ae_{j1} - \frac{b}{2}e_{j1}^2 - \frac{c}{2}z_1^2$$
$$s.t. \ \ z_1 = \left(1-\delta\right)z_0 + ne_{i1} + \left(N-n-1\right)\overline{e}_{j1} + e_{j1}$$

The first-order condition is

$$a - be_{j1} = cz_1\left(\frac{\partial z_1}{\partial e_{j1}}\right) \tag{8}$$

From Equation (8), the optimality condition for this problem is for non-signatory to choose her emission in period 1 up to the point where the marginal benefit is equal to the marginal damage cost in period 1

According to the assumptions, all countries are identical. So, we obtain the non-signatory's reaction function in period 1 given by

$$e_{j1} = \frac{a - c(1-\delta) z_0 - cne_{i1}}{b + c(N-n)} \tag{9}$$

4.1.2 Signatory's Maximization Problem in Period 1

Each signatory chooses her emission in period 1 (e_{i1}) to maximize the aggregate net benefit in period 1 subject to the pollution stock constraint in period 1 and Equation (9). The signatory's maximization problem at the period 1 is given by

$$\max_{\{e_{i1}\}} \; n\left(ae_{i1} - \frac{b}{2}e_{i1}^2 - \frac{c}{2}z_1^2 \right)$$
$$s.t. \;\; z_1 = (1-\delta) z_0 + ne_{i1} + (N-n)e_{j1}$$
$$e_{j1} = \frac{a - c(1-\delta) z_0 - cne_{i1}}{b + c(N-n)}$$

The first-order condition is

$$n(a - be_{i1}) = n\left[cz_1 \left(\frac{\partial z_1}{\partial e_{i1}} \right) \right] \tag{10}$$

From Equation (10), the optimality condition for this problem is for each signatory to choose her emission in period 1 up to the point where the coalition's marginal benefit is equal to the coalition's marginal damage cost in period 1.

From Equation (10), we obtain the signatory's emissions in period 1 given by

$$e_{i1} = \frac{a - ncz_1}{b} \tag{11}$$

4.1.3 Non-signatory's Maximization Problem in Period 0

Each non-signatory chooses her emission in period 0 $\left(e_{j0}\right)$ to maximize her own net benefit in period 0 subject to the pollution stock constraints and Equation (9), given her expectation of other non-signatories' emissions in period 1 $\left(\overline{e}_{j0}\right)$. The non-signatory's maximization problem in period 0 is given by

$$\max_{\{e_{j0}\}} \left(ae_{j0} - \frac{b}{2}e_{j0}^2 - \frac{c}{2}z_0^2\right) + \beta\left(ae_{j1} - \frac{b}{2}e_{j1}^2 - \frac{c}{2}z_1^2\right)$$

$$s.t.\ \ z_0 = ne_{i0} + \left(N-n-1\right)\overline{e}_{j0} + e_{j0}$$

$$z_1 = \left(1-\delta\right)z_0 + ne_{i1} + (N-n)e_{j1}$$

$$e_{j1} = \frac{a - c\left(1-\delta\right)z_0 - cne_{i1}}{b + c\left(N-n\right)}$$

The first-order condition is

$$a - be_{j0} + \beta\left[a\left(\frac{\partial e_{j1}}{\partial e_{j0}}\right) - be_{j1}\left(\frac{\partial e_{j1}}{\partial e_{j0}}\right)\right] = cz_0\left[\frac{\partial z_0}{\partial e_{j0}}\right] + \beta\left[cz_1\left[\frac{\partial z_1}{\partial e_{j0}}\right]\right] \qquad (12)$$

From Equation (12), the optimality condition for this problem is for non-signatory to choose her emission in period 0 up to the point where the present value of marginal benefit is equal to the present value of marginal damage cost.

Since non-signatories are identical, we obtain the non-signatory's reaction function in period 0 given by

$$e_{j0} = \frac{1}{b}\left[a - c\left(ne_{i0} + (N-n)e_{j0}\right) - \left(1-\delta\right)\beta cz_1 - \frac{\left(1-\delta\right)\beta c^2 z_1}{b}\right] \qquad (13)$$

4.1.4 Signatory's Maximization Problem in Period 0

Each signatory chooses her emission in period 0 $\left(e_{i0}\right)$ to maximize the aggregate net benefit in period 0 subject to the pollution stock constraints, Equation (11) and (13). The signatory's maximization problem in period 0 is given by

$$\max_{\{e_{i0}\}} \; n\left\{\left(ae_{i0}-\frac{b}{2}e_{i0}^{2}-\frac{c}{2}z_{0}^{2}\right)+\beta\left(ae_{i1}-\frac{b}{2}e_{i1}^{2}-\frac{c}{2}z_{1}^{2}\right)\right\}$$

$$s.t.\;\; z_{0}=ne_{i0}+\left(N-n-1\right)\overline{e}_{j0}+e_{j0}$$

$$z_{1}=\left(1-\delta\right)z_{0}+ne_{i1}+(N-n)e_{j1}$$

$$e_{i1}=\frac{a-ncz_{1}}{b}$$

$$e_{j0}=\frac{1}{b}\left[a-c\left(ne_{i0}+(N-n)e_{j0}\right)-\left(1-\delta\right)\beta cz_{1}-\frac{\left(1-\delta\right)\beta c^{2}z_{1}}{b}\right]$$

The first-order condition is

$$n\left\{a-be_{i0}+\beta\left[a\left(\frac{\partial e_{i1}}{\partial e_{i0}}\right)-be_{i1}\left(\frac{\partial e_{i1}}{\partial e_{i0}}\right)\right]\right\}=n\left\{cz_{0}\left(\frac{\partial z_{0}}{\partial e_{i0}}\right)+\beta\left[cz_{1}\left(\frac{\partial z_{1}}{\partial e_{i0}}\right)\right]\right\} \tag{14}$$

From Equation (14), the optimality condition for this problem is for each signatory to choose her emission in period 0 up to the point where the coalition's present value of marginal benefit is also equal to the coalition's present value of marginal damage cost.

From Equation (14), we obtain the signatory's emissions in period 0 given by

$$e_{i0}=\frac{1}{b}\left[a-ncz_{0}-n\left(1-\delta\right)\beta cz_{1}-\frac{n^{3}\left(1-\delta\right)\beta c^{2}z_{1}}{b}\right] \tag{15}$$

The results from Equations (9), (11), (13), and (15) give rise to Proposition 1.

Proposition 1 In the self-enforcing IEA model with the Stackelberg assumptions, signatory's emissions are lower than non-signatory's emissions, that is, $e_{i0} < e_{j0}$ and $e_{i1} < e_{j1}$.

4.2 The Two-period Self-enforcing IEA Model with the Cournot Assumptions

In this model, n signatories act as the Cournot players with respect to $N-n$ non-signatories. Both signatories and non-signatories choose their emissions simultaneously. Therefore, signatory's emissions and non-signatory's emissions can be calculated through standard method.

4.2.1 Non-signatory's Maximization Problem

Each non-signatory chooses her emissions e_{j0} and e_{j1} to maximize her own net benefit such that given her expectation of the other non-signatories' emissions $\bar{e}_{j0}$ and $\bar{e}_{j1}$. The non-signatory's maximization problem is given by

$$\max_{\{e_{j0},e_{j1}\}} \left(ae_{j0} - \frac{b}{2}e_{j0}^2 - \frac{c}{2}z_0^2\right) + \beta\left(ae_{j1} - \frac{b}{2}e_{j1}^2 - \frac{c}{2}z_1^2\right)$$
$$s.t.\ \ z_0 = ne_{i0} + \left(N-n-1\right)\bar{e}_{j0} + e_{j0}$$
$$z_1 = \left(1-\delta\right)z_0 + ne_{i1} + \left(N-n-1\right)\bar{e}_{j1} + e_{j1}$$

The first-order conditions are

$$a - be_{j0} = cz_0\left(\frac{\partial z_0}{\partial e_{j0}}\right) + \beta\left[cz_1\left(\frac{\partial z_1}{\partial z_0}\right)\left(\frac{\partial z_0}{\partial e_{j0}}\right)\right] \qquad (16)$$

$$a - be_{j1} = cz_1\left(\frac{\partial z_1}{\partial e_{j1}}\right) \qquad (17)$$

Equation (16) implies that the optimality condition for this problem is for non-signatory to emit her emissions in period 0 up to the point where the marginal benefit in period 0 is equal to the sum of the marginal damage cost occurred in period 0 and the marginal damage cost affected by e_{j0} that will occur in period 1.

Equation (17) implies that the optimality condition for this problem is for non-signatory to emit her emissions in period 1 up to the point where the marginal benefit in period 1 is equal to the marginal damage cost occurred in period 1.

According to the assumptions, all countries are identical. So, we obtain the non-signatory's emissions in period 0 and period 1 given by

$$e_{j0} = \frac{a - cz_0 - (1-\delta)\beta c z_1}{b} \tag{18}$$

$$e_{j1} = \frac{a - cz_1}{b} \tag{19}$$

4.2.2 Signatory's Maximization Problem

Each signatory chooses her emissions e_{i0} and e_{i1} to maximize the aggregate net benefit. The signatory's maximization problem is given by

$$\max_{\{e_{j0},e_{j1}\}} \; n\left\{\left(ae_{i0} - \frac{b}{2}e_{i0}^2 - \frac{c}{2}z_0^2\right) + \beta\left(ae_{i1} - \frac{b}{2}e_{i1}^2 - \frac{c}{2}z_1^2\right)\right\}$$

$$s.t.\;\; z_0 = ne_{i0} + (N-n)e_{j0}$$

$$z_1 = (1-\delta)z_0 + ne_{i1} + (N-n)e_{j1}$$

The first-order conditions are

$$n\{a - be_{i0}\} = n\left\{cz_0\left(\frac{\partial z_0}{\partial e_{i0}}\right) + \beta\left[cz_1\left(\frac{\partial z_1}{\partial z_0}\right)\left(\frac{\partial z_0}{\partial e_{i0}}\right)\right]\right\} \tag{20}$$

$$n\{a - be_{i1}\} = n\left\{cz_1\left(\frac{\partial z_1}{\partial e_{i1}}\right)\right\} \tag{21}$$

Equation (20) implies that the optimality condition for this problem is for each signatory to emit her emissions in period 0 up to the point where the coalition's marginal benefit in period 0 is equal to the sum of the coalition's marginal damage cost occurred in period 0 and the coalition's marginal damage cost caused by e_{i0} that will occur in period 1.

Equation (21) implies that the optimality condition for this problem is for each signatory to emit her emissions in period 1 up to the point where the coalition's marginal benefit in period 1 is equal to the coalition's marginal damage cost occurred in period 1.

From Equation (20) and (21), we obtain signatory's emissions in period 0 and period 1 given by

$$e_{i0} = \frac{a - ncz_0 - n(1-\delta)\beta cz_1}{b} \qquad (22)$$

$$e_{i1} = \frac{a - ncz_1}{b} \qquad (23)$$

The results from Equations (18), (19), (22), and (23) give rise to Proposition 2.

Proposition 2 : In the self-enforcing IEA model with the Cournot assumptions, signatory's emissions are lower than non-signatory's emissions, that is, $e_{i0} < e_{j0}$ and $e_{i1} < e_{j1}$.

5. The Simulation Results

According to the two models in the previous section, the results do not clearly indicate for the stability conditions. We thus apply the simulation technique in order to explain how the stability conditions operate to select a stable IEA. Furthermore, the numerical results can be useful to analyze the effect of the parameters on the signatory's emissions, non-signatory's emissions, and the stock pollution. The parameters are selected from the study of Rubio and Casino (2005).

Table 1 The number of signatories in the Stackelberg case for various b and c

c \ b	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000
0.3	10	10	10	10	10	10	10	10	10	10
0.4	7	7	7	7	7	7	7	7	7	7
0.5	5	5	5	5	5	5	5	5	5	5
0.6	3	3	3	3	3	3	3	3	3	3
0.7	2	2	2	2	2	2	2	2	2	2
0.8	0	0	0	0	0	0	0	0	0	0

Source : Own Calculation

Table 2 The number of signatories in the Cournot case for various b and c

c \ b	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000
0.001	0	0	0	0	0	0	0	0	0	0
0.01	2	2	2	2	2	2	2	2	2	2
0.3	3	3	3	3	3	3	3	3	3	3
0.4	3	3	3	3	3	3	3	3	3	3
0.5	3	3	3	3	3	3	3	3	3	3
0.6	3	3	3	3	3	3	3	3	3	3

Source : Own Calculation

Table 1 and Table 2 present the effects of the ratio of b to c on the number of signatories in the Stackelberg and Cournot cases, respectively. Various attempts in varying the slope of marginal damage cost show that the number of signatories in both Cournot and Stackelberg cases are affected by the slope of marginal damage cost. In the Stackelberg case, the increase in the slope of marginal damage cost reduces the number of signatories. In the Cournot case, although the increase in the slope of marginal damage cost raises the number of signatories, the agreement in this case can consist of no more than three countries.

Table 3 Total pollution in period 0 in the Stackelberg case for various b and c

c \ b	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000
0.3	5,535	2,876	1,944	1,467	1,179	985	846	741	660	594
0.4	5,668	2,913	1,945	1,477	1,185	989	849	744	661	595
0.5	5,755	2,935	1,970	1,482	1,189	992	850	745	662	596
0.6	5,838	2,956	1,979	1,488	1,191	994	853	746	664	598
0.7	5,857	2,961	1,982	1,489	1,193	994	853	746	664	598
0.8	5,857	2,963	1,982	1,490	1,193	994	853	746	664	598

Source : Own Calculation

Table 4 Total pollution in period 0 in the Cournot case for various b and c

c \ b	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000
0.001	5,989	2,995	1,997	1,497	1,198	998	856	749	666	599
0.01	5,988	2,995	1,997	1,497	1,198	998	856	749	666	599
0.3	5,934	2,985	1,992	1,495	1,196	997	855	748	665	599
0.4	5,917	2,982	1,991	1,494	1,196	997	855	748	665	598
0.5	5,900	2,978	1,989	1,493	1,195	997	854	748	665	598
0.6	5,887	2,975	1,988	1,493	1,195	996	854	748	664	598

Source : Own Calculation

Table 3 and Table 4 present the effects of the ratio of b to c on total pollution in the Stackelberg and Cournot cases; respectively. The results from numerical simulation show that total pollution in both cases are determined by the slope of marginal benefit and the slope of marginal damage cost. The increase in the slope of marginal benefit enlarges both coalition's marginal benefit and non-signatory's marginal benefit. Thus, both signatories and non-signatories reduce their emissions, and hence total pollution is lower as the slope of marginal benefit rises. However, the increase in the slope of marginal damage cost enlarges both coalition's marginal damage cost and non-signatory's marginal damage cost. Thus, signatory and non-signatory reduce their emissions, and hence total pollution is lower as the slope of marginal damage cost rises.

Furthermore, the numerical results present the comparison between total pollutions in the Stackelberg and Cournot cases. The results show that under a situation in which the coalition acts as the Stackelberg leader, total pollution is lower than that under a situation in which the coalition acts as the Cournot player. This result is similar to the conclusion of Barrett (1994), which shows that total pollution in one period under the Stackelberg assumptions is lower than that under the Cournot assumptions. However, the weakness of conjecture of Stackelberg is that the number of signatories decreases as the slope of marginal damage cost rises. Since signatory's net benefit is lower whereas non-signatory's net benefit is higher when the slope of marginal damage cost rises, non-signatory that looks like a free rider gains from the increase in the slope of marginal damage cost whereas signatory who is the first player to choose her emission loses her net benefit. Thus, the number of signatories decreases as the slope of marginal damage cost rises. For the Cournot case, although the number of signatories increases as the slope of marginal damage cost rises, the coalition can consist of no more than three countries.

6. Conclusion and Recommendation

The objectives of this paper is to analyze the stability of self-enforcing international environmental agreement in a dynamic framework such that the environmental damage cost is associated with a stock externality, and to investigate the factors affecting total pollution. The literature of international environmental agreement has employed the concept of non-cooperative game. The concept of the non-cooperative game is to assume that players make decision simultaneously and independently. Therefore, in the absence of any international authority, the successful agreement must be self-enforcing. Coalition formation has been designed as a two-stage game. In the first stage (membership game), each country decides non-cooperatively whether or not to join an IEA. In the second stage (emissions game), signatories and non-signatories choose their emissions to maximize the aggregate net benefit and own net benefit, respectively. The emission game is separated into two cases using the two different concepts. The first concept is based on the Cournot assumptions, where signatories and non-signatories simultaneously choose their emissions. The second concept is based on the Stackelberg assumptions, where the group of signatories who act as the leader are the first player to choose their emissions.

According to the results of this paper, there are two main conclusions in this paper. The first conclusion is that signatory's emissions are always lower than the non-signatory's emissions. Since signatories who care the global environmental problem must commit themselves to prevent the environmental problem, non-signatories who look like the free riders do not care the environmental problem, but they care only their own net benefit.

The second conclusion shows that total pollution under a situation in which the coalition acts as the Stackelberg leader is always lower than that under a situation in which the coalition acts as the Cournot player. However, the weakness of Stackelberg concept is that the number of signatories decreases as the slope of marginal damage cost rises. Since signatory's net benefit is lower whereas non-signatory's net benefit is higher when the slope of marginal damage cost rises, non-signatories gain from the increase in the slope of marginal damage cost whereas signatory who is the first player to choose her emissions loses her net benefit. Thus, the number of signatories decreases when the slope of marginal damage cost rises. For the Cournot case, although the number of signatories increases as the slope of marginal damage cost rises, the coalition can consist of no more than three countries. This conclusion leads to a suggestion for the policy to the Untied Nations Framework Convention on Climate Change (UNFCCC). The concept of Stackleberg is suitable for mittigating the global environmental problem. Annex I countries that have a commitment to reduce the levels of greenhouse gases (GHGs) should be the first group to reduce GHGs. Non Annex I countries that have not ratified the agreement will choose their emissions afterwards. ✍

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