Strategic International Agreement on Global Environment Management*

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Abstract

When future international agreement on global environmental control is anticipated, decisions for controlling current carbon gas emissions by improving the country's abatement capabilities are strongly affected by the likelihood of such agreements as well as their probable outcome. We construct a two-period, two-country model where the quality of the atmospheric environment is a global public capital. Countries invest in abatement investments in the first period and engage in production activities in the second period. Applying the incomplete contract approach to this model where (re)negotiation with or without side payments may take place in the second period, we examine the following questions: What are the characteristics of countries that make their bargaining position more advantageous? What are the cause of distortions in *ex ante* capital investments as well as in *ex post* incentives for environmental improvement? What are the characteristics of countries that are prone to these distortions?

Key words and phrases. environmental regulations, strategic effects, Nash bargaining, comparative statics

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1 Introduction

The problem of global warming is a universal concern for all humankind. Its effects will be felt widely, from high-tech firms in the industrialized world to people living in arid areas of developing countries. Actions carried out by our generation will significantly affect the welfare of all future generations. Despite the universal impact our decisions regarding the management of environmental change and sustainable development, there are heterogeneous and sometimes conflicting views about how to tackle global warming. For example, some people propose severe reductions in carbon gas emissions, while others oppose them. Even among these advocates, some support uniform taxation, while others argue for non-uniform taxation whose rates positively relate with the country's GDP.[1] The present paper is aimed at theoretically analyzing why these heterogeneous views emerge and what factors we should consider when another international agreement for global environmental controls is in sight.

Compared with a decade ago, the issue of global environmental control has become much more widespread and the public's awareness environmental problems has increased drastically. In 1995, an international agreement was struck in Kyoto to start a coordinated effort to contain world-wide carbon gas emissions. However, no developing countries pledged to actively participate in this cooperative effort. In fact, emission levels for many developing countries have actually increased rapidly since the Kyoto agreement. Moreover, the US, the country with the highest level of carbon emissions, declared that it will not ratify this protocol. Why doesn't increasing public concern coupled with greater visibility of global environmental issues induce leading countries to try to contain environmental destruction?

We view that one of the reasons for unwillingness of several major governments to cooperate lies in the very fact that they anticipate a future inter-

[1] Uzawa [8] is an example of the proposal for non-uniform taxation.

national agreement to cover the post-Kyoto period. When governments get together to negotiate and design an (new) international agreement, the outcome will be significantly affected by the bargaining power of each country. Unfortunately, the magnitude of a country's bargaining power will depend negatively upon its stake in the bargaining outcome. For example, countries with larger stakes will become more desperate to sign an agreement. Countries with relatively less pollution control costs tend to be easily persuaded to accept smaller bargaining gains. On the other hand, countries with higher cost to contain emissions and/or who are known to care little about the environment may resist an unfavorable compromise. Because such non-cooperation will be credibly viewed by other negotiation partners, the negotiation is likely to end with those countries with the latter characteristics benefiting more at the cost of those with the former characteristics.

The above arguments suggest that, anticipating future international bargaining, an incentive exists to refrain from investments for controlling environmental destruction because doing so only deteriorates the country's future bargaining position. Thus, a government may be allured to improve its strategic position in future negotiations by holding back energy saving investment and, in extreme cases, by further deteriorating its own environmental situation.

In this paper, we analyze such a possibility using a simple two-period, two-country model. Each country emits carbon gas as a by-product of economic activity in the second period. An increase in this emission adversely affects both countries as external diseconomies. The extent of this effect, however, is assumed to depend upon the recipient country's environmental consciousness, the parameter representing how sensitive the country is to degradation of the world environment. A country's carbon gas emission per GDP is assumed to depend upon its efficiency of pollution abatement. Abatement efficiency, in turn, is assumed to depend upon investment in pollution control during the first period. Two countries may differ in their technologies for abatement investment. We assume two countries expect to sign a binding international agreement in period 2 and they choose efficiency improvement investment non-cooperatively in period 1, anticipating the period 2 bargaining.

For the second-period bargaining, we mainly use the Nash bargaining solution with side-payments, under the assumption that associated non-cooperative outcomes will be realized if the negotiation breaks down. With this solution concept, the agreement will provide exactly one half of the bargaining surplus (i.e., the aggregate gains from achieving efficient outcome compared with the non-cooperative equilibrium) to each country, in addition to the payoff it would have obtained had the non-cooperative outcome prevailed.

We explore the incentives for strategic investment that emerge because the countries anticipate future bargaining. We identify two effects of pre-bargaining investment incentives compared with when there is no *ex-post* bargaining. They are the *bargaining-frontier expansion effect* and the *individual bargaining reservation-value effect*. The former represents the change in the total bargaining surplus created by extra investment, and the latter is the associated change in the country's payoff at the non-cooperative equilibrium. We identify conditions under which the strategic incentive for abatement investment is negative vis-a-vis the country's environmental consciousness and/or its marginal cost of abatement investment.

The rest of the paper is organized as follows. We present our model and analyze both the two-period non-cooperative equilibrium as well as the world optimum equilibrium in section 2. Section 3 adds an analysis of the two period model anticipating an international bargaining with side payments in the second period. We present comparative statics results for this model in section 4. Section 5 concludes the paper with remarks about the possible extensions for the case when international bargaining takes place with the Nash solution without side payments.

2 Model Set-up

We consider a world consisting of two countries, 1 and 2. Country i ($i = 1$, and 2) produces a single final good, which can be used either for consumption or investment, while emitting carbon gas as its by-product. The final goods produced by the two countries are perfect substitutes. Thus if they are traded freely in the world market, their prices should become equal.

Let y_i denote country i's real produced national income, z_i its carbon gas emissions, a_i its abatement investment capturing the efficiency level in environmental control. The reduced-form production function for the final good in country i is denoted by $y_i = f^i(z_i, a_i)$, while its abatement investment cost function is given by $c(a_i, \beta_i)$ where β_i is a parameter representing the level of marginal abatement investment costs. A higher β_i implies the greater marginal investment costs. We assume

Assumption 1 *A) Each country's production function $f^i(z_i, a_i)$ is (i) strictly monotone-increasing, (ii) continuously differentiable, and (iii) strictly concave.*

B) Each country's abatement investment cost function $c(a_i, \beta_i)$is (i) strictly increasing in a_i, (ii) continuously differentiable in (a_i, β_i), (iii) convex in a_i, and (iv) strictly convex in β_i.

Each country's emission of carbon gas worsens the quality of global environment and damages the welfare of both countries. Such damage depends upon the world total emission of carbon gas, z_T, which is defined by $z_T := \sum_\ell z_\ell$.

The world damage from global warming is measured in terms of the final good and assumed proportional to the world total emission of carbon gas, and country i perceives only a portion of such world damage as its own. We denote such proportion by θ_i and call it country i's *environmental consciousness*. Let $\mathbf{z} := (z_1, z_2)$ represent the emission profile. Then country i's gross welfare is expressed by:

$$\tilde{u}_i(\mathbf{z}, a_i, \theta_i) \quad := \quad f^i(z_i, a_i) - \theta_i \sum_\ell z_\ell, \tag{1}$$

while the associated world gross welfare is shown by

$$\tilde{U}\left(\mathbf{z}, \mathbf{a}, \theta\right) \quad := \quad \sum_\ell f^\ell\left(z_\ell, a_\ell\right) - \theta_T \sum_\ell z_\ell, \tag{2}$$

where $\mathbf{a} := (a_1, a_2)$ represents the abatement investment profile, $\theta := (\theta_1, \theta_2)$ the environmental consciousness profile, and $\theta_T := \sum_\ell \theta_\ell$ the world environmental consciousness.

The net welfare of each country, i.e., the gross welfare minus the abatement investment costs, is then given by

$$\tilde{v}_i\left(\mathbf{z}, a_i, \theta_i, \beta_i\right) \quad = \quad \tilde{u}_i\left(\mathbf{z}, a_i, \theta_i\right) - c\left(a_i, \beta_i\right), \tag{3}$$

while the associated world net welfare is denoted by

$$\tilde{V}\left(\mathbf{z}, \mathbf{a}, \theta, \beta\right) \quad := \quad \sum_\ell f^\ell\left(z_\ell, a_\ell\right) - \theta_T \sum_\ell z_\ell - \sum_\ell c\left(a_\ell, \beta_\ell\right), \tag{4}$$

where $\beta := (\beta_1, \beta_2)$ represents the abatement efficiency profile.

In view of Assumption 1, the following conditions hold

Assumption M. *(i) The gross welfare of each country $\tilde{u}_i\left(\mathbf{z}, a_i, \theta_i\right)$ is strictly concave in z_i, while the world counterpart $\tilde{U}\left(\mathbf{z}, \mathbf{a}, \theta\right)$ is strictly concave in $\mathbf{z}$.*
(ii) The net welfare of each country $\tilde{v}_i\left(\mathbf{z}, a_i, \theta_i, \beta_i\right)$ is strictly concave in (z_i, a_i), while the world counterpart $\tilde{V}\left(\mathbf{z}, \mathbf{a}, \theta, \beta\right)$ is strictly concave in $(\mathbf{z}, \mathbf{a})$.

This completes the minimum necessary structure underlying our model.

In fact, given the smoothness of the payoff functions, Assumption M is what we need for the succeeding discussion. Insofar as this assumption holds, one can easily extend the analysis to more general problems as explored in the footnotes.

2.1 Non-cooperative environmental policy equilibrium

Let us explore the properties of the non-cooperative equilibrium as our reference state. We consider the following two-stage sequential non-cooperative game:

Step 1 Each country decides simultaneously and independently on its abatement investments.

Step 2 After observing the abatement investments by both countries, each decides simultaneously and independently on its carbon gas emission.

Our concept of equilibrium is one of subgame perfection, so that we can solve the game by backward induction.

Given the abatement investment profile $\mathbf{a} := (a_1, a_2)$ in the second stage, the associated Nash equilibrium $\mathbf{z} := (z_1, z_2)$ should maximize each country's gross welfare (1) based on the other's carbon gas emission, i.e.,

$$0 = f_z^i(z_i, a_i) - \theta_i \tag{5}$$

which gives the best carbon-gas emission given the abatement investment a_i and the environmental consciousness θ_i. This constrained-optimal level of carbon gas emission is the second-stage equilibrium emission, which we denote by $z_i^N(a_i, \theta_i)$. This equilibrium emission level is decreasing according to its own environmental consciousness θ_i, while it is decreasing or increasing in a_i since $f_{az}^i(\cdot)$ can be negative or positive.[2]

[2]The present model assumes that the damage from global warming is linear to the world emissions. However, as discussed in an earlier version of this paper, one may assume

Remark 1 *(i)* $\frac{\partial z_i^N(a_i,\theta_i)}{\partial \theta_i} < 0$. *(ii)* $\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} < 0 \iff f_{az}^i(z_i, a_i) < 0$.

The associated second-stage equilibrium gross-welfare of country i is then given by

$$\begin{aligned} u_i^N(\mathbf{a},\theta) &:= \tilde{u}_i\left(z_i^N(a_i,\theta_i), z_j^N(a_j,\theta_j), a_i, \theta_i\right) \\ &= f^i\left(z_i^N(a_i,\theta_i), a_i\right) - \theta_i \sum_\ell z_\ell^N(a_\ell,\theta_\ell) \end{aligned} \tag{6}$$

At the first stage, each country chooses its abatement investment so as to maximize the above second-stage equilibrium gross welfare minus the investment cost, i.e., the net welfare

$$v_i^N(\mathbf{a},\theta,\beta_i) := u_i^N(\mathbf{a},\theta) - c(a_i,\beta_i). \tag{7}$$

Let $\mathbf{a}^N := \left(a_1^N, a_2^N\right)$ denote the equilibrium abatement investment profile. Then it should satisfy[3]

$$0 = \frac{\partial v_i^N}{\partial a_i} = f_a^i\left(z_i^N\left(a_i^N,\theta_i\right), a_i^N\right) - c_a\left(a_i^N,\beta_i\right), \tag{8}$$

that the word damage is given by a strictly convex function $D\left(\sum_\ell z_\ell\right)$. In this case, the associated first-order condition for each country's gross welfare maximization $0 = f_z^i(z_i,a_i) - \theta_i D'\left(\sum_\ell z_\ell\right)$gives rise to its reaction function $z_i = r^i(z_j,a_i,\theta_i)$, and one may define the non-cooperative equilibrium emission profile $z^N := \left(z_1^N, z_2^N\right)$ by $z_i^N = r^i\left(z_j^N, a_i, \theta_i\right)$ for $i,j = 1,2\,(j \neq i)$. This equilibrium emission by each country depends on the abatement and environment-consciousness profile $(\mathbf{a},\theta)$, so that we may express it by $z_i^N(\mathbf{a},\theta)$. By replacing $z_i^N(a_i,\theta_i)$ with $z_i^N(\mathbf{a},\theta)$, we can extend our discussion to more general situations. Note that insofar as the standard stability conditions are assumed to hold, all the results stated in the following remark hold.

[3]Note that $u_i^N(\mathbf{a},\theta)$ is strictly concave in a_i, for there hold

$$\begin{aligned} \frac{\partial \hat{u}_i^N}{\partial a_i} &= f_a^i \ (\because (5)) \\ \frac{\partial^2 \hat{u}_i^N}{\partial a_i^2} &= f_{az}^i \frac{\partial z_i^N}{\partial a_i} + f_{aa}^i \\ &= \frac{1}{f_{zz}^i}\left(f_{zz}^i f_{aa}^i - \left(f_{az}^i\right)^2\right) < 0, \end{aligned}$$

by virtue of Assumption 1. Coupled with the convexity of the abatement investment cost function, the result above assures that the net welfare $v_i^N(\mathbf{a},\theta,\beta_i)$ is strictly concave in a_i.

where use was made of the envelope theorem. The equilibrium abatement investment thus depends on both the own environmental consciousness and abatement efficiency. We express this relationship by $a_i^N(\theta_i, \beta_i)$. It is straightforward to see that an increase in the marginal abatement investment costs, i.e., β_i, lowers the abatement investment incentive, i.e., $\frac{\partial a_i^N(\cdot)}{\partial \beta_i} < 0$, while an increase in environmental consciousness increases the abatement incentive if and only if an increase in the abatement investment reduces the carbon gas emission, since it holds that

$$\frac{\partial^2 u_i^N}{\partial \theta_i \partial a_i} = f_{az}^i(\cdot) \frac{\partial z_i^N}{\partial \theta_i}.$$

Remark 2 *(i)* $\frac{\partial a_i^N(\theta_i,\beta_i)}{\partial \beta_i} < 0$. *(ii)* $\frac{\partial a_i^N(\theta_i,\beta_i)}{\partial \theta_i} > 0 \iff f_{az}^i\left(z_i^N\left(a_i^N, \theta_i\right), a_i^N\right) < 0$.

2.2 World optimum equilibrium

Given the first-stage choice over abatement investments, the constrained world-optimal emission profile $\mathbf{z}^{op} := (z_1^{op}, z_2^{op})$ should maximize the gross world welfare (2), so that it should satisfy

$$0 = \frac{\partial \tilde{U}}{\partial z_i} = f_z^i(z_i^{op}, a_i) - \theta_T, \tag{9}$$

which shows that the constrained optimal emission by country i depends on its abatement investment and world environmental consciousness. We represent this relationship by $z_i^{op}(a_i, \theta_T)$. In view of (5) and (9), it is straightforward to find that there holds $z_i^{op}(a_i, \theta_T) = z_i^N(a_i, \theta_T)$.

Given this constrained optimal emission profile, the world optimal abatement profile $\mathbf{a}^{op} := (a_1^{op}, a_2^{op})$ should maximize the net world welfare given by

$$U^{op}(\mathbf{a}, \theta) - \sum_{\ell} c(a_\ell, \beta_\ell),$$

where $U^{op}(\mathbf{a},\theta) := \tilde{U}(\mathbf{z}^{op},\mathbf{a},\theta)$. The associated first-order condition is

$$\frac{\partial U^{op}(\mathbf{a}^{op},\theta)}{\partial a_i} - c_a(a_i^{op},\beta_i) \quad = \quad 0,$$

or alternatively

$$f_a^i\left(z_i^{op}\left(a_i^{op},\theta_T\right),a_i^{op}\right) - c_a\left(a_i^{op},\beta_i\right) \quad = \quad 0, \tag{10}$$

where use was made of the envelope theorem. Thus the optimal abatement investment by country i should depend on world environmental consciousness θ_T and its marginal abatement investment cost parameter β_i. We express this relation by $a_i^{op}(\theta_T,\beta_i)$.

Let us compare each country's abatement investment levels between the non-cooperative equilibrium and the world optimum. Since $z_i^{op}(a_i,\theta_T) = z_i^N(a_i,\theta_T)$, Assumption 1, (8) and (10) jointly imply that $a_i^{op}(\theta_T,\beta_i)\left\{\begin{array}{c} > \\ = \\ < \end{array}\right\} a_i^N(\theta_i,\beta_i)$ when $\frac{df_a^i\left(z_i^N(a_i,\theta_i),a_i\right)}{d\theta_i}\left\{\begin{array}{c} > \\ = \\ < \end{array}\right\}0$. Here holds

$$\begin{aligned}\frac{df_a^i\left(z_i^N(a_i,\theta_i),a_i\right)}{d\theta_i} &= f_{az}^i\left(z_i^N(a_i,\theta_i),a_i\right)\frac{\partial z_i^N(a_i,\theta_i)}{\partial\theta_i}\\ &= -\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i}\end{aligned}$$

where use was made of

$$\begin{aligned}\frac{\partial z_i^N(a_i,\theta_i)}{\partial\theta_i} &= \frac{1}{f_{zz}^i},\\ \frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} &= -\frac{f_{az}^i}{f_{zz}^i} = -f_{az}^i\frac{\partial z_i^N(a_i,\theta_i)}{\partial\theta_i}.\end{aligned} \tag{11}$$

Thus we have established

Proposition 1 *$a_i^{op}(\theta_T,\beta_i)\left\{\begin{array}{c} > \\ = \\ < \end{array}\right\} a_i^N(\theta_i,\beta_i)$ when there holds $\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i}\left\{\begin{array}{c} < \\ = \\ > \end{array}\right\}0$ for $\forall\theta_i$.*

It is easy to endow the above result with an intuitive explanation. The negative externalities should induce each country to emit more carbon gas at the non-cooperative equilibrium than is efficient from the view-point of world allocational efficiency. This emission level depends on the abatement investment chosen at the first stage. If more abatement investment promotes (or suppresses) the carbon gas emissions, the non-cooperative equilibrium abatement investment level should be greater (or smaller) than the world-optimal one.

2.3 $t-$effective cooperation

As will be made clear later, when we compare abatement incentives between the case of full international coordination and that of no coordination in period 2, it is often useful to consider partial coordination of emission policies between the two countries.

More specifically, one can construct what we may call the following $t-$***effective cooperation*** game. In the first stage, both countries agree to coordinate their abatement investments so as to maximize the sum of their net welfares. In the second stage, after observing the abatement investments each country chooses its own emissions independently so as to maximize gross welfare

$$u_i^{\dagger}(t, \mathbf{z}, \mathbf{a}, \theta) \quad := \quad \frac{1}{1+t}\tilde{u}_i(\mathbf{z}, a_i, \theta_i) + \frac{t}{1+t}\tilde{u}_j(\mathbf{z}, a_j, \theta_j), \tag{12}$$

where $t \in [0, 1]$ parameterizes the extent of internalizing the effect of each country's emission on the other country's welfare at the second stage. For $t = 0$, each country's choice on the own emissions coincides with the non-cooperative one, while for $t = 1$ it maximizes the world welfare. An increase in t thus represents the extent of policy cooperation at the second stage.

Given the abatement investment profile chosen at the first stage, each country thus chooses its emissions $\hat{z}_i$ satisfying[4]

[4] In view of Assumption M, $u_i^{\dagger}(0, \mathbf{z}, \mathbf{a}, \theta)$ is strictly concave in z_i and so is $u_i^{\dagger}(1, \mathbf{z}, \mathbf{a}, \theta)$.

$$0 = (1+t) \quad \frac{\partial u_i^\dagger}{\partial z_i} = \frac{\partial \tilde{u}_i}{\partial z_i} + t\frac{\partial \tilde{u}_j}{\partial z_i}, \tag{13}$$

or alternatively

$$0 \quad = \quad f_z^i(\hat{z}_i, a_i) - \theta_i(t), \tag{14}$$

where

$$\theta_i(t) \quad := \quad (1-t)\,\theta_i + t\theta_T\,(=\theta_i + t\theta_j) \text{ for } i,j = 1,2\,(j \neq i) \tag{15}$$

for $\forall t \in [0,1]$. Since $\hat{z}_i$ depends on (t, a_i, θ), we denote the relation by $\hat{z}_i(t, a_i, \theta)$. This constitutes the $t-$effective cooperation equilibrium at the second stage.

The associated equilibrium emission by country i, denoted by $\hat{z}_i(t, a_i, \theta)$, is thus equal to $z_i^N(a_i, \theta_i(t))$, i.e.,[5]

$$\hat{z}_i(t, a_i, \theta) \quad := \quad z_i^N(a_i, \theta_i(t)). \tag{16}$$

By its construction, it should satisfy

$$\begin{aligned}\hat{z}_i(0, a_i, \theta) &= z_i^N(a_i, \theta_i), \\ \hat{z}_i(1, a_i, \theta) &= z_i^{op}(a_i, \theta_T).\end{aligned}$$

And for $\forall t \in (0,1)$, since there holds $\frac{\partial^2 \tilde{u}_i}{\partial z_j \partial z_i} = 0$ by virtue of Assumption 1, it is straightforward to verify that $u_i^\dagger(t, \mathbf{z}, \mathbf{a}, \theta)$ is strictly concave in z_i for $\forall t \in (0,1)$.

[5]More generally, we may construct this $t-$effective cooperation second-stage equilibrium as follows. Let $z_i = \hat{r}^i(z_j, \mathbf{a}, \theta, t)$ represents country i's reaction function associated with (12), i.e., a solution to (13).

The associated equilibrium emission profile $\mathbf{z}^e := (z_1^e, z_2^e)$ is a solution to the following set of equations.

$$z_i^e = \hat{r}^i\left(z_j^e, \mathbf{a}, \theta, t\right) \quad \text{for} \quad i,j = 1,2\,(j \neq i).$$

Each country's emission depends on the parameter profile $(t, \mathbf{a}, \theta)$, and it is $\hat{z}_i(t, \mathbf{a}, \theta)$ in the text. This procedure also elucidates the way to generalize our discussion in this paper.

The associated equilibrium gross welfare of each country as well as the world is represented respectively by

$$\hat{u}_i(t, \mathbf{a}, \theta) := f^i(\hat{z}_i(t; a_i, \theta), a_i) - \theta_i \sum_{\ell} \hat{z}_\ell(t; a_\ell, \theta), \tag{17}$$

$$\hat{U}(t, \mathbf{a}, \theta) := \sum_{\ell} \hat{u}_\ell(t, \mathbf{a}, \theta), \tag{18}$$

which imply

$$\hat{u}_i(0, \mathbf{a}, \theta) = u_i^N(\mathbf{a}, \theta),$$

$$\hat{U}(0, \mathbf{a}, \theta) = \sum_{\ell} u_\ell^N(\mathbf{a}, \theta).$$

Consider then the social marginal return on each country's abatement investment given $t-$effective cooperation. To make the analysis sensible, let us assume [6] [7]

Assumption 2 *$\hat{U}(t, \mathbf{a}, \theta, \beta)$ is strictly concave in* $\mathbf{a}$ *for* $\forall t \in [0, 1]$.

The social marginal return on each country's abatement investment is easily derived as below.

[6] In fact, one can further relax Assumption 2 by assuming that $\hat{V}(t, \mathbf{a}, \theta, \beta)$ is strictly concave in $\mathbf{a}$.

[7] One can obtain a sufficient condition for Assumption 2 to hold. When we use (19) derived below, it is straightforward to derive

$$\frac{\partial^2 \hat{U}}{\partial a_i^2} = \frac{f_{aa}^i\left(z_i^N(a_i, \theta_i), a_i\right) f_{zz}^i\left(z_i^N(a_i, \theta_i), a_i\right) - \left\{f_{az}^i\left(z_i^N(a_i, \theta_i), a_i\right)\right\}^2}{f_{zz}^i\left(z_i^N(a_i, \theta_i), a_i\right)} -\theta_j(1-t)\frac{\partial^2 z_i^N(a_i, \theta_i(t))}{\partial a_i^2},$$

by virtue of (11) below and

$$\frac{\partial^2 \hat{U}}{\partial a_j \partial a_i} = 0.$$

Therefore $\hat{U}(t, \mathbf{a}, \theta)$ is strictly concave in $\mathbf{a}$ if $\frac{\partial^2 \hat{U}}{\partial a_i^2} < 0$, which holds if (i) $f^i(z_i, a_i)$ is strictly concave in (z_i, a_i) and (ii) $\frac{\partial^2 z_i^N(a_i, \theta_i(t))}{\partial a_i^2} \geq 0$ for $\forall t \in [0, 1)$. But one should note that this set of conditions is only a sufficient condition.

$$
\begin{aligned}
\frac{\partial \hat{U}(t,\mathbf{a},\theta)}{\partial a_i} &= f_a^i\left(\hat{z}_i(t;a_i,\theta),a_i\right)+\left(f_z^i\left(\hat{z}_i(t;a_i,\theta),a_i\right)-\theta_T\right)\frac{\partial \hat{z}_i(t;a_i,\theta)}{\partial a_i} \\
&= f_a^i\left(\hat{z}_i(t;a_i,\theta),a_i\right)-(1-t)\,\theta_j\frac{\partial \hat{z}_i(t;a_i,\theta)}{\partial a_i}, \qquad (19)
\end{aligned}
$$

where use was made of (14).

As (19) shows, the social marginal return on country i's abatement investment under $t-$effective cooperation is (i) the private marginal return with partial coordination (the first term on the RHS) minus (ii) the externalities left out by partial coordination by country i (the second term). We call this second term the ***remaining externalities*** under $t-$effective cooperation.

Let us now explore how the social marginal return on abatement is affected by effectiveness of partial coordination at the second stage and each country's environmental consciousness. Since their effects are straightforward by partially differentiating (19) with respect to the parameters in question, our task is to find the conditions governing the signs of those partial derivatives. For this purpose, the following relations as well as (11) are of a great use.

$$
\begin{aligned}
\frac{\partial \hat{z}_i(t;a_i,\theta)}{\partial \theta_i} &= \frac{\partial z_i^N(a_i,\theta_i(t))}{\partial \theta_i}=\frac{1}{f_{zz}^i}, \\
\frac{\partial \hat{z}_i(t;a_i,\theta)}{\partial \theta_i} &= \frac{\partial z_i^N(a_i,\theta_i(t))}{\partial \theta_i}=\frac{1}{\theta_j}\frac{\partial \hat{z}_i(t;a_i,\theta)}{\partial t}, \qquad (20) \\
\frac{\partial \hat{z}_i(t;a_i,\theta)}{\partial \theta_j} &= t\frac{\partial z_i^N(a_i,\theta_i(t))}{\partial \theta_i}=\frac{t}{\theta_j}\frac{\partial \hat{z}_i(t;a_i,\theta)}{\partial t}, \qquad (21)
\end{aligned}
$$

where use was made of (15) and (16).

Then as with $\frac{\partial^2 \hat{U}}{\partial t \partial a_i}$, (19) gives rise to

$$
\begin{aligned}
\frac{\partial^2 \hat{U}}{\partial t \partial a_i} &= f^i_{az}\left(\hat{z}_i\left(t; a_i, \theta\right), a_i\right) \frac{\partial \hat{z}_i\left(t; a_i, \theta\right)}{\partial t} + \theta_j \frac{\partial \hat{z}_i\left(t; a_i, \theta\right)}{\partial a_i} \\
&\quad - \left(1-t\right) \theta_j \frac{\partial^2 \hat{z}_i\left(t; a_i, \theta\right)}{\partial t \partial a_i} \\
&= f^i_{az}\left(\hat{z}_i\left(t; a_i, \theta\right), a_i\right) \theta_j \frac{\partial z^N_i\left(a_i, \theta_i\left(t\right)\right)}{\partial \theta_i} + \theta_j \frac{\partial z^N_i\left(a_i, \theta_i\left(t\right)\right)}{\partial a_i} \\
&\quad - \left(1-t\right) \theta_j^2 \frac{\partial^2 z^N_i\left(a_i, \theta_i\left(t\right)\right)}{\partial \theta_i \partial a_i} \ \left(\because (20) \text{ and } (16)\right),
\end{aligned}
$$

so that we obtain

$$
\frac{\partial^2 \hat{U}}{\partial t \partial a_i} = -\left(1-t\right) \theta_j^2 \frac{\partial^2 z^N_i\left(a_i, \theta_i\left(t\right)\right)}{\partial \theta_i \partial a_i} = -\left(1-t\right) \theta_j \frac{\partial^2 \hat{z}_i\left(t, a_i, \theta\right)}{\partial t \partial a_i}, \quad (22)
$$

where use was made of (11) and (20). The RHS shows the direct effect of more $t-$effective cooperation on the externalities effect, the second term of (19). This establishes

Proposition 2 *More effective cooperation at the second stage enhances the social marginal return on country i's abatement investment if and only if its direct impact on the externalities effect is negative. That is,* $\frac{\partial^2 \hat{U}}{\partial t \partial a_i} > 0 \iff \frac{\partial^2 \hat{z}_i(t, a_i, \theta)}{\partial t \partial a_i} < 0$.

Similarly, $\frac{\partial^2 \hat{U}}{\partial \theta_i \partial a_i}$ is evaluated as below.

$$
\begin{aligned}
\frac{\partial^2 \hat{U}}{\partial \theta_i \partial a_i} &= f^i_{az}\left(\hat{z}_i\left(t; a_i, \theta\right), a_i\right) \frac{\partial \hat{z}_i\left(t; a_i, \theta\right)}{\partial \theta_i} - \left(1-t\right) \theta_j \frac{\partial^2 \hat{z}_i\left(t; a_i, \theta\right)}{\partial \theta_i \partial a_i} \\
&= -\frac{\partial z^N_i\left(a_i, \theta_i\left(t\right)\right)}{\partial a_i} - \left(1-t\right) \theta_j \frac{\partial^2 z^N_i\left(a_i, \theta_i\left(t\right)\right)}{\partial \theta_i \partial a_i} \qquad (23) \\
&\quad \left(\because (11) \text{ and } (20)\right).
\end{aligned}
$$

As the above derivation shows, the first term on the RHS of (23) shows the change in private marginal return of the abatement investment with partial coordination and the second the associated change in the remaining externalities. It thus yields

Proposition 3 *(i) For* $\forall t \in [0,1)$, $\frac{\partial z_i^N(a_i,\theta_i(t))}{\partial a_i} < \ (or\ >)\ 0$ *and* $\frac{\partial z_i^N(a_i,\theta_i(t))}{\partial \theta_i \partial a_i} \leq (or\ \geq)\ 0$ *jointly imply* $\frac{\partial \hat{a}_i(t,\theta,\beta_i)}{\partial \theta_i} > \ (or\ <) 0$. *(ii) For* $t = 1$, *there holds* $sgn\left(\frac{\partial \hat{a}_i(1,\theta,\beta_i)}{\partial \theta_i}\right) = sgn\left(-\frac{\partial z_i^N(a_i,\theta_T)}{\partial a_i}\right)$.

Lastly, $\frac{\partial^2 \hat{U}}{\partial \theta_j \partial a_i}$ is derived as follows.

$$\begin{aligned}\frac{\partial^2 \hat{U}}{\partial \theta_j \partial a_i} &= f_{az}^i\left(\hat{z}_i\left(t; a_i, \theta\right), a_i\right) \frac{\partial \hat{z}_i\left(t; a_i, \theta\right)}{\partial \theta_j} \\ &\quad - (1-t)\frac{\partial \hat{z}_i\left(t; a_i, \theta\right)}{\partial a_i} - (1-t)\,\theta_j \frac{\partial^2 \hat{z}_i\left(t; a_i, \theta\right)}{\partial \theta_j \partial a_i} \\ &= t f_{az}^i\left(z_i^N\left(a_i, \theta_i(t)\right), a_i\right) \frac{\partial z_i^N\left(a_i, \theta_i(t)\right)}{\partial \theta_i} \\ &\quad - (1-t)\frac{\partial z_i^N\left(a_i, \theta_i(t)\right)}{\partial a_i} - t(1-t)\,\theta_j \frac{\partial^2 z_i^N\left(a_i, \theta_i(t)\right)}{\partial \theta_i \partial a_i},\end{aligned}$$

so that there holds

$$\frac{\partial^2 \hat{U}}{\partial \theta_j \partial a_i} = -\frac{\partial z_i^N\left(a_i, \theta_i(t)\right)}{\partial a_i} - (1-t)\,t\theta_j \frac{\partial^2 z_i^N\left(a_i, \theta_i(t)\right)}{\partial \theta_i \partial a_i}, \qquad (24)$$

where use was made of (11). The RHS shares the same interpretation as (23).

Proposition 4 *(i) Given* $t \in [0,1)$, $\frac{\partial z_i^N(a_i,\theta_i(t))}{\partial \partial a_i} < \ (or\ >) 0$ *and* $\frac{\partial^2 z_i^N(a_i,\theta_i(t))}{\partial \theta_i \partial a_i} \leq (or\ \geq) 0$ *imply* $\frac{\partial \hat{a}_i(t,\theta,\beta_i)}{\partial \theta_j} > \ (or\ <) 0$. *(ii) For* $t = 1$, *there holds* $sgn\left(\frac{\partial \hat{a}_i(1,\theta,\beta_i)}{\partial \theta_j}\right) = sgn\left(-\frac{\partial z_i^N(a_i,\theta_T)}{\partial a_i}\right)$.

3 Strategic Bargaining Game

We have now fully characterized the non-cooperative equilibria, the world optimum and the social marginal return on the individual country's abatement under $t-$effective cooperation. In this section, using the Nash bargaining solution, we shall analyze the outcome of ex post cooperation given the first-stage decision on abatement investments when an enforceable international agreement is possible only for the carbon gas emissions at the second stage.

The equilibrium hinges on the nature of bargaining expected at the second stage. When the second-stage bargaining is one with transferable utilities (or more precisely, side payments), we call the game strategic bargaining with transferable utilities (hereafter ***strategic BTU game***). When second-stage bargaining takes place with non-transferable utilities, we call the game strategic bargaining with non-transferable utilitiles (hereafter ***strategic BNU game***). In this paper, we we focus attention on strategic BTU game in the main text and discuss possible extensions of the model into the strategic BNU game in the concluding section.

3.1 Equilibrium for the strategic BTU Game

Such bargaining requires the two countries to coordinate their emissions. Such coordinated emission policies denoted by $\mathbf{z}$ give country i the gross welfare given by (1). When the bargaining takes place with side payments, the two countries collect each other's surplus of the gross welfare over the non-cooperative equilibrium and divide it between them. In this sense, In this sense, each country's surplus realized by the coordinated emission policy, $\tilde{u}_i(\mathbf{z}, a_i, \theta_i) - u_i^N(\mathbf{a}, \theta)$, is its contribution to the bargaining (i.e., *bargaining contribution*), while its share of the total surplus is its reward for participation in the bargaining (i.e., *bargaining reward*).

The axioms of Nash bargaining with transferable utilities require the two countries to split into half the total of each country's bargaining contribution, i.e., the *total bargaining surplus*, given by

$$\tilde{S}^{BT}(\mathbf{z}, \mathbf{a}, \theta) \quad := \quad \sum_{\ell} \tilde{u}_{\ell}(\mathbf{z}, a_{\ell}, \theta_{\ell}) - \sum_{\ell} u_{\ell}^N(\mathbf{a}, \theta_{\ell}).$$

Since bargaining allows the two countries to coordinate their emissions so as to maximize the above bargaining surplus, country i's emission z_i^{BT} should be set at such a level that satisfies

$$0 = f_z^i\left(z_i^{BT}, a_i\right) - \theta_T,$$

which implies that the cooperative solution satisfies $z_i^{BT} = \hat{z}_i\left(1, \mathbf{a}, \theta\right)$, i.e., $t = 1$ for the $t-$effective cooperation regime. Thus the maximized total bargaining surplus, defined as $S^{BT}\left(\mathbf{a}, \theta\right) := \max_{\{\mathbf{z}\}} \tilde{S}^{BT}\left(\mathbf{z}, \mathbf{a}, \theta\right)$ should satisfy

$$S^{BT}\left(\mathbf{a}, \theta\right) = \hat{U}\left(1, \mathbf{a}, \theta\right) - \hat{U}\left(0, \mathbf{a}, \theta\right), \tag{25}$$

where use was made of the fact that $t = 0$ corresponds to the non-cooperation regime.

Each country can get half of this surplus in addition to the payoff secured even when both countries disagree during bargaining. That is, when we directly apply the Nash-bargaining formula, the gross payoff expected by country i at the first stage, denoted by u_i^{BT}, is given by[8]

$$\begin{aligned} u_i^{BT}\left(\mathbf{a}, \theta\right) &:= \tfrac{1}{2} S^{BT}\left(\mathbf{a}, \theta\right) + u_i^N\left(\mathbf{a}, \theta\right) \\ &= \tfrac{1}{2}\hat{U}\left(1, \mathbf{a}, \theta\right) - \tfrac{1}{2}\hat{U}\left(0, \mathbf{a}, \theta\right) + u_i^N\left(\mathbf{a}, \theta\right). \end{aligned} \tag{26}$$

The equation decomposes the gross payoff for the strategic BTU game into three components. The first $\hat{U}\left(1, \mathbf{a}, \theta\right)$ represents the maximized gross social surplus at the bargaining, the change of which is equivalent to the shifts of the gross utility possibilities frontier (UPF) facing the two countries at the second stage. We may thus call its increase the ***gross-UPF expansion effect***. The second subtracted term $\hat{U}\left(0, \mathbf{a}, \theta\right)$ indicates the social gross surplus secured in the absence of cooperation, which is in fact

[8] Note that it is easy to extend the discussion from the present symmetric bargaining to an asymmetric one. Again let $\sigma_i \in [0, 1]$ for $i = 1, 2$ satisfying $\sigma_1 + \sigma_2 = 1$ represent the bargaining power of country i. Then the gross payoff of country i is expressed by

$$u_i^{BT}\left(\mathbf{a}, \theta\right) = \sigma_i \hat{U}\left(1, \mathbf{a}, \theta\right) - \sigma_i \hat{U}\left(0, \mathbf{a}, \theta\right) + u_i^N\left(\mathbf{a}, \theta\right).$$

equal to the sum of the individually secured ones, i.e., the second-stage non-cooperative equilibrium gross welfare $u_\ell^N(\mathbf{a},\theta)$ for $\ell = 1,2$. $u_i^N(\mathbf{a},\theta)$, which is shown by the last term, serves as country i's reservation payoff at the bargaining table, $\hat{U}(0,\mathbf{a},\theta)$ defines the social reservation value for the bargaining. For this reason, we may call the change in $u_i^N(\mathbf{a},\theta)$ the ***individual bargaining reservation-value effect*** and that in $\hat{U}(0,\mathbf{a},\theta)$ the ***social bargaining reservation-value effect***. Since the difference between $\hat{U}(1,\mathbf{a},\theta)$ and $\hat{U}(0,\mathbf{a},\theta)$ shows the bargaining surplus and its change is associated with a shift of the bargaining frontier at the second stage, one may also call an increase in $\hat{U}(1,\mathbf{a},\theta) - \hat{U}(0,\mathbf{a},\theta)$ the ***bargaining-frontier expansion effect***.

The above decomposition formula (26) enables us to express the payoff as below

$$u_i^{BT}(\mathbf{a},\theta) = \frac{1}{2}\int_0^1 \frac{\partial \hat{U}(t,\mathbf{a},\theta)}{\partial t}dt + u_i^N(\mathbf{a},\theta). \tag{27}$$

That is, the gross payoff of country i in the strategic BTU game is equal to the total bargaining-frontier expansion effect of the second-stage cooperation weighed with the bargaining power $1/2$ plus the individual bargaining reservation-value.

Though $u_i^N(\mathbf{a},\theta)$ is strictly concave in a_i, [9]. it is generally difficult to assure the same condition for $u_i^{BT}(\mathbf{a},\theta)$. For this reason, we assume[10] [11]

Assumption 3 *Each country's gross payoff in the strategic BTU game, $u_i^{BT}(\mathbf{a},\theta)$, is strictly concave in the own abatement investment.*

Then the equilibrium abatement investment profile denoted by $\mathbf{a}^{BT} :=$

[9]See footnote 3

[10]One further relax this condition by assuming that $v_i^{BT}(\mathbf{a},\theta,\beta_i)$ is strictly concave in its own abatement investment.

[11]However some additional assumptions would assure it. In fact, when $\hat{U}(t,\mathbf{a},\theta)$ is strictly concave in $\mathbf{a}$ for $\forall t \in [0,1,]$, $v_i^{BT}(\mathbf{a},\theta)$ becomes strictly concave in a_i. See also footnote 7.

$\left(a_1^{BT}, a_2^{BT}\right)$ should equate the marginal abatement investment cost $c_a\left(a_i^{BT}, \beta_i\right)$ with the marginal return given by

$$\frac{\partial u_i^{BT}\left(\mathbf{a}^{BT}, \theta\right)}{\partial a_i} = \frac{1}{2}\int_0^1 \frac{\partial^2 \hat{U}\left(t, \mathbf{a}, \theta\right)}{\partial t \partial a_i} dt + \frac{\partial u_i^N\left(\mathbf{a}, \theta\right)}{\partial a_i} \text{ for } i = 1, 2. \quad (28)$$

Since the private marginal return on abatement investment depends on both countries' environmental consciousness and the marginal cost on the cost parameter β_i, we may represent country i's equilibrium abatement investment by $a_i^{BT}\left(\theta, \beta_i\right)$. As is shown by (28), the private marginal return on the abatement investment, which governs the abatement incentive given the investment cost condition, is the sum of the change in the bargaining-frontier effect of cooperation and the individual bargaining reservation-value effect.

3.2 Comparison with the non-cooperative equilibrium

Let us first compare the abatement investment incentive between the strategic BTU game and the non-cooperative one. This requires us to compare the associated marginal returns on each country's abatement investment between the two games. However, in general, they depend on the other country's abatement investment level.

So we first fix the other country's abatement investment level and focus our attention on the direct effect of the second-stage bargaining opportunity to the individual country's investment decision. This serves to capture as much general results as possible. Here (28) yields

$$\begin{aligned} \frac{\partial u_i^{BT}}{\partial a_i} - \frac{\partial u_i^N}{\partial a_i} &= \frac{1}{2}\frac{\partial S^{BT}}{\partial a_i} \\ &= \frac{1}{2}\int_0^1 \frac{\partial^2 \hat{U}\left(t, \mathbf{a}, \theta\right)}{\partial t \partial a_i} dt. \end{aligned}$$

As the first line shows, for country i's abatement incentive to become greater in the strategic BTU game, it is necessary and sufficient that the bargaining-frontier expansion effect of the second-stage cooperation is positive, i.e., an increase in its investment increases the bargaining surplus at the second stage. The second line further elucidates a sufficient condition for this positive bargaining-frontier expansion effect that more $t-$effective cooperation always enhances the social marginal return on investment, i.e., $\frac{\partial^2 \hat{U}(t,\mathbf{a},\theta)}{\partial t \partial a_i} > 0$ for $\forall t \in [0,1]$.

Theorem 1 *Given the other country's abatement investment, (i) country i has greater abatement investment incentive in the strategic BTU game than in the non-cooperative one if and only if its investment yields the positive bargaining-frontier expansion effect, and (ii) the bargaining-frontier expansion effect is positive if more $t-$effective cooperation always enhances each country's social marginal return on abatement investment.*

In our model specified by Assumption 1, there further holds (22), i.e.,

$$\frac{\partial^2 \hat{U}(t,\mathbf{a},\theta)}{\partial t \partial a_i} = -(1-t)\,\theta_j^2 \frac{\partial^2 z_i^N(a_i,\theta_i(t))}{\partial \theta_i \partial a_i},$$

which implies that the social marginal return on each country's abatement is independent of the other country's abatement investment. Thus by virtue of Proposition 2 we can establish

Proposition 5 *Compared with non-cooperative equilibrium, country i has greater (or smaller) abatement investment incentive when $\frac{\partial^2 z_i^N(a_i,\theta_i(t))}{\partial \theta_i \partial a_i} < (or >) 0$, i.e., more abatement decreases (or increases) the externalities effect at the second stage for any $t-$effective cooperation.*

3.3 Comparison with the world optimum

Let us now compare the private abatement incentive under the strategic BTU game with the world optimum. Given the other country's abatement, it suffices to compare the private marginal return on abatement $\frac{\partial u_i^{BT}(\mathbf{a},\theta)}{\partial a_i}$ with the social one $\frac{\partial \hat{U}(1,\mathbf{a},\theta)}{\partial a_i}$. Then (26) gives rise to

$$\frac{\partial u_i^{BT}(\mathbf{a},\theta)}{\partial a_i} - \frac{\partial \hat{U}(1,\mathbf{a},\theta)}{\partial a_i} = -\frac{\partial u_j^{BT}(\mathbf{a},\theta)}{\partial a_i},$$

where use was made of $\sum_\ell u_\ell^{BT}(\mathbf{a},\theta) = \hat{U}(1,\mathbf{a},\theta)$. Since the gross payoffs of both countries sum up to the gross world welfare and they bargain over the total surplus, each tries to become more advantage by strategically reducing the other's bargaining reservation value. Thus we have established

Theorem 2 *Given the other country's abatement investment, each country has greater (or smaller) abatement incentive in the strategic BTU game than at the world optimum when its investment lowers the other's bargaining reservation value.*

Under Assumption 1, one may obtain a stronger assertion independent of the other country's investment level by rewriting the above equation as follows.

$$\begin{aligned}
-\frac{\partial u_j^{BT}(\mathbf{a},\theta)}{\partial a_i} &= -\frac{\partial u_j^{N}(\mathbf{a},\theta)}{\partial a_i} - \frac{1}{2}\int_0^1 \frac{\partial^2 \hat{U}(t,\mathbf{a},\theta)}{\partial t \partial a_i} dt \ \ (\because (27) \text{ for } j) \\
&= \theta_j \frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} + \frac{\theta_j}{2}\int_0^1 (1-t)\frac{\partial^2 \hat{z}_i(t,a_i,\theta)}{\partial t \partial a_i} dt \\
&\quad (\because (6) \text{ and } (22)) \\
&= \theta_j \frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} + \frac{\theta_j}{2}\left\{\left[(1-t)\frac{\partial \hat{z}_i(t,a_i,\theta)}{\partial a_i}\right]_0^1 + \int_0^1 \frac{\partial \hat{z}_i(t,a_i,\theta)}{\partial a_i} dt\right\} \\
&= \theta_j \frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} + \frac{\theta_j}{2}\left\{-\frac{\partial \hat{z}_i(0,a_i,\theta)}{\partial a_i} + \int_0^1 \frac{\partial \hat{z}_i(t,a_i,\theta)}{\partial a_i} dt\right\} \\
&= \frac{\theta_j}{2}\left\{\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} + \int_0^1 \frac{\partial z_i^N(a_i,\theta_i(t))}{\partial a_i} dt\right\}
\end{aligned}$$

so that we have established[12]

[12] In the case of asymmetric bargaining, there holds

$$\frac{\partial u_i^{BT}(\mathbf{a},\theta)}{\partial a_i} - \frac{\partial \hat{U}(1,\mathbf{a},\theta)}{\partial a_i} = \theta_j \left\{\sigma_i \frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} + \sigma_j \int_0^1 \frac{\partial z_i^N(a_i,\theta_i(t))}{\partial a_i} dt\right\}.$$

Proposition 6 *Compared with the world optimum, each country has greater (or smaller) abatement incentive under the strategic BTU game when an increase in its own abatement investment increases (or decreases) its own carbon gas emissions for any $t-$effective cooperation.*

3.4 Sensitivity of the abatement investment incentive

We now discuss the sensitivity of the abatement investment incentives against changes in each country's environmental consciousness and marginal abatement investment costs. If there is any change in the exogenous parameters θ_ℓ $(\ell = 1, 2)$ and β_i to increase the above private marginal return, it leads to an increase the abatement investment incentive. Since the effect of an increase in β_i is straightforward,[13] we focus our attention on the cases in which the countries become more environmentally conscious. In view of (28), there holds the following basic result.

Theorem 3 *Given the other country's abatement investment, as any country becomes more environmentally conscious, each country's abatement investment incentive becomes greater if and only if there is an increase in the sum of the gross-UPF expansion effect of the second-stage cooperation and the individual bargaining reservation-value effect.*

Given Assumption 1, we may derive more specific results. In fact, as with the effect of greater θ_i, there holds[14]

[13]Since an increase in β_i raises the marginal abatement investment costs by virtue of Assumption 1, it decreases country i's abatement investment incentive.

[14]In the case of asymmetric bargaining, there follows

$$\frac{\partial^2 u_i^{BT}}{\partial\theta_i\partial a_i} = -\sigma_j\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} - \sigma_i\frac{\partial z_i^N(a_i,\theta_T)}{\partial a_i} + \sigma_i\theta_j\frac{\partial^2 z_i^N(a_i,\theta_i)}{\partial\theta_i\partial a_i}.$$

$$
\begin{aligned}
\frac{\partial^2 u_i^{BT}}{\partial\theta_i\partial a_i} &= \frac{\partial^2 u_i^N(\mathbf{a},\theta)}{\partial\theta_i\partial a_i} + \frac{1}{2}\int_0^1 \frac{\partial^3 \hat{U}(t,\mathbf{a},\theta)}{\partial t\partial\theta_i\partial a_i}dt \\
&= f_{az}^i\left(z_i^N(a_i,\theta_i),a_i\right)\frac{\partial z_i^N(a_i,\theta_i)}{\partial\theta_i} - \frac{\theta_j}{2}\int_0^1 (1-t)\frac{\partial^3 \hat{z}_i(t,a_i,\theta)}{\partial\theta_i\partial t\partial a_i}dt \ (\because (22)) \\
&= -\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} - \frac{1}{2}\int_0^1 (1-t)\frac{\partial^3 \hat{z}_i(t,a_i,\theta)}{\partial t^2\partial a_i}dt \\
&\quad (\because (11), (16) \text{ and } (20)) \\
&= -\frac{\partial \hat{z}_i(0,a_i,\theta)}{\partial a_i} - \frac{1}{2}\left\{\left[(1-t)\frac{\partial^2 \hat{z}_i(t,a_i,\theta)}{\partial t\partial a_i}\right]_0^1 + \int_0^1 \frac{\partial^2 \hat{z}_i(t,a_i,\theta)}{\partial t\partial a_i}dt\right\} \\
&= -\frac{\partial \hat{z}_i(0,a_i,\theta)}{\partial a_i} - \frac{1}{2}\left\{-\frac{\partial^2 \hat{z}_i(0,a_i,\theta)}{\partial t\partial a_i} + \frac{\partial \hat{z}_i(1,a_i,\theta)}{\partial a_i} - \frac{\partial \hat{z}_i(0,a_i,\theta)}{\partial a_i}\right\} \\
&= -\frac{1}{2}\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} - \frac{1}{2}\frac{\partial z_i^N(a_i,\theta_T)}{\partial a_i} + \frac{\theta_j}{2}\frac{\partial^2 z_i^N(a_i,\theta_i)}{\partial\theta_i\partial a_i} \\
&\quad (\because (16) \text{ and } (20)). \\
&= -\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i} - \int_0^1 \frac{1}{2}\frac{\partial z_i^N(a_i,\theta(t))}{\partial a_i}dt + \frac{\theta_j}{2}\frac{\partial^2 z_i^N(a_i,\theta_i)}{\partial\theta_i\partial a_i}
\end{aligned}
$$

Thus we have established[15]

Proposition 7 *(i) When there hold* $\frac{\partial z_i^N(a_i,\theta_i(t))}{\partial a_i} < (or >) 0$ *for* $\forall t \in [0,1]$ *and* $\frac{\partial^2 z_i^N(a_i,\theta_i)}{\partial\theta_i\partial a_i} \geq (or \leq) 0$*, then country i's equilibrium abatement investment is increasing in its own environmental consciousness in the strategic BTU game, i.e.,* $\frac{\partial a_i^{BT}(\theta,\beta_i)}{\partial\theta_i} > (or <) 0$.
(ii) When $\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i}$ *is linear in* θ_i*, there holds* $sgn\left\{\frac{\partial a_i^{BT}(\theta,\beta_i)}{\partial\theta_i}\right\} = sgn\left\{-\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i}\right\}$.

Similarly, the effect of greater θ_j is evaluated by

[15] As with the second result, note that $\frac{\partial^2 z_i^N(a_i,\theta_i)}{\partial\theta_i\partial a_i}$ takes a constant value, for $\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i}$ is linear in θ_i. Then the equation in the text can be reduced to $\frac{\partial^2 u_i^{BT}}{\partial\theta_i\partial a_i} = -\frac{\partial z_i^N(a_i,\theta_i)}{\partial a_i}$.

$$
\begin{aligned}
\frac{\partial^2 u_i^{BT}}{\partial\theta_j\partial a_i} &= \frac{\partial^2 u_i^N(\mathbf{a},\theta)}{\partial\theta_j\partial a_i} + \frac{1}{2}\int_0^1 \frac{\partial^3 \hat{U}(t,\mathbf{a},\theta)}{\partial t\partial a_i\partial\theta_j}dt \\
&= \frac{1}{2}\int_0^1 \frac{\partial^3 \hat{U}(t,\mathbf{a},\theta)}{\partial\theta_j\partial t\partial a_i}dt \left(\because \frac{\partial^2 u_i^N(\mathbf{a},\theta)}{\partial\theta_j\partial a_i} = 0\right) \\
&= -\frac{1}{2}\int_0^1 \left\{(1-t)\frac{\partial^2 \hat{z}_i(t,a_i,\theta)}{\partial t\partial a_i} + (1-t)\,t\frac{\partial^3 \hat{z}_i(t,a_i,\theta)}{\partial t^2\partial a_i}\right\}dt \\
&\quad (\because (22)) \\
&= \frac{1}{2}\int_0^1 \frac{\partial \hat{z}_i(t,a_i,\theta)}{\partial a_i}dt - \frac{\partial \hat{z}_i(1,a_i,\theta)}{\partial a_i} \\
&\quad (\because \text{integration by parts}) \\
&= \frac{1}{2}\int_0^1 \frac{\partial z_i^N(a_i,\theta_i(t))}{\partial a_i}dt - \frac{\partial z_i^N(a_i,\theta_i(t))}{\partial a_i}.
\end{aligned}
$$

Proposition 8 *When* $\frac{\partial^2 z_i^N(a_i,\theta_i(t))}{\partial\theta_i\partial a_i}\left\{\begin{array}{c}>\\=\\<\end{array}\right\}0$ *for* $\forall t\in[0,1]$, *then there holds* $\frac{\partial a_i^{BT}(\theta,\beta_i)}{\partial\theta_j}\left\{\begin{array}{c}<\\=\\>\end{array}\right\}0.$

4 Examples

To elucidate our analysis, let us consider the following two further specific examples.

Example 1 $f^i(a_i,z_i) = 2\sqrt{a_i z_i}$.

Example 2 $f^i(a_i,z_i) = A - \frac{1}{a_i z_i}$ where A is a sufficiently large positive constant.

4.1 Example 1

It is straightforward to compute

$$
z_i^N(a_i,\theta_i) = \frac{a_i}{\theta_i^2}.
$$

Then since $\frac{\partial z_i^N}{\partial a_i} = \frac{1}{\theta_i^2} > 0$, Proposition 1 implies $a_i^{op} < a_i^N$. And as $\frac{\partial^2 z_i^N}{\partial \theta_i \partial a_i} = -\frac{2}{\theta_i^3} < 0$, Proposition 5 implies $a_i^{BT} > a_i^N$. Thus there follows $a_i^{op} < a_i^N < a_i^{BT}$. The opportunity of bargaining at the second stage makes each country's abatement investment further excessive. As with the sensitivity of the abatement incentive in the strategic BTU game, Proposition 7 implies $\frac{\partial a_i^{BT}}{\partial \theta_i} < 0$, while Proposition 8 yields $\frac{\partial a_i^{BT}}{\partial \theta_j} > 0$.

4.2 Example 2

The non-cooperative equilibrium for this Example 2 satisfies

$$z_i^N (a_i, \theta_i) = \frac{1}{\sqrt{a_i \theta_i}} = a_i^{-1/2} \theta_i^{-1/2}.$$

Since this satisfies $\frac{\partial z_i^N}{\partial a_i} = -\frac{1}{2} a_i^{-3/2} \theta_i^{-1/2} < 0$ and $\frac{\partial^2 z_i^N}{\partial \theta_i \partial a_i} = \frac{1}{4} a_i^{-3/2} \theta_i^{-3/2} > 0$, Propositions 1 and 5 imply $a_i^{op} > a_i^N > a_i^{BT}$. In this example, the second-stage bargaining makes each country's abatement investment further smaller than at the non-cooperative equilibrium. As with the sensitivity of the abatement incentive in the strategic BTU game, Proposition 7 implies $\frac{\partial a_i^{BT}}{\partial \theta_i} > 0$, while Proposition 8 yields $\frac{\partial a_i^{BT}}{\partial \theta_j} < 0$. The results are the opposite of Example 1.

5 Concluding Remarks

In this paper, we analyzed a two-period two-country model with or without anticipating a future international agreement on environmental control by using strategic bargaining games. Several remarks may be in order before we conclude the paper.

First, we confine ourselves to bargaining with transferable utilities. This is the case in which the parties have some mechanism of side payments or inter-country income transfers. However creation of such income transfers may involve a lot of conflicts between the parties during bargaining. When they cannot agree and have access to such transfer mechanisms, then they must undertake bargaining without transferable utilities or side payments. The analysis in the present paper is easily extended to such a case by considering shadow prices for each party's bargaining contribution and reward as discussed in Kiyono and Okuno-Fujiwara [6]. The new crucial factor is what we may call the *strategic relative shadow price effect* indicating the change in the shadow prices strategically altered by each country's choice over the abatement investment at the first stage. We can then decompose the effect of strategic investment choice at the first stage into the bargaining-frontier expansion and strategic relative shadow price effects, which recalls what Miyazaki [4] once did over the manager-worker negotiations *à* la Slutsky.

Second, in order to simplify our analysis and to enable us to track the likely outcomes, we employed several crucial assumptions. One of the most important is that the international agreement is binding. Any foreseeable international agreement on global environment will likely lack enforcement power other than voluntary measures, because there is no world authority that can enforce the agreement. Ideally, we should analyze a two period model with second period agreement being designed only to satisfy voluntary measures, or, even better, renegotiation-proof voluntary measures. Unfortunately, little is known about renegotiation-proof equilibrium of this nature and restricting feasible outcomes to be either self-enforcing or renegotiation-proof would make our analysis more complicated than necessary. Therefore, instead of using these equilibrium concepts to be satisfied for all feasible negotiation outcomes, we simply assumed that a binding contract is possible and any feasible outcome is potentially agreeable.

The specific mathematical formulation which we employed for national welfare (1) may also be restrictive at a first glance. However, as our discussion shows, our approach can be easily extended to more general cases. We also believe that we have succeeded in elucidating that the incentives for ex ante investment critically depends on whether international negotiation is anticipated with or without transfers. Since the creation of an international market for tradable emission permits requires a certain allocation of initial permits among countries, emissions trading involves international transfers of income. Our analysis reveals that the feasibility of such a trading system as a global environmental management strategy affects the ex-ante abatement investment of each country.

Lastly, in the model, we treated the two periods, ex ante and ex post, without paying any attention to their lengths. However, the ex ante investment is a flow variable and its impact on the ex post becomes larger as the length of the first period (ex ante period) becomes longer. An obvious implication of this observation is that, once the possibility of a future international agreement becomes non-negligible and the sooner an agreement is struck, the less impact this negative incentive affects the ex ante investment for improving emission efficiency.

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