Sustainability and International Environmental Agreements

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Abstract: *This paper examines the perceptions of sustainability, which is conceptualised as cross-generational social preferences, on the formation of international environmental agreements (IEAs) in a two-stage game in two periods. There are two scenarios are considered: myopic and sustainable development scenarios. The myopic scenario assumes the decision makers only concern the present welfare. Whilst the scenario of sustainable development has two characters: cross-generational fairness and altruism. When both are taken into account, a coalition will be expanded. The numerical example indicates that the marginal cost of the total emissions is the crucial factor for the formation of IEAs. Only when the marginal cost is low, a sustainable system can be succeeded. While, the technological advancement may lead to a more efficient production per unit of emissions, it also encourages countries to emit more in total and have a lower level of welfare.*

The results confirm the importance of sustainability to IEAs. The lesson learnt from this study is: when decision makers are myopic, the system is unsustainable even if an IEA is formed. Only when the perception of sustainability is considered, the system could be sustainable. Regardless of the existence of IEAs, international environmental conventions shall not neglect the fundamental goal to pursue sustainable development.

Keywords: Sustainable development, international environmental agreements, climate change, social preferences

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I. Introduction

Human activities have left many enduring footprints and legacies. As a result, the ecosystems on earth have changed dramatically due to the rapid industrial development in the past decades. Our society is now facing a range of environmental crises. Actions are urged to maintain basic needs of the future generations, because the outcome of human development is often irreversible and will be passed on to the next generations. When environmental problems occur across boundaries, it is believed that signing international environmental agreements (IEAs) is the most viable solution to controlling the problems.

The most common purpose of the existing IEAs is to assure *sustainable development*. The term 'sustainable development' is first used in the report *Our Common Future,* published by the World Commission on Environment and Development (WCED) in 1987. In that publication, it is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Lately, 'sustainability' and 'sustainable development' have become buzzwords overloaded with fuzzy meanings. At the discussion of IEAs, stakeholders such as governments, industries, NGOs, trade unions, academics all have different understandings of 'sustainability'. For instance, the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 declares that '... Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner' (UNFCCC, 1992, p. 4). In 1997, the UNFCCC states in the Kyoto Protocol that 'Each Party included in Annex I, in achieving its quantified emissions limitation and reduction commitments under Article 3, in order to promote sustainable development' (Kyoto Protocol, 1997, Article 2). Although sustainability has been inscribed in many formal and informal talks and documents, and is a key goal for IEAs, there are miscellaneous ways to define and achieve it.

1.1 Literature Review

Based on a literature review, the concept of sustainability can be categorised at three levels: individual, societal, and the ecosystem levels. To individuals, sustainability usually means to achieve constant utility (Solow, 1974 and Hartwich, 1977) and avoid any decline in utility (Pearce *et al*. 1989; Pezzey, 1997). More precisely, employing utility as a measuring tool, Pezzey (*ibid*) identifies three distinct stages for classifying sustainability: sustainable level, sustained level, and survivable level.

Other definitions of sustainability in the societal level include the WCED's concept of satisfying the basic needs of the future generations (WCED, 1987); the length of the existence of the human race is maximised (Georgescu-Roegen, 1971); the present value of the social welfare is not declining (Riley, 1980); and the per capita incomes of the future generations are no worse off (Pearce *et al*, *ibid*). The indicators of sustainability at this level comprise the idealistic social welfare and the empirical statistical figures (such as Green Net National Product expanded by Hartwick, 1977 and Genuine Savings provided by Hamilton and Clemens, 1999).

Moving on to the ecosystem, levels of sustainability can be measured and evaluated against a wide range of indicators which include exhaustible natural resources (Meadows *et al*, 1972), renewable natural resources, production waste, and biological diversity. In order to achieve sustainability, exhaustible resources, such as minerals and fossil fuel deposits, have to be extracted at a rate at which the length of use is maximised. Renewable resources, such as fisheries and forests, have to be harvested at a natural and manageable speed of regeneration. In addition, biological diversity also has to be maintained for the basic needs of the survival development.

In a nutshell, the previous studies have proposed three main types of policy goals for sustainability: (1) achieving constant or non-declining individual utility function (Solow, 1974 and Pezzy, 1997); (2) avoiding any decline in social values from the present time onwards (Riley, 1980); and (3) maintaining existing 'safe minimum standards' (Toman, 1994). These can be applied onto management of natural exhaustible resources and renewable resources and waste emissions (Solow, 1974 and Stiglitz, 1974).

In order to avoid any decline in social present value, Woodward (2000) identifies a set of behaviours that would lead to sustainable life; these behaviours entail intergenerational fairness. This means that the future generations will not envy the present one, and there exists an alternative, feasible choice that there is no envy between generations. Woodward's ethical assumption emphasises the current generation's responsibility to the future generations. That said, the current generation has to consider not only their present welfare but also the welfare of future generations. Woodward's concept of sustainability emphasises the notion of fairness across generations.

Toman (1994) discusses the concept of `safe minimum standard' when speaking of strong sustainability. Because human activities have 'irreversible' effects on natural environments, the human capital cannot substitute the natural assets when decision makers have low level of information but high potential asymmetry in the payoff. Similarly, Barbier and Markandya (1990) suggest to impose a minimum stock of environmental assets as a safety reserve. According to their theory, when the asset is driven below this safety criterion, environmental degradation will destroy the natural clean-up and regenerative processes in the environment. Following these concepts, Martinet (2011) proposes an approach that defines the objectives of sustainability using sustainability threshold indicators.

Though the importance of sustainability to IEAs is widely approved, relatively little attention has been paid to discuss the relationship between the sustainable development process and the formation of IEAs. The majority of the theoretical studies have employed static models to analyse the coalition formation (e.g. Barrett, 1994, 2005; Yi, 1997 and Carraro and Siniscalco, 1998). These static models do not reflect the practical discussion in the environmental conventions, and fail to take the concept of sustainability which emphasises the moral relationship between generations into account.

Recent studies (e.g. Germain *et al*. 2003; de Zeeuw, 2008; Rubio and Ulph, 2007) employ dynamic models to describe human development in the infinite horizon. These models, pursues the maximised over-generational welfare, neglect the core of sustainability which pursues the non-declining welfare. That said, the cross-generational social preferences are hardly considered in the existing literature.

This paper, to my best knowledge, is the first to consider cross-generational altruism and fairness in an economic model for IEAs. This paper recognises that there are different definitions of sustainability and various ideas of how it can be achieved. This study considers the perceptions of sustainability by building a cross-generational model with a two-stage game in two periods. The decision makers in different periods are considered as agents of two generations, young and old. In each period, they decide whether or not to participate in an IEA in the first stage. In terms of their membership status, the emissions levels are determined in the second stage. To examine the effect of different perceptions of sustainability on the formation of IEAs, we consider two scenarios: in the myopic (MYO) scenario, the decision makers of the old generation care about their own welfare. In the sustainable development (SD) scenario, the decision makers of the old generation care about not only the present welfare but also the welfare of the young generation. The old generation attempts to maximise the over-generational welfare and ensure that the welfare of the young generation is no worse off than the young one.

The model in the SD scenario presented in this paper will take the diversity of perceptions of sustainability into account. The cross-generational altruism denotes that the current decision makers would consider the welfare of the future generation as well as the present welfare. The cross-generational fairness imposes a sustainability criterion demanding for non-declining social welfare. The criterion dictates that the social welfare of the future generation should not be worse than that of the present generation. In so doing, this paper re-defines ‘sustainability’ by providing a more balanced perspective on present the welfare of the present and the future generations, and the dynamics in the decision-making process.

The results provide some policy implications: when decision makers are myopic, the system is unsustainable even if an IEA is formed. Only when the perceptions of sustainability are taken into account, a sustainable system could succeed. Regardless of the existence of IEAs, international environmental conventions should not neglect the fundamental goal to pursue sustainable development.

In addition, the numerical results suggest that the marginal cost of the total emissions plays an important role. The higher the marginal cost is, the lower the individual emissions level. A grand coalition formation is possibly formed when the marginal cost is very small. Besides, the cross-generational concerns have small but ambiguous impact on the coalition formation in two periods.

The study is structured as follows. In Section two, a two-stage two-period game is built in two scenarios. A numerical example in Section 3 illustrates the coalition formation in different scenarios. The conclusion and discussion are in the final section.

II. The model

This study investigates the cross-generational preferences based on a model that focuses on the frameworks of IEAs and ignore individualities. This assumption of identical countries is drawn on Barrett (1994), Rubio and Ulph (2007) and Breton *et al.* (2010) which assume countries are homogeneous in their analyses of incentives of participating in IEAs. We appreciate to the assumption of heterogeneous players, however, we have emphasised the point in the introduction: to my best understanding, there is no paper which model sustainability in the discussion of the formation of IEAs.

Table 1 shows the decision process of the model. The decision makers live for one period only: the old generation lives in Period 1 and the young generation lives in Period 2. In each period, there is a two-stage game: in the first stage membership game, countries decide whether or not to participate in an IEA. In the second stage emission game, they make the decision on the level of emissions in terms of their membership status. Nonsignatories choose emissions in a non-cooperative way to maximise their own payoffs, whilst signatories act as one to maximise the coalition payoff. The total stock of emissions is the sum of the accumulated emissions from the past and the aggregated emissions in that period. In order to understand the importance of sustainability to the formation of IEAs, this study focuses on the coalition formation in two scenarios: the myopic (MYO) and the sustainable development (SD) scenarios.

There is a finite set of N identical countries and each country determines its stock of emissions . It is built on the fact that the pollutant is a by-product of production. Obviously, the stock of pollutant has a strong positive correlation with industrial processes. The normalised benefit function from the production can be presented as

$$B(e_{k,t}) = \frac{1}{b} e_{k,t}^{b}$$

where $e_{k,t}$ denotes the emissions level[2] of a country k in Period t , $k \in \{1, \dots, N\}$ and $t \in \{1,2\}$. The parameter b is the benefit elasticity of emission where $b \in (0,1)$. This assumption of a concave benefit function implies the diminishing rate of returns. When emissions are generated from the production, the marginal benefit will decrease. It should be noted that the benefit elasticity of emission b is a constant[3] and determined by available technology level, or management of the production process. Higher benefit elasticity implies advanced technology which brings a higher benefit per unit of emissions. This elasticity measures the correspondent of benefit against the change in level of emissions stock. For example, $b = 0.5$ means that a 1% increase in emissions stock would lead to approximately 0.5% increase in benefit.

On the other hand, the pollutant also causes severe damage to the environment. The damage cost function for country k is highly correlated with the global stock of emissions and can be presented in a linear function as

$$C(E_t) = \gamma E_t$$

where γ is the marginal cost of the total stock of emissions E_t where $\gamma > 0$. The total stock of emissions contains the accumulated emissions from the past and the aggregate emissions generated by the signatories and the nonsignatories denoted as

$$E_t \equiv \delta E_{t-1} + \left(\sum_{i=1}^{n} e_{i,t} + \sum_{j=n+1}^{N} e_{j,t}\right) \qquad \text{(Eqn. 1)}$$

(Eqn. 1) can be read as the total stock of emissions is the sum of the accumulated emissions from the past, the emissions from signatories and the emissions from nonsignatories in the current period. The remain emissions is the cumulate emissions in the past with the natural decay factor denoted as $\delta \in (0,1)$. Despite increases in carbon dioxide emissions by the human activities, the vegetation and oceans can absorb the cumulated emissions. Hence, it is reasonable to assume that the decay rate is between zero and one. The later bracket shows the

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[2] The emissions are by-products from the production. Considering the facilities and resources are constrained, we normalise the highest level of emissions to 1.

[3] This restrictive assumption does not consider the technological improvement which is another important factor to IEAs. Having said that, the perceptions of sustainability is the objective in this study. The discussion on technological improvement is the task for the future studies.

current aggregate emissions. Suppose n countries[4] join an IEA, the individual emissions of a signatory i in Period t is denoted as $e_{i,t} \geq 0,\ i = 1, \dots, n$ and $t = 1, 2$. On the other hand, , the individual emissions of a nonsignatory j in Period t is denoted as $e_{j,t},\ j = n + 1, \dots, N$ and $t = 1, 2$.

Having defined the benefit and cost functions. In period t, a country k's net benefit function is

$$\pi_{k,t} = B(\,e_{k,t}) - C(\,E_t)$$

Each decision maker lives for one period and optimises its welfare simultaneously with respect to its current level of emissions as

$$\max_{e_{k,t}} \pi_{k,t} = [\tfrac{1}{b} e_{k,t}^{b} - \gamma E_t] \qquad \text{(eqn. 2)}$$

As mentioned previously, given the initial stock of the pollutant, there is a two-stage game:

1. In the first stage, countries decide whether or not to join an IEA.
2. In the second stage, countries decide their emission in terms of their membership status.
   I. Signatories move as one by determining a common emissions level to maximise the coalition welfare.
   II. Nonsignatories decide their own emissions level to maximise their own individual welfare.

The discussion on the formation of self-enforcing IEAs follows Rubio and Ulph (2007), the membership of any country is determined by a random process such that the probability of any country being a signatory in that period is simply the membership of the stable IEA in that period divided by the total number of countries. This probability is the same for all countries in each period. Two scenarios in the decision process have been shown in Table 1: (i) myopic (MYO), (ii) sustainable development (SD). The young generation faces the same objective function in both scenarios, while the policy goals for the old generation are different. In the MYO scenario, the old generation is myopic and the decision makers only

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[4] n is an integer value between 0 and N.

concern their own welfare in Period 1. In the SD scenario, the old generation concerns not only its own welfare but also the expected welfare of the young generation. Besides, the sustainability criterion dictates that the welfare of the young generation cannot be worse than the welfare of the old generation.

We would like to highlight that for the SD scenario, the expected welfare of the young generation is based on the membership status of the old generation. In Period 1, the old decision makers have the expectation and belief about the membership of the young generation when they consider the cross-generational welfare. This assumption is adequate because practical IEAs do not usually set an expiry date unless the policy goal has been achieved[5]. The young generation is expected to inherit the membership from the old generation. However, in Period 2, the young generation can withdraw from the coalition and participate freely in terms of their domestic situations. In other words, the coalition formation could be different in both periods[6].

The game is solved by backward induction. Section 2.1 discusses the young generation's two-stage decisions which include the emission plan and the membership status in Period 2. Then the old generation's two-stage decisions in Period 1 are discussed in two scenarios: section 2.2 illustrates the MYO scenario where the old generation cares about its welfare only; whilst section 2.3 illustrates the SD scenario where the old generation cares about not only its welfare but also the young generation's.

2.1 Decisions in Period 2

2.1.1 Second-stage emissions game

Regardless of the decision makers are myopic or not, the young generation faces the same decision process. Suppose that n_2 countries has decided to participate in the coalition in Period 2, so that the rest $(N - n_2)$ countries are nonsignatories. Extended from (eqn. 2), a

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[5] For example, the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987.

[6] For example, the Kyoto Protocol has two commitments periods. The first commitment period applies to emissions between 2008-2012, and the second commitment period applies to emissions between 2013-2020. Japan, New Zealand, Russia and Canada (which withdrew from the Kyoto Protocol in 2012) have participated in Kyoto's first-round but have not taken on new targets in the second commitment period.

young nonsignatory j maximises its individual payoff as

$$\max_{e_{j,2}} \pi_{j,2} = [\frac{1}{b} e_{j,2}^{b} - \gamma E_2] \qquad \text{(eqn. 3)}$$

where $e_{j,2}$ is j's emissions in Period 2. The total emissions $E_2 = \delta E_1 + \sum_{i=1}^{n_2} e_{i,2} + \sum_{j=n_2+1}^{N} e_{j,2}$ is the sum of the accumulated stock of emissions in the past period with the decay rate δ, as well as the aggregated emissions from signatories and nonsignatories in Period 2.

Hence, the optimal level of emissions for a young nonsignatory is

$$e_{j,2} = (\gamma)^{\frac{-1}{1-b}} \qquad \text{(eqn. 4)}$$

The derivative with respect to the parameter b of the emissions level ($\partial e_{j,2}/\partial b$) is ambiguous[7]. When the marginal cost of total emissions is smaller than 1, it implies that the higher technology level may incur more pollution. In light of the history of human development, the more advanced technology we have, the more we would like to produce for the life convenience. Despite the technologies become more efficient and generate fewer pollutants per unit of product, the level of emissions could increase due to the increasing consumption of products. On the other hand, when the marginal cost of total emissions γ is greater than 1, the pollution cost increases faster than the growth of benefit by the technology development. It implies that the more advanced technology would lower the emissions level.

A signatory attempts to maximise the coalition payoff with regard to the common emissions level $e_{i,2}$, $\forall i \in 1, \ldots, n_2$. The coalition objective function is presented as

$$\max_{e_{i,2}} \Pi_2 = \sum_{i=1}^{n}[\frac{1}{b} e_{i,2}^{b} - \gamma E_2] \qquad \text{(eqn. 5)}$$

From (eqn. 5), the optimal emissions level for a young signatory i in Period 2 is

$$e_{i,2} = (n_2\gamma)^{\frac{-1}{1-b}} \qquad \text{(eqn. 6)}$$

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[7] A simple proof is below:

(1) take logarithms of both side $\ln(e) = \frac{-1}{1-b}\ln(\gamma)$

(2) take the derivative with respect to b, we have $\frac{\partial \ln(e)}{\partial e}\frac{\partial e}{\partial b} = \frac{-\ln(\gamma)}{(1-b)^2}$.

So $(\frac{\partial e}{\partial b})$ is positive when γ is less than 1 and negative when γ is greater than 1.

$\frac{\partial e_{i,2}}{\partial n_2} < 0$ and $\frac{\partial e_{i,2}}{\partial \gamma} < 0$ mean the size of the IEA and the marginal cost of the total emissions would breakdown the optimal emissions level of a signatory. Since all signatories make a common decision to maximise the coalition payoff , the coalition emissions is the number of signatories times of an individual signatory's emissions level. When the coalition becomes bigger, this group effect motivates each signatory to have a larger individual emission reduction. Also, the high marginal cost would lead to a low emissions level. However, as mentioned earlier, the technology parameter (b) has multiple effects and its impact on the emissions level is ambiguous.

The payoffs of a nonsignatory j and a signatory i in Period 2 are

$$\pi_{j,2} = \frac{1}{b}(\gamma)^{\frac{-b}{1-b}} - \gamma[\delta E_1 + n_2(n_2\gamma)^{\frac{-1}{1-b}} + (N-n_2)(\gamma)^{\frac{-1}{1-b}}]$$

$$\pi_{i,2} = \frac{1}{b}(n_2\gamma)^{\frac{-b}{1-b}} - \gamma[\delta E_1 + n_2(n_2\gamma)^{\frac{-1}{1-b}} + (N-n_2)(\gamma)^{\frac{-1}{1-b}}]$$

The enlarged coalition formation benefits to every country ($\frac{\partial \pi_{j,2}}{\partial n_2} > 0$ and $\frac{\partial \pi_{i,2}}{\partial n_2} > 0$). We also learnt that a nonsignatory has a higher payoff than a signatory does, because of the free-riding benefit for the nonsignatory.

2.1.2 First-stage membership game

Following D'Aspremont *et al.* (1983), a n_2^* -member stable coalition is found when two constraints below are satisfied

$$\pi_{j,2}(n_2^* - 1) \leq \pi_{i,2}(n_2^*) \qquad \text{(eqn. 7)}$$

$$\pi_{i,2}(n_2^* + 1) \leq \pi_{j,2}(n_2^*) \qquad \text{(eqn. 8)}$$

As mentioned earlier, $\pi_{i,2}$ and $\pi_{j,2}$ are the payoffs for a signatory and a nonsignatory respectively.. The number in the parenthesis indicates the number of signatories in the IEA. The internal constraint (eqn. 7) implies the incentive of participation of a signatory *i*. A country would participate in a coalition as one of n_2^* member countries only if being a signatory is better than being a nonsignatory. When the number of signatories drops and the coalition is no longer profitable, the consequence is that the IEA could no longer exist and all countries suffer. On the other hand, the external constraint (eqn. 8) explains the incentive of a nonsignatory. A country would stay away from a coalition when the payoff of being an outsider is better than that of being the $(n_2^* + 1)$-th member. When both constraints are satisfied, the coalition is considered as stable.

Following, Section 2.2 and 2.3 discuss the decisions of the old generation in Period 1 in the MYO and SD scenarios respectively.

2.2 Decisions in Period 1 in the Myopic (MYO) scenario

2.2.1 Second-stage emissions game

In the myopic scenario, the decision makers care about the welfare in Period 1 only. Similar to the objective function of the young generation in Period 2, an old nonsignatory j maximises only its payoff with respect to its individual emissions level $(e_{j,1})$

$$\max_{e_{j,1}} \pi_{j,1} = \left[\frac{1}{b} e_{j,1}^{b} - \gamma E_1\right] \qquad \text{(eqn. 9)}$$

where $e_{j,1}$ is the emissions level of a nonsignatory j in Period 1, and the total stock of emissions E_1.

Hence, the optimal emissions level of j is obtained from (eqn. 9). The myopic old generation emits the same level as the young generation does.

$$e_{j,1} = (\gamma)^{\frac{-1}{1-b}}$$

On the other hand, suppose there are n_1 members, the coalition attempts to maximise the aggregate payoff with respect to the common emissions level $e_{i,1}$

$$\max_{e_{i,1}} \Pi_1 = \sum_{i}^{n_1} \left[\frac{1}{b} e_{i,1}^{b} - \gamma E_1\right] \qquad \text{(eqn. 10)}$$

The first order derivative suggests that the number of signatories and marginal cost are negatively correlated with the optimal emissions level of a myopic old signatory. The optimal emissions level is presented as

$$e_{i,1} = (n_1\gamma)^{\frac{-1}{1-b}}$$

The post-distribution payoffs for a myopic signatory i and a myopic nonsignatory j in period 1 are

$$\pi_{j,1} = \frac{1}{b}(\gamma)^{\frac{-b}{1-b}} - \gamma\left[\delta E_0 + n_1(n_1\gamma)^{\frac{-1}{1-b}} + (N - n_1)(\gamma)^{\frac{-1}{1-b}}\right]$$

$$\pi_{i,1} = \frac{1}{b}(n_1\gamma)^{\frac{-b}{1-b}} - \gamma\left[\delta E_0 + n_1(n_1\gamma)^{\frac{-1}{1-b}} + (N - n_1)(\gamma)^{\frac{-1}{1-b}}\right]$$

2.2.2 First-stage membership game

Similar to (eqn. 7) and (eqn. 8), the stable coalition with n_1^* members in Period 1 can also be found when two constraints below are satisfied.

$$\pi_{j,1}(n_1^* - 1) \leq \pi_{i,1}(n_1^*) \qquad \text{(eqn. 11)}$$

$$\pi_{i,1}(n_1^* + 1) \leq \pi_{j,1}(n_1^*) \qquad \text{(eqn. 12)}$$

$\pi_{i,1}$ is the post-redistribution payoff when a country decides to participate in an IEA and $\pi_{j,1}$ is the payoff of that country decides not to participate. The number in the parenthesis means the size of the IEA in Period 1.

It should be noted that IEAs being formed in the beginning of each period, the coalition formation in Period 1 (n_1) does not necessary remain the same to that in Period 2 (n_2). The emissions level and the welfare might be different when the formation size changes. Given an extreme example that the coalition size remains the same for two periods ($n_1 = n_2$), the emissions levels are the same in two periods. Having said that, we have learnt from (eqn.1) that the accumulated emissions is an extra cost to the young generation. The young generation would therefore have worse welfare than the old generation. According to the concepts of sustainability defined previously, this can be labelled an unsustainable system.

2.3 Decisions in Period 1 in the Sustainable development (SD) scenario

The result from the MYO scenario suggests that the system could be unsustainable if the formation size remains unchanged. In order to ensure a sustainable system, we now restructure the model for the sustainable development (SD) scenario in Period 1. The old generation has cross-generational altruism by concerning the welfares of two generations. In addition, the old generation has cross-generational fairness by setting up the sustainable criterion. The criterion ensures the social welfare of the young generation would be no worse than that of the old generation. The two-stage game is also solved by backward induction.

2.3.1 Second-stage emissions game

In the SD scenario, the old generation considers not only the welfare in Period 1 but also that of that in Period 2. Let π_2^f denote the expected welfare of the young generation under the coalition formation in Period 1. As mentioned earlier, the membership of the young generation is expected to inherit the membership. So that if there are n_1 signatories in an IEA in Period 1, the expected coalition formation in Period 2 remains the same[9]. With this assumption, the old generation could predict the emissions level and the welfare of the young generation.

An old nonsignatory *j*'s objective function is presented as

$$\max_{e_{j,1}} \pi_{j,1} + \beta\pi_{j,2}^f = \left(\frac{1}{b}e_{j,1}^b - \gamma E_1\right) + \beta\left(\frac{1}{b}e_{j,2}^b - \gamma E_2\right)$$

$$\pi_{j,1} \leq \pi_{j,2}^f \qquad \text{(eqn. 13)}$$

where β is the discount factor attached by one generation to the welfare of the next. The discount factor, in the range of 0 and 1, implies the weight of how much the old generation cares about the young generation. With the definition of sustainable development, decision makers consider the over-generational welfare. An old generation cares not only about the payoff at present but also that in the future. This setting implies cross-generational altruism, which the current generation sacrifice without asking anything in return from the future generation. The higher value of β, higher is the weight put on the young generation concerned by the old generation.

Inequality (eqn. 13) refers to the sustainability criterion of which the welfare of the future generation should not be worse than that of the present generation[11]. It implies cross-generational fairness that the old generation live no better than another. To do so, the

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[9] However, the young generation could reform the coalition and decides its actual membership in Period 2. The young generation does not have to follow the expectation of the old generation.

[11] I acknowledge that it is unusual to impose a non-declining welfare criterion in a two-period model where the welfare in Period 1 is compared with that in Period 2. Given that what happens in Period 1 is irreversible but affects to the generation in Period 2, it will be necessary to reduce emissions in Period 1 for the purpose of sustainable development. This may not be a very satisfactory model with which to study the impact of the non-declining welfare constraint. However, the constraint is adequate to study sustainability.

constraint urges the old generation to adjust its emissions level for the cross-generational fairness.

Hence, the Lagrange function with respect to $e_{j,1}$ is set up as

$$\mathcal{L}_j(e_{j,1}) = \pi_{j,1} + \beta\pi_2^f + \lambda_j(\pi_2^f - \pi_{j,1}) \quad \text{(eqn. 14)}$$

The Kuhn-Tucker conditions for the maximisation problem in (eqn. 14) are

$$\frac{\partial\mathcal{L}_j}{\partial e_{j,1}} = -\gamma[(1+\beta\gamma) - \lambda_j(1-\delta)] + (1+\lambda_j)e_{j,1}^{b-1} = 0, e_{j,1} \geq 0 \quad \text{(eqn. 15)}$$

$$\frac{\partial\mathcal{L}_j}{\partial\lambda_j} = \pi_2^f - \pi_{j,1} \geq 0,\ \lambda_j \geq 0,\ \lambda_j(\pi_2^f - \pi_{j,1}) = 0 \quad \text{(eqn. 16)}$$

The members in the coalition will attempt to maximise the coalition welfare in two periods. Their membership status last for the expected payoff Π_2^f. The objective function of the old generation is

$$\max_{e_{i,1}} \Pi_1 + \beta\Pi_2^f = \sum_i^{n_1}\left(\frac{1}{b}e_{i,1}^b - \gamma E_1\right) + \beta\sum_i^{n_1}\left(\frac{1}{b}e_{i,1}^b - \gamma E_2\right) \qquad \Pi_1 \leq \Pi_2^f$$

This can be rewritten in a Lagrangian with respect to $e_{i,1}$ as

$$\mathcal{L}_i(e_{i,1}) = \Pi_1 + \beta\Pi_2^f + \lambda_i(\Pi_2^f - \Pi_1) \quad \text{(eqn. 17)}$$

The Kuhn-Tucker conditions for the maximisation problem in (eqn. 17) are

$$\frac{\partial\mathcal{L}_i}{\partial e_{i,1}} = -\gamma n_1[(1+\beta\gamma) - \lambda_i(1-\delta)] + (1+\lambda_i)e_{i,1}^{b-1} = 0, e_{i,1} \geq 0 \quad \text{(eqn. 18)}$$

$$\frac{\partial\mathcal{L}_i}{\partial\lambda_i} = \Pi_2^f - \Pi_1 \geq 0,\ \lambda_i \geq 0,\ \lambda_i(\Pi_2^f - \Pi_1) = 0 \quad \text{(eqn. 19)}$$

To solve the problem, there are following four cases:

Case 1. No criterion is binding ($\lambda_j = \lambda_i = 0$)

When no criterion is binding, $\lambda_j = \lambda_i = 0$. From (eqn. 15) and (eqn. 18), the optimal levels of emissions for a nonsignatory *j* and a signatory *i* in Period 1 are

$$e_{j,1} = [\gamma(1+\beta\gamma)]^{\frac{-1}{1-b}}$$

$$e_{i,1} = [\gamma n_1(1+\beta\gamma)]^{\frac{-1}{1-b}}$$

The level of emissions of a signatory i is lower than that of a nonsignatory j. A further emission reduction is made by signatories, when the coalition is expanded. The result also shows that the discount factor (β) and the emission decay rate (δ) are correlated to the level of emissions. It means that, if the young generation is more valuable, the old generation would do more emission reduction , for the sake of the young generation.

Taking the expected number of signatories n_1 into (eqn. 6), the expected level of emission for a signatory in Period 2 is yielded and it is higher than the emissions level in Period 1. This result is also applied to nonsignatories. Compared to the result in the MYO scenario in Section 2.2, the old generation emits fewer carbon emissions in the SD scenario.

Case 2. The sustainability criterion for signatories is binding ($\lambda_j = 0$, but $\lambda_i > 0$)

When the sustainability criterion for nonsignatories is not binding, $\lambda_j = 0$. From (eqn. 15), the level of emissions for a nonsignatory j is

$$e_{j,1} = [\gamma(1+\beta\gamma)]^{\frac{-1}{1-b}}$$

On the other hand, when the criterion is binding for signatories, $\lambda_i > 0$. The level of emissions of a signatory i can be derived from (eqn. 19)

$$\frac{1}{b}e_{i,1}^{b} - \gamma(1-\delta)\left[\delta E_0 + n_1 e_{i,1} + (N-n_1)e_{j,1}\right] = \frac{1}{b}(n_1\gamma)^{\frac{-b}{1-b}} - \gamma\left[n_1(n_1\gamma)^{\frac{-1}{1-b}} + (N-n_1)(\gamma)^{\frac{-1}{1-b}}\right] \qquad \text{(eqn. 20)}$$

Suppose the discount rate and the remaining emissions are very high (e.g., $\beta \approx 1, \delta \approx 1$), an old nonsignatory emits $(2\gamma)^{\frac{-1}{1-b}}$, which is less than the result in the MYO scenario. When the sustainability criterion for signatories is binding, from (eqn. 20), the level of emission for an old signatory is $\left\{(n_1\gamma)^{\frac{-b}{1-b}} - b\gamma\left[n_1(n_1\gamma)^{\frac{-1}{1-b}} + (N-n_1)(\gamma)^{\frac{-1}{1-b}}\right]\right\}$. It is the technology parameter times the expected welfare of a young signatory to the power of the inverse technology parameter. On the other hand, either countries have a low discount rate ($\beta \approx 0$) or the remaining emissions becomes small ($\delta \approx 0$), an old nonsignatory emits $(\gamma)^{\frac{-1}{1-b}}$ which is at the same level to the result in the MYO scenario. Because an extra cost from the remaining emission, old generation would emit less for the young generation.

Case 3. The sustainability criterion for nonsignatories is binding ($\lambda_j > 0$, but $\lambda_i = 0$)

When the sustainability criterion for nonsignatories is binding, $\lambda_j > 0$. The level of emissions of a nonsignatory j can be derived from (eqn. 16)

$$\frac{1}{b}e_{j,1}^{b} - \gamma(1-\delta)\left[\delta E_0 + n_1 e_{i,1} + (N-n_1)e_{j,1}\right] = \frac{1}{b}(\gamma)^{\frac{-b}{1-b}} - \gamma\left[n_1(n_1\gamma)^{\frac{-1}{1-b}} + (N-n_1)(\gamma)^{\frac{-1}{1-b}}\right]$$

(eqn. 21)

On the other hand, if the criterion for signatories is not binding, $\lambda_i = 0$. From (eqn. 18), the level of emissions of a signatory i is therefore

$$e_{i,1} = [\gamma n_1(1+\beta\gamma)]^{\frac{-1}{1-b}}$$

Suppose the discount rate and the remaining emissions are very high (e.g. ≈ 1 and $\delta \approx 1$), an old signatory emits $(2n_1\gamma)^{\frac{-1}{1-b}}$ which is less than the result in the MYO scenario. It implies that the old generation reduces its emissions due to the concerns on the future generation and the unsolvable remaining pollutants. When the sustainability criterion for nonsignatories is binding, from (eqn. 21) we learn that the level of emission for an old nonsignatory $\left\{(\gamma)^{\frac{-b}{1-b}} - b\gamma\left[n_1(n_1\gamma)^{\frac{-1}{1-b}} + (N-n_1)(\gamma)^{\frac{-1}{1-b}}\right]\right\}$ which is the technology parameter times the expected welfare of a young nonsignatory to the power of the inverse technology parameter. When either the discount rate or the remaining emissions are very low (e.g. $\beta \approx 0$ or $\delta \approx 0$), an old signatory emits $(\gamma n_1)^{\frac{-1}{1-b}}$ which is at the same level to the result in the MYO scenario. Because the concerns on the remaining emissions, an old nonsignatory emits less than that of a young nonsignatory.

Case 4. The sustainability criteria for all countries are binding ($\lambda_j > 0,\ \lambda_i > 0$)

In this case, $\lambda_j > 0$ and $\lambda_i > 0$. The levels of emissions of a nonsignatory j and a signatory i can be derived from (eqn. 16) and (eqn. 19) as

$$\frac{1}{b}e_{i,1}^{b} - \gamma(1-\delta)\left[\delta E_0 + n_1 e_{i,1} + (N-n_1)e_{j,1}\right] = \frac{1}{b}(n_1\gamma)^{\frac{-b}{1-b}} - \gamma\left[n_1(n_1\gamma)^{\frac{-1}{1-b}} + (N-n_1)(\gamma)^{\frac{-1}{1-b}}\right]$$

$$\frac{1}{b}e_{j,1}^{b} - \gamma(1-\delta)\left[\delta E_0 + n_1 e_{i,1} + (N-n_1)e_{j,1}\right] = \frac{1}{b}(\gamma)^{\frac{-b}{1-b}} - \gamma\left[n_1(n_1\gamma)^{\frac{-1}{1-b}} + (N-n_1)(\gamma)^{\frac{-1}{1-b}}\right]$$

The discount factor (β) affects neither a signatory nor a nonsignatory. It does not mean the old generation concerns nothing about the future, but the sustainable criteria have to be accomplished. Having said that, the remaining emissions ratio (δ) is an important factor to the level of emissions. When the remaining emissions is very small ($\delta \approx 0$), pollutants are absorbed by the nature, the old generation emits at the level as the technology parameter times the expected welfare of the young generation to the power of the inverse technology parameter. But if the nature cannot absorb the pollutants and the remaining emissions is at a very high level ($\delta \approx 1$), the old generation emits less for the extra cost from the remaining pollutants.

The optimal levels of emissions for a signatory and a nonsignatory are not obvious. A numerical example in the following section can help our understanding on these results.

2.3.2 First-stage membership game

To find a stable coalition in the first period, the internal constraint and external constraint for the old generation can be rewritten as

$$\pi_{j,1}(n_1^* - 1) + \beta\pi_{j,2}^f(n_1^* - 1) \leq \pi_{i,1}(n_1^*) + \beta\pi_{i,2}^f(n_1^*) \qquad \text{(eqn. 23)}$$

$$\pi_{i,1}(n_1^* + 1) + \beta\pi_{i,2}^f(n_1^* + 1) \leq \pi_{j,1}(n_1^*) + \beta\pi_{j,2}^f(n_1^*) \qquad \text{(eqn. 24)}$$

The constraints with a cross-generational objective function imply that the decision makers take the expected welfare of the young generation into account. The constraint (eqn. 23) shows that when the welfare of being a nonsignatory is not higher than that of being a signatory, the coalition is stable internally. On the other hand, the constraint (eqn. 24) shows that the coalition is stable externally, when there is no signatory have the incentive to leave.

Consider the case of $n_1 = N$ where all countries join the IEA, the individual levels of emissions are $[\gamma N(1+\beta\gamma)]^{\frac{-1}{1-b}}$ in Period 1 and $[\gamma N]^{\frac{-1}{1-b}}$ in Period 2. The expected emissions level in Period 2 is higher than that in Period 1. This implies that the old generation has not only a lower benefit but also a lower cost to the young generation. It is unclear to claim whether this is a sustainable system. Hence, the following simulation provides a numerical example to illuminate the result.

III. Simulation analysis

Given $N = 10$ countries[12], we assume the gap between generations is five decades because the international treaties are usually valid for a long term. The remaining emissions (δ) is set as (100-0.866)% per year from the natural annual removal rate of CO2 stock given by Nordhaus (1994). The parameters of benefit (b) is set from 0.01 to 0.1 and the marginal cost of total emissions (γ) is set from 0.01 to 0.9. [14]

Table 2 shows the individual level of emissions and welfare in the myopic (MYO) scenario. As mentioned previously, a signatory produces less pollution than a nonsignatory does. Hence, the welfare of a signatory is always less than that of a nonsignatory in both periods. The individual optimal emissions levels of signatories and nonsignatories in two different periods are positively related to the technology level (b) and negatively related to the marginal cost of total emissions (γ).

The membership decision is determined *ex ante* the emissions game. A consistent result in the MYO scenario suggests that a 2-member coalition in Period 1, and a larger 5-member coalition in Period 2. The individual level of emissions and welfare are related to the size of IEA. The nonsignatories generate the same level of emissions in two periods, whilst the signatories emit less in Period 2. When the welfares for generations are compared, the old generation has a higher welfare than the young generation. In other words, the system in the MYO scenario is always unsustainable.

Table 3 reports the individual level of emissions and welfare in the sustainable development (SD) scenario. Here, the discount rate (β) is set as 0.5 as the weight of concerns on the future generation. The level of emissions in Period 1 is less than that in Period 2 in general. When the technology is more advanced (higher b), the emissions level increases but the welfare shrinks. On the other hand, when the marginal cost of the total emissions (γ)

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[12] We acknowledge that $N = 10$ might not a large number, compared to the numerical examples in Barrett (1994) and Rubio and Ulph (2007). It is more difficult to find a robust result in our exponential benefit function with a case of large number of countries. Hence, this assumption is adequate to represent an international negotiation while a robust result could be found.

[14] Here we assume the marginal cost is at the range of 0 and 1. As we mentioned in footnote 5, when the marginal cost γ is less than 1, the higher technology will increase the emission level. It implies that when the advanced technology would lead to the increase of emissions for the life convenience.

increases, countries are more aware of the damage and reduce the levels of emissions. The marginal cost is positively related to the emissions level but negatively to the welfare.

The cells with stars refer to the binding sustainability criterion that the expected welfare in Period 2 is worse than that in Period 1. The system could be sustainable in most cases, but not always. We have to emphasise that the sustainability criterion is for the old generation in Period 1 only. When the criterion is binding, the expected welfare in Period 2 is equal to that in Period 1. However, due to the coalition formation might be changed in Period 2, the actual welfare in Period 2 is not necessary to be the expected welfare. The numerical example shows that the criteria are not binding when the marginal cost of total emissions is high. In the SD scenario, the system is usually sustainable as the welfare of the young generation is higher than the welfare of the old generation. However, when the marginal cost is high, the system could be unsustainable as the young generation might yield a lower level of welfare.

Compared to the result in the MYO scenario in Table 2, the level of emissions of SD scenario is far less than that of MYO scenario. In addition, the welfare of signatories and nonsignatories in Period 2 in the SD scenario are usually higher than those in the MYO scenario. In other words, the SD scenario is better to maintain a sustainable system than the MYO scenario.

Table 4 reports the coalition formation of IEAs in the SD scenario. When the marginal cost of the stock of emissions (γ) is low, countries have a higher incentive to form an IEA and a grand coalition is possible. Countries have a higher incentive to form an IEA when the marginal cost is low. The marginal cost is negatively related to the coalition formation in Period 2. However, the marginal cost has an ambiguous impact on the formation in Period 1. Compared to the result in MYO scenario where there are always a 2-member coalition in Period 1 and 5-member in Period 2, the formation in the SD scenario is larger than that in the MYO scenario. On the other hand, the level of technology (b) has no impact on the coalition formation in the SD scenario, while there is also no impact in the MYO scenario. As mentioned earlier in section 2.3, it might due to the multiple effects of the technology development.

Table 5 shows the sizes of stable IEAs in the SD scenario in relation to the levels of discount rate (β) and the marginal cost of total emissions (γ) when the technology level b is set at 0.05. A grand coalition happens when the marginal cost is very low. However, the marginal cost does not show a clear correlation with the coalition formation in two periods. It seems that the formation in Period 2 decreases when the marginal cost increases, while that in Period 1 may firstly shrink then expanded. When the discount rate (β) is very small, it implies that the old generation's preference weighting attached by one generation to the next, the formation in Period 1 could be very small but a grand coalition is still possible in Period 2. It is interesting that the discount rate has small but ambiguous effect on the coalition formation.

We have to note that a robust outcome is not found when the level of discount rate s more than 0.05, however, the impact of the discount rate is not as significant as the marginal cost of total emission. The coalition usually expands when the marginal cost increases.

IV. Conclusions

This study examines the perceptions of sustainability in IEAs by building a two-stage two-period game. We firstly consider a myopic (MYO) scenario in which the old generation is myopic and does not care about the young generation. It implies that there is no fairness and altruism between generations. The old generation only concerns about its payoff in Period 1. It is suggested that only a small size (2 members) coalition could possibly be formed in Period 1 and a larger (5 members) coalition in Period 2. The simulation results show that the level of emissions decreases when the marginal cost increases since the environmental damages are awarded. On the other hand, a more advanced technology development level could encourage countries to emit more for the life convenience and have lower welfare. Overall, the system in the MYO scenario is demonstrated to be unsustainable.

This study then builds a model in the sustainable development (SD) scenario which its preference weighting attached by one generation to the next and the sustainability criterion to ensure welfare is non-declining over time. There are two characters in the SD scenario: the intergenerational fairness and altruism. Firstly, the countries have cross-generational altruism that the old generation would sacrifice without asking for return from the young generation. They care about not only their welfare in Period 1 but also that of the young generation in Period 2. Secondly, the countries care about the cross-generational fairness whereby the old generation should not make the young generation worse off. When both are taken into account, a coalition will be expanded.

The numerical example indicates that the marginal cost of the total emissions is the crucial factor for the formation of IEAs. Only when the marginal cost is low, a sustainable system can be succeeded. Having said that, the impact of the discount rate is insignificant. The concerns on the future generation may lead to the coalition in Period 1 expand but that in Period 2 shrinks. This unusual case implies that the old generation are more likely to participate when the concern is stronger, but the young generation may withdraw since environmental threats have mitigated. On the other hand, the technology development level has no impact on the formation. The technological advancement may lead to a more efficient production per unit of emissions, whilst it also encourages countries to emit more in total and have a lower level of welfare.

This study confirms the importance of the awareness of sustainability to creating IEAs. The results provide policy advice to international environmental conventions. When decision makers are myopic, the system is unsustainable even if an IEA is formed. Only when sustainable development is taken into account, the system could be sustainable. However, it must be noted that the criterion does not guarantee a sustainable system. In a few cases, the system is still unsustainable because the young generation could make a different decision to what the old generation expected. Regardless of the existence of IEAs, international environmental conventions shall not neglect the fundamental goal to pursue sustainable development.

Table 1. The decision process of the model

Time horizon	Period 1		Period 2	
Player	Old generation		Young generation	
2-stage game	Membership game	Emission game	Membership game	Emission game
Total emission	$E_1 = \delta E_0 + \sum_{i=1}^{n_1} e_{i,1} + \sum_{j=n_1+1}^{N} e_{j,1}$		$E_2 = \delta E_1 + \sum_{i=1}^{n_1} e_{i,2} + \sum_{j=n_1+1}^{N} e_{j,2}$	
Objective function (MYO scenario)	Nonsignatory : $\pi_{j,1}$ Signatory : Π_1		Nonsignatory : $\pi_{j,2}$ Signatory : Π_2	
Objective function (SD scenario)	Nonsignatory : $\pi_{j,1} + \beta\pi_{j,2}^{f}$ $s.t. \pi_{j,1} \leq \pi_{j,2}^{f}$ Signatory : $\Pi_1 + \beta\Pi_2^{f}$ $s.t. \Pi_1 \leq \Pi_2^{f}$		Nonsignatory : $\pi_{j,2}$ Signatory : Π_2	

Table 2. Individual level of emissions and welfare of a nonsignatory and a signatory in two periods in the myopic (MYO) scenario

	b			
γ	0.01	0.02	0.05	0.1
0.02	$\begin{pmatrix} 52.02 & 94.68 \\ 25.83 & 93.95 \\ 52.02 & 93.78 \\ 10.24 & 92.10 \end{pmatrix}$	$\begin{pmatrix} 54.16 & 44.42 \\ 26.70 & 43.66 \\ 54.16 & 43.51 \\ 10.48 & 41.76 \end{pmatrix}$	$\begin{pmatrix} 61.43 & 13.56 \\ 29.62 & 12.68 \\ 61.43 & 12.59 \\ 11.29 & 10.60 \end{pmatrix}$	$\begin{pmatrix} 77.22 & 1.66 \\ 35.75 & 0.51 \\ 77.22 & 0.60 \\ 12.92 & 0.00 \end{pmatrix}$
0.1	$\begin{pmatrix} 10.24 & 93.15 \\ 5.08 & 92.43 \\ 10.24 & 92.26 \\ 2.01 & 90.61 \end{pmatrix}$	$\begin{pmatrix} 10.48 & 42.99 \\ 5.17 & 42.25 \\ 10.48 & 42.10 \\ 2.03 & 40.41 \end{pmatrix}$	$\begin{pmatrix} 11.29 & 12.46 \\ 5.44 & 11.65 \\ 11.29 & 11.57 \\ 2.07 & 9.74 \end{pmatrix}$	$\begin{pmatrix} 12.92 & 1.39 \\ 5.98 & 0.43 \\ 12.92 & 0.50 \\ 2.16 & 0.00 \end{pmatrix}$
0.5	$\begin{pmatrix} 2.01 & 91.65 \\ 1.00 & 90.94 \\ 2.01 & 90.78 \\ 0.40 & 89.15 \end{pmatrix}$	$\begin{pmatrix} 2.03 & 41.60 \\ 1.00 & 40.89 \\ 2.03 & 40.74 \\ 0.39 & 39.10 \end{pmatrix}$	$\begin{pmatrix} 2.07 & 11.45 \\ 1.00 & 10.70 \\ 2.07 & 10.63 \\ 0.38 & 8.95 \end{pmatrix}$	$\begin{pmatrix} 2.16 & 1.16 \\ 1.00 & 0.36 \\ 2.16 & 0.42 \\ 0.36 & 0.00 \end{pmatrix}$
0.9	$\begin{pmatrix} 1.00 & 91.01 \\ 0.50 & 90.31 \\ 1.00 & 90.14 \\ 0.20 & 88.53 \end{pmatrix}$	$\begin{pmatrix} 1.00 & 41.01 \\ 0.49 & 40.31 \\ 1.00 & 40.17 \\ 0.19 & 38.55 \end{pmatrix}$	$\begin{pmatrix} 1.00 & 11.04 \\ 0.48 & 10.32 \\ 1.00 & 10.25 \\ 0.18 & 8.63 \end{pmatrix}$	$\begin{pmatrix} 1.00 & 1.07 \\ 0.46 & 0.33 \\ 1.00 & 0.39 \\ 0.17 & 0.00 \end{pmatrix}$

Given $N = 10$ and $\delta = (1 - 0.00866)^{50}$. From left top to down in each cell are the emissions of a nonsignatory and a signatory in period 1 and a nonsignatory and a signatory in period 2 respectively in the MYO scenario. From right top to down are their individual payoffs.

Table 3. Individual emission levels and the welfare of a nonsignatory and a signatory in two periods in the sustainable development (SD) scenario

	b		
γ	0.01	0.02	0.05
0.02	$\begin{pmatrix} - & - \\ 3.83 & 93.85 \\ - & - \\ 5.08 & 95.77 \end{pmatrix}$	$\begin{pmatrix} - & - \\ 3.88 & 43.59 \\ - & - \\ 5.17 & 45.60 \end{pmatrix}$	$\begin{pmatrix} - & - \\ 4.05 & 12.69 \\ - & - \\ 5.44 & 15.01 \end{pmatrix}$
0.1	$\begin{pmatrix} - & - \\ 1.52 & 92.99 \\ - & - \\ 0.05 & 94.89 \end{pmatrix}$	$\begin{pmatrix} - & - \\ 1.52 & 42.78 \\ - & - \\ 2.03 & 44.75 \end{pmatrix}$	$\begin{pmatrix} - & - \\ 1.54 & 12.09 \\ - & - \\ 2.07 & 14.30 \end{pmatrix}$
0.5	$\begin{pmatrix} 1.52 & 87.84 \\ 0.50 & 86.73 \\ 0.50 & 92.14 \\ 0.25 & 91.44 \end{pmatrix}$	$\begin{pmatrix} 1.52 & 37.78 \\ 0.50 & 36.66 \\ 0.49 & 42.12 \\ 0.24 & 41.43 \end{pmatrix}$	$\begin{pmatrix} 1.54 & 7.59 \\ 0.49 & 0.44 \\ 0.48 & 12.08 \\ 0.23 & 11.39 \end{pmatrix}$
0.6	$\begin{pmatrix} 1.26 & 87.68 \\ 0.42 & 86.57 \\ 0.60 & 90.41 \\ 0.27 & 89.64 \end{pmatrix}$	$\begin{pmatrix} 1.27 & 37.61 \\ 0.41 & 36.53 \\ 0.59 & 40.41 \\ 0.27 & 39.64 \end{pmatrix}$	$\begin{pmatrix} 1.27 & 7.52 \\ 0.40 & 6.38 \\ 0.58 & 10.4 \\ 0.26 & 9.62 \end{pmatrix}$
0.9	$\begin{pmatrix} 0.13 & 88.72 \\ 0.43 & 89.88 \\ 0.90 & 89.66 \\ 0.18 & 88.08 \end{pmatrix}^*$	$\begin{pmatrix} 0.13 & 38.74 \\ 0.43 & 39.89 \\ 0.90 & 39.70 \\ 0.18 & 38.11 \end{pmatrix}^*$	$\begin{pmatrix} 0.12 & 8.79 \\ 0.42 & 9.95 \\ 0.90 & 9.80 \\ 0.17 & 8.21 \end{pmatrix}^*$

Given $N = 10$ and $\delta = (1 - 0.00866)^{50}$. From left top to down in each cell are the emissions of a nonsignatory and a signatory in period 1 and a nonsignatory and a signatory in period 2 respectively in the SD scenario. From right top to down are their individual payoffs.

The cells with star * refer to the sustainability criterion is binding.

Table 4. Number of signatories out of 10 for the parameter of the level of technology and the marginal cost of the total emissions in the SD scenario

	b		
γ	0.01	0.02	0.05
0.02	10 10	10 10	10 10
0.1	10 10	10 10	10 10
0.5	3 8	3 8	3 8
0.6	3 6	3 6	3 6
0.9	6 6	6 6	6 6

The discount rate β is 0.5. From top to down in each cell report the number of signatories in the periods 1 and 2.

Table 5. Number of signatories out of 10 for the parameter of the perceptions of sustainability and the marginal cost of the total emissions in the SD scenario (*b*=0.05)

	β				
γ	0.01	0.25	0.5	0.75	1
0.02	10 10	10 10	10 10	10 10	10 10
0.4	2 10	3 10	3 10	4 10	4 10
0.5	2 10	3 9	3 8	3 8	3 7
0.9	6 6	6 6	6 6	6 6	6 6

From top to down in each cell report the number of signatories in the periods 1 and 2.

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