Sustainability Criteria and Incentives for Participation in International Environmental Agreements

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Version : 13th August 2012

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Keywords : International environmental agreements; Sustainable development; Climate change policy; Public goods

JEL codes : H41, Q01, Q54, Q56

1 Introduction

The ecosystem has changed dramatically due to the rapid industrial development in the past decades. Our society is therefore facing a big challenge of environmental crises. Actions are urged to maintain basic needs for the future generations, because the outcome of human development is irreversible and will be passed on to the next. When the environmental problem is at the national level, it can be managed by governments. Nevertheless, an effective supra-national governmental authority has not existed for crises in the international or global scale. Hence, international environmental agreements (IEAs) have become the second-best solution.

IEAs can be grouped into two main categories: natural resource sharing and international environmental problems. Regarding IEAs related to natural resource sharing, their common characteristics are the objectives which transit over the national boundaries (e.g. the atmosphere, rivers, lakes, oceans, and terrestrial habitats) and the limited natural resources (e.g. water, fisheries, timber and other elements of the natural world). Due to the geographic reason, the scale of this sort of IEAs could be limited. The well known subcategory objectives related to these IEAs include freshwater resources (Convention on the Protection and Use of Transboundary Watercourses and International Lakes, 1992); marine living resources (Common Fisheries Policy of the European Union); terrestrial living resources (Convention on Biological Diversity, 1992; International Tropical Timber Agreement, 1994) and marine environment resources (United Nations Convention on the Law of the Sea, 1982; International Convention for the Prevention of Pollution From Ships, 1983). In practice. fairness is the key to maintaining a stable IEA. Nevertheless, the neoclassical economics literature is still more likely to examine an IEA in terms of the production efficiency.

The second category is international environmental problems. Some issues of these IEAs are on a regional scale, such as acid rain and sea pollution. Other issues are on a global scale, such as the ozone layer, climate change, global warming. This sort of IEA aims to reduce the environmental damage by developing a cleaning mechanism and an emission abatement scheme. The well known subcategory objectives related to these IEAs include the ozone layer (Montreal Protocol, 1997), climate change (the United

Nations Framework Convention on Climate Change (UNFCCC), 1992), acid deposition (Protocol on the Reduction of Sulphur Emissions, 1985). The research objectives in this paper belong to this category, more precisely, carbon and greenhouse gas emissions.

The final purpose of the majority IEAs aims to assure the sustainable development. For instance, the objective of the Convention of the UNFCCC in 1992 declared "...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." Later in 1997, the UNFCCC stated in the Kyoto Protocol that "Each Party included in Annex I, in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development". The term, sustainable development or sustainability, has become common buzzwords among the IEAs. With the importance of sustainability to the IEAs, this study therefore would like to investigate the relationship between sustainability and the incentives for participation in IEAs. To our best knowledge, this would be the first study to consider sustainability in the literature of IEAs.

The practice of sustainable development aims to improve the total quality of life, both in the present and the future. To this end, the value of the social welfare of the future generation has to be taken into the present generation's account. Meanwhile, the social welfare what the future generation has is no worse than what the present generation has. We examine the effect of sustainability requirements upon IEAs in optimal emission level and the stability of coalition. To do so, we compare a framework of IEA with myopic decision makers to a framework with the sustainability criteria. Our results show that the coalition scale is very small in the myopic framework. With the sustainability requirements, both the present and the future welfare are taken into account. All signatories and nonsignatories would reduce more carbon emission for higher overall social welfare. The stable size of a coalition would be enlarged with the concern on sustainability.

The structure of this study is organised as follows. In Section 2, we review the studies on IEAs and sustainability. Following, a benchmark model in the business-as-usual (BAU) scenario is built in subsection 3.1. The model captures the characteristic of the myopic decision makers. The framework with the sustainability criteria is proposed in subsection 3.2. In order to compare both frameworks, the simulation is raised in Section 4. Conclusion is in the final section.

2 Literature Review

2.1 Literature on IEAs

Barrett (1994) [5] provides the milestone study to define the interactions in the IEAs is with a self-enforcing incentive. He claims that all countries are free to enter or withdraw from the coalition, no one can be forced. This important characteristic implies that policy makers make their decisions based on rational economic considerations, rather than political considerations. Every country maximises its net benefit. Signatories receive the reward from acceding to the agreement and avoid the punishment from withdrawing. Nonsignatories take the punishment but acquire the free-riding benefit. Following D'Aspremont *et al.* (1983)[2], the stable coalition is found when two constraints hold : the internal constraint - if every signatory has no incentive to withdraw from the coalition; and the external constraint - if no nonsignatory has the incentive to accept the coalition. The optimal number of signatories to maintain the coalition is determined by the stable constraints. This theoretical argument is supported empirically by Bratberg *et al.* (2005)[8] in their study of the Sofia Protocol during the period 1985-1996. The empirical evidence shows that the estimated yearly reduction in nitrogen oxides is nearly 2.1% higher than it would have been without the Protocol. Though Barrett (1994) [5] provides a fundamental explanation for the difficulty in holding a stable IEA, three major assumptions limit his contribution. The first assumption - all countries are identical - does not fit the reality very well. With this assumption, being a signatory or a nonsignatory depends on the proportion of all countries. We are not able to distinguish between signatories and nonsignatories. All policy mechanisms would only change the possibility of being a signatory.

Though the assumption of homogeneous countries leads to simplified results for describing the given scenarios, these results are likely to deviate from the reality. Therefore, with the assumption of heterogeneous countries, the studies attempt to distinguish the reactions of countries with diverse characteristics. The assumption of heterogeneous countries has received more attention due to the limited contribution of the assumption of identical countries, that has to be addressed. Barrett (2001) [6] distinguishes asymmetric countries into 'rich' countries with more ozone-depleting substances and 'poor' countries with less substances. Barrett's results show that stronger asymmetry between players would enhance the willingness of participating in an IEA. Dellink and Finus (2009) [10] also find support for Barrett's result with the addition of transfers within the IEAs.

From another perspective, the assumption of identical countries may be due to the designs of the IEAs. Batabyal (2000) [7] studies the framework of the IEA in the 1992 Rio Earth Summit. He claims that the supra-national governmental authority prefers to treat developing countries as identical because its payoff is higher when it contracts *ex ante* rather than contracting with the various developing countries *ex post*. Some of the literature assumes countries are asymmetric in order to fit the reality. Bahn *et al.* (2009) [3] consider countries with various marginal environmental damage costs and show that the players with the highest marginal cost are those who are most interested in participating in an IEA to reduce pollution. However, their results only tell us that the optimal emission levels are different between countries rather than investigating the effect on the scale and stability of an IEA.

The assumption of heterogeneous countries can be presented in two ways : asymmetric environmental costs and asymmetric environmental contributions (Barrett, 2001 [6], Kolstad and Ulph, 2008 [22]). An example of stratosphere ozone depletion from Barrett (2001) [6] distinguishes 'poor' countries from 'rich' countries. The rich countries can contribute more to the environment with their greater ability to pay and/or their larger influence on global emission abatement. The poor have neither the ability to pay nor the global influence. On the other hand, the poor may be suffering from immediate and severe effects of the environmental damages. But the influence of damages are minor for the rich countries.

The second assumption in Barrett (1994)'s paper is perfect information. The assumption constrains the ability to capture the uncertain reality. Accurate information is compulsory for decision makers in international, especially global, environmental policies. Environmental problems are not well understood due to the complexities of nature. Hence, even with the most advanced branches of science, decision makers negotiate on abatement with limited information. Nevertheless, the debate on the scientific evidence on the issue of climate change has not come to a conclusion. Since the evidence is controversial, people's preferences have become ambiguous. Hence, uncertainty has turned out to be an important issue to be discussed.

In practise, in order to avoid a 'wrong' policy being launched, the report from the House of Lords has warned decision makers to take the uncertain science of climate change into account.

> The scientific context is one of uncertainty, although as the science progresses these uncertainties might be expected to diminish and be resolved, one way or the other. Hence it is important that the Government continues to take a leading role in supporting climate science, and encourages a dispassionate evidence-based approach to debate and decision making. (pp. 70, House of Lords, 2005)

Since the scientific evidence is ambiguous, a perfect far-sighted decision-making process does not exist. In order to study the strategic implications of uncertainty, previous studies have assumed the distribution of the random parameters and the functional form to specify how agents form expectations (Finus and Pintassilgo (2009)[12]). Besides, in order to solve the problem of uncertainty, decision makers are able to do this through learning. Here, the learning process means that more information will be available with time. Timing is important in the learning process. On the one hand, if the environmental threats are not as serious as scientists have warned, what we do currently will be unnecessary waste. On the other hand, if the threats are more severe than we thought, we might need to pay much more in the future. The worst thing is that most environmental damage is irreversible, such as the damage from the accumulation of greenhouse gases on the ozone layer. With an irreversible decision making process, a decision maker may prefer over-protection to doing nothing.

Hence, Kolstad (2007)[21] and Kolstad and Ulph (2008)[22] consider the effects of the learning process and irreversibility on a single decision maker under uncertainty.

With the various beliefs updated sequentially, they assume players could have partial learning and complete learning. They claim that uncertainty with complete learning leads to higher expected membership but lower expected aggregate net benefits than no learning. Besides, partial learning would lead to lower membership and even lower expected aggregate net benefits. Their results, surprisingly, show that certain information has a negative effect for the IEAs. Helm (1998) [17] explains that countries can use the veil of uncertainty to hide their distributional interests and lead to the success of the IEAs without the learning process. Dellink and Finus (2009) [10] attempt to investigate uncertainty with their simulation on climate change. They find that the learning processes (both complete and partial) can only be positive when transfers are considered.

The third and the last major assumption in Barrett (1994)'s study is taking pollution abatement as a choice instrument. In mathematical terms, this assumption is equivalent to taking emission levels as the choice instrument. However, considering the results in the model, a zero abatement does not exist in the optimal equilibrium. It implies that every country would always choose a positive level of abatement, whether joining an IEA or not. The assumption limits the possibility of doing business as usual. The last assumption Barrett makes that can be challenged is that pollutants would not accumulate in the environment. This assumption neglects the fundamental problem of pollution, that it is accumulative and difficult to decompose. The following subsections analyse how the most recent literature attempts to address these limitations.

Many studies on IEA have investigated the incentives of participating in IEAs by examining the effect of policy instruments, such as punishment scheme, sanctions and side payment, to enlarge the stable coalition. The stable number mostly depends on the framework design of IEAs. With different policy instruments are introduced, the stability would be changed. The results might help the policy makers when they attempt to build larger coalitions, but the motivation of forming IEAs has not been explained.

Transboundary environmental issues are considered public goods/bads in general. One of the key characteristics of public goods is the free-riding effect. In order to balance this effect and maintain a stable self-enforcing IEA, an efficient policy mechanism is necessary. In practice, punishment (or sanction) and side payment schemes are widely applied to existing IEAs. Consequently, the punishment scheme appears popular both in practical and theoretical studies. The majority of the literature considers punishment schemes in models to stabilise the membership of the IEAs (e.g. Bahn *et al.*, 2009 [3] ; Barrett, 1994 [5]; Breton *et al.*, 2010 [9]; Lessmann *et al.*, 2009 [23]). Without punishment schemes, these studies show both theoretically and empirically that there is a significant disincentive to being a signatory.

Side payment is also a popular scheme in forming IEAs. In practice, this is visible in the report by the UNFCCC [13] which states that

> In order to achieve the full, effective and sustained implementation of the Convention, developed countries shall provide new, additional, adequate, predictable and sustained financial resources. [Developed countries commit to a goal of mobilizing jointly USD 100 billion dollars] [Developed countries shall make assessed contributions of 1.5 per cent of the GDP of those countries] a year by 2020 to support enhanced action on mitigation and adaptation, technology development and transfer, and capacity-building in developing countries. (page 6-7, FCCC/AWGLCA/2010/8)

In a theoretical study, Hoel and Schneider (1997) [18] argue that the prospect of receiving a transfer for reducing one's emissions, provided the country does not commit itself to cooperation, tends to reduce the incentive a country might have to commit itself to cooperation. They emphasise that the side payment is the disincentive to participate in an IEA and total emissions will be even higher. Several empirical studies support the effect of the policy. Empirical studies by Eyckmans and Finus (2006) [11] and Dellink and Finus (2009) [10] both show the importance of transfers for successful treaty-making in the case of global warming. Dellink and Finus (2009) [10] even emphasise that transfers can turn the asymmetry gap between countries into an asset for the coalition on climate change mitigation.

While the issues of global warming and climate change have become a worldwide concern, the on-going Emission Trading Scheme (ETS) has been discussed and has even been launched in practice over six major greenhouse gases. McKibbin *et al.* (1999) [25] examine the effects of the tradable emissions permit system proposed in the Kyoto

Protocol with an econometric estimated multi-region, multi-sector general equilibrium model of the world economy. Their results suggest that capital flows significantly affect the domestic effects of the emissions mitigation policy. Furthermore, Karp and Zhao (2010) [20] claim that the policy effect of the ETS is ambiguous. Only with an escape clause policy and a safety valve policy, would the ETS have a significant effect on enlarging the equilibrium level of abatement and the number of signatories.

To summarise the literature on IEAs, the framework of IEAs is the core. The fundamental purpose which aims to achieve the sustainable development has been neglected in the discussion. Following, we summarise the literature on sustainability.

2.2 Literature on Sustainability

Since *Our Common Future* was vowed in the World Commission on Environment and Development (WCED) in 1987, Pezzey and Toman [31] claims that economists have noticed on the issue of sustainability. We summarise the concepts of sustainability in the literature, the requirements to meet sustainability are various in three levels : the individuals, the society, and the ecosystem.

In the level of the individuals, sustainability means to achieve constant utility (Solow, 1974 [33] and Hartwich, 1977 [15]) and avoid any decline in utility (Pearce *et al.*, 1989 [29]; Pezzey, 1997 [30]). More precious, Pezzey (1997) [30] defines three distinct constraints as sustainable level, sustained level, and survivable level. Here, utility is the objective for individuals to achieve sustainability. In this micro-level utility, the choice of individual consumption plays an important role to reach the individual sustainability.

In the level of the society, sustainability requires future generations can meet their basic needs (WCED, 1987 [36]); maximise the length of existence of the human race (Georgescu-Roegen, 1971 [14]); the per capita incomes of future generations are no less than that of present generations (Pearce et al, 1989 [29]); and avoiding any decline in the present value of the social welfare (Riley, 1980 [32]). Either the ideal social welfare or the numerical macro-level indicators (e.g. Green Net National Product expanded by Hartwick, 1990 [16]; Ahmed *et al*. 1989 [1]; and Genuine Savings provided by

World Bank, 1999) is the objective to describe the transition of the society. Compare to the indicators which capture the human-made productivity, the environmental transition has been taken into account in the indicators of sustainability measuring.

When the scale is extended to the ecosystem, the requirements of sustainability cover a wide range of objectives which include extracting exhaustible natural resources (Meadows *et al*, 1972 [26]), renewable natural resource, production waste, and biological diversity (NSESD, 1993 [28]). In order to meet sustainability, extracting exhaustible resources, such as minerals and fossil fuel deposits, are required to be kept at the rate at which renewable can be substituted for the emitting wastes within the assimilative capacity of the environment. Harvesting of renewable resources, such as fishery and forest, has to be kept within their natural and managed rate of regeneration. In addition, biological diversity is the basic need for the survival development.

Regarding the possible response objective functions, we categorise literature in three main categories of policy goals : (1) achieving constant or non-declining individual utility function (eg. Solow, 1974 [33] and Pezzy, 1997 [30]); (2) avoiding any decline in social present value from time t onwards (eg. Riley, 1980 [32]); and (3) maintaining the 'safe minimum standard' (eg. Toman, 1994 [35]). The target objectives upon these objective functions include natural exhaustible resources in the early literature (eg. Slow, 1974 [33] and Stiglitz, 1974 [34]) and renewable resources and waste emissions in the later studies.

In order to avoid any decline in social present value, Woodward (2000) [37] defines a set of choices as sustainable if they are intergenerational fair. It means that the future generations does not envy the present, and there exists an alternative feasible choice such that there is no envy between generations. His ethic assumption emphasises the nature of the current generation's responsibility to future generations. The current generation consider not only the present welfare but also the welfare of future generations.

Besides, Toman (1994) [35] emphasise the concept of 'safe minimum standard' within the discussion of strong sustainability. Because the human impacts on the natural environment are 'irreversibility', when particularly the decision makers have low information but high potential asymmetry in the payoff function, the human capital shall not substitute the natural assets. Hence, Barbier and Markandya (1990) [4] impose a minimum stock of environmental assets. When the asset is driven below this safety criterion, environmental degradation will have destroyed the natural clean-up and regenerative processes in the environment. Following the concept, Martinet (2011) [24] proposes an approach that defines sustainability objectives using sustainability threshold indicators.

In practice, sustainable development has been introduced in national environmental policies in many countries, as well as international treaties for the past three decades (NSESD, 1993 [28]). The goal of achieving non-declining social welfare/utility over generations is in IEAs definitely. Nevertheless, to our best knowledge, the term of sustainability has not been taken into account in the literature on IEAs. In the following section, the concepts of sustainability are introduced into the model.

3 The Model

Following Barrett (1994)[5], Breton *et al.* (2010)[9] and literature on the IEA, the assumption of homogeneous country is accepted for the analyses of the incentives of IEAs. In order to investigate the long term effect of abatement, the game is set in 2 periods: t implies the present, and $t+1$ implies the future. In period t and $t+1$, each country chooses its abatement amounts to maximise its own payoff.

The game is considered with a finite set of N identical countries. Each country has to choose an abatement level of pollutant, $a_{k,t}$, $k \in \{1, ..., N\}$ in period t. The aggregate abatement in period t, $A_t \equiv \sum_{k=1}^{N} a_{k.t}$, is composed of the abatement of k and the rest of the world. Such aggregate abatement will accumulate until next period (δA_t). Hence, the aggregate abatement in period $t+1$ is $A_{t+1} = \delta A_t + \sum_{k=1}^{N} a_{k.t+1}$. With the ability of Nature to absorb CO2 stock, the pollution decay would be slightly more than the man-made abatement. It is therefore reasonable to assume that the accumulated abatement rate is larger than one ($\delta > 1$).

Emission abatement can be seen as a public good. Abating benefits not only the country itself but also other countries symmetrically. Therefore, the benefit of abatement on a country k is presented as

$$B_{k,t} = \gamma\, A_t$$

where γ is the marginal abatement benefit.

We assume a quadratic cost function of any individual country k in period t

$$C\left(a_{k,t}\right) = \frac{a_{k,t}^2}{2}$$

where $a_{k,t}$ represents country k's emission abatement amount in period t.

The abatement game with international environmental agreements (IEAs) framework will be played within two scenarios: (i) business as usual (BAU), (ii) sustainable development (SD). In the first scenario, both signatories and nonsignatories attempt to maximise their own current payoffs. In the second scenario, each signatory is concerned not only about its current payoff but also about its future payoff.

3.1 Business As Usual (BAU) Scenario

In the scenario of BAU, an myopic country k's payoff in period t which can be presented as

$$\begin{aligned} \underset{a_{k,t}}{\pi_{k,t}} &= B_{k,t} - C\left(a_{k,t}\right) \\ &= \left[\gamma\, A_t - \frac{a_{k,t}^2}{2}\right] \end{aligned} \tag{1}$$

Each country only take into account its present payoff affected by the abatements from itself, and the rest of the world. In the BAU scenario, decision makers are myopic and only the current payoff is taken into account. Since each country operates individually, its decision has singular effect on total emission as $\frac{\partial A_t}{\partial a_{k,t}} = 1$.

Without a framework of international environmental agreements, we differentiate (1) with respect to the current emission reduction and yield the optimal abatement of country k in period t, $a_{k,t}$, is

$$a_{k,t} = \gamma \tag{2}$$

The abatement depends on the marginal benefit γ. This result will not be influenced with time. The payoff in period t for each country are $\gamma^2 \left(N - \frac{1}{2}\right)$.

Similarly, we can find the optimal abatement of country k in period $t+1$ is the same to the result in period t. Due to the accumulated effect of abatement, the payoff in period $t+1$, $\pi_{k,t+1} = \gamma^2 \left[(1+\delta) N - \frac{1}{2}\right]$ which is larger than that in period t.

3.1.1 International Environmental Agreement (IEA) in the BAU scenario

In the following analyses, we extend the model to a 2-stage game model with international environmental agreement (IEA) framework in the scenario of BAU. In the first stage, countries play a membership game to decide whether to participate in an IEA or not. The membership status is played in stage 1 and will be still valid for the coming periods. In the second stage, countries play an abatement game in terms of their status. This model is solved by backward induction.

Abatement game We start from the second stage. Given that players have decided whether or not to be in the coalition in the first stage, their payoffs depend on the status of their membership. We assume that an IEA which is formed by n countries, the rest $(N-n)$ countries are nonsignatories. The coalition decisions have been made in the period t and still valid in the period $t+1$. The global abatements in period t and $t+1$ are

$$A_t \equiv \sum_{i=1}^{n} a_{i.t} + \sum_{j=n+1}^{N} a_{j.t} \tag{3}$$

$$A_{t+1} = \delta A_t + \sum_{i=1}^{n} a_{i.t+1} + \sum_{j=n+1}^{N} a_{j.t+1} \tag{4}$$

which is the sum of signatories' and nonsignatories' abatements.

Because players have been categorised in two groups at the first stage, their optimal abatements are decided through different processes.

A nonsignatory j achieves its own payoff *individually*. Thus, increasing one unit of nonsignatory's abatement causes only one unit increasing on the global abatement as $\frac{\partial A_t}{\partial a_{j,t}} = 1$. Any nonsignatory j maximises its current payoff ($\pi_{j,t}$) with respect to its abatement level ($a_{j,t}$) in the period t.

Any signatory i who follows the agreement might give up its control on the individual abatement and follow the common decision. As the number of the coalition is n, increase by one unit common abatement will cause n units increasing in the global abatement as $\frac{\partial A_t}{\partial a_{i,t}} = n$. This coalition effect implies that the more signatories brings the higher influence on the global abatement amount. The coalition payoff (Π_t) is the sum of member payoffs. Since all countries are identical, the optimum problem of the coalition is exactly what each member's optimum problem.

In period t, the payoff function of the coalition is written as

$$\begin{aligned} \max_{a_{i,t}} \Pi_t &= \sum_i^n \pi_{i,t} \\ &= \sum_i^n \left(\gamma A_t - \frac{a_{i,t}^2}{2} \right) \end{aligned} \tag{5}$$

and the payoff of nonsignatory j

$$\max_{a_{j,t}} \pi_{j,t} = \left[\gamma A_t - \frac{a_{j,t}^2}{2} \right] \tag{6}$$

We solve the coalition payoff and individual nonsignatory j's payoff simultaneously. The optimal abatements of a coalition member i and a nonsignatory j are respectively,

$$a_{i,t} = \gamma n \tag{7}$$

$$a_{j,t} = \gamma \tag{8}$$

From (7) and (8), we learn that a nonsignatory j follows the marginal benefit as no IEA exists. With the group effect, a signatory i considers the marginal benefit and the number of signatories. The more members in the coalition, the more emission the coalition is able to remove.

The aggregate abatements in period t and $t+1$ are

$$A_t = \gamma \left(n^2 + N - n\right) \tag{9}$$

$$A_{t+1} = \gamma \left(n^2 + N - n\right)(1+\delta) \tag{10}$$

Payoffs of a signatory i in period t and $t+1$ are

$$\pi_{i,t} = \gamma^2 \left(n^2 + N - n\right) - \frac{\gamma^2 n^2}{2} \tag{11}$$

$$\pi_{i,t+1} = \gamma^2 \left(n^2 + N - n\right)(1+\delta) - \frac{\gamma^2 n^2}{2} \tag{12}$$

, and a nonsignatory j always receives larger payoffs in both periods

$$\pi_{j,t} = \gamma^2 \left(n^2 + N - n\right) - \frac{\gamma^2}{2} \tag{13}$$

$$\pi_{j,t+1} = \gamma^2 \left(n^2 + N - n\right)(1+\delta) - \frac{\gamma^2}{2} \tag{14}$$

Membership game Back to the first stage, we solve the membership game with respect to the number of signatories. Once the decision has been made in period t, this agreement will resume in the next period. The reason of participating in a coalition depends on the payoff that country receives from its decision. To find the stable coalition size, n^*, we follow D'Aspremont *et al.* (1983) [2] and set two stability constraints as

$$\pi_{j,t}\left(n^* - 1\right) \leq \pi_{i,t}\left(n^*\right) \tag{15}$$

$$\pi_{i,t}\left(n^* + 1\right) \leq \pi_{j,t}\left(n^*\right) \tag{16}$$

Here, $\pi_{i,t}$ is the payoff of signatory i in period t and $\pi_{j,t}$ is the payoff of nonsignatory j in period t. The *internal constraint* (15) implies the incentive of participation of a signatory i. A country i would participate in a coalition only if being a signatory is better than being a nonsignatory. When the constraint is not obeyed, any signatory would withdraw from the coalition. The *external constraint* (16) explains the incentive of a nonsignatory. A country j would stay away from a coalition when the payoff of being a nonsignatory is better than that of being a signatory. When both constraints are obeyed, the coalition is called *stable* because the size of the coalition is robust. However, no particular country would definitely join the coalition, since all countries are identical. Any coalition combination is possible as long as the coalition size satisfies both constraints. If one signatory withdraw from the coalition must be with the participation of one nonsignatory, and vice versa.

With (11) and (13), we can rewrite the internal constraint (11) as

$$\gamma^2\left[\left(n^*-1\right)^2+N-\left(n^*-1\right)\right]-\frac{\gamma^2}{2}\leq\gamma^2\left(n^{*2}+N-n^*\right)-\frac{\gamma^2 n^{*2}}{2} \tag{17}$$

and the external constraint (13)

$$\gamma^2\left[\left(n^*+1\right)^2+N-\left(n^*+1\right)\right]-\frac{\gamma^2\left(n^*+1\right)^2}{2}\leq\gamma^2\left(n^{*2}+N-n^*\right)-\frac{\gamma^2}{2} \tag{18}$$

From (17), we derive the internal constraint as $1 \leq n^* \leq 3$. Within this range, any signatory does not have the incentive to leave. From (18), we derive that the external constraint holds when $n^* \geq 2$. When a coalition is no less than 2, none nonsignatory would have the incentive to participate. To summarise, both 2 and 3-members coalitions are stable coalitions. Any other exogeneous parameter, such as the marginal benefit of abatement γ and the overall country number N, does not affect the results.

3.2 Sustainable Development Scenario

In this part, we restructure the model for the scenario of sustainable development (SD). From the previous part, with myopic decision makers, we've learnt that a large number of coalition would not be hold. However, the demand of IEAs have been increased since the past decades, the intention of participants should be considered in another way. In the majority IEAs, sustainable development plays the principal role of the agreement purposes. Hence, we introduce sustainability criteria into the model as following.

For countries do not participate in a coalition, nonsignatories do not have the obligation to achieve sustainability. Hence, a nonsignatory j cares only the payoff in the present. The payoffs in both periods are the same as the case in the BAU scenario (6)

$$\max_{a_{j,t}} \pi_{j,t} = \gamma A_t - \frac{a_{j,t}^2}{2} \tag{19}$$

$$\max_{a_{j,t+1}} \pi_{j,t+1} = \gamma A_{t+1} - \frac{a_{j,t+1}^2}{2} \tag{20}$$

For countries participate in a coalition, the goal is to achieve sustainable development. To this end, the social welfare has to be maintained at a non-decreasing level. Different to the myopic assumption in the BAU scenario, both the present and the future welfare are considered by the current decision makers. Meanwhile, sustainability requires that the future generation feels no worse than the current generation. This assumption on intergenerational ethic is more reasonable in reality.

Hence, in the period t and $t+1$, the coalition payoffs are given by

$$\begin{aligned} & \max_{a_{i,t}} \Pi_t + \beta \Pi_{t+1}^E \\ = & \sum_i^n \left(\gamma A_t - \frac{a_{i,t}^2}{2} \right) + \beta \sum_i^n \left(\gamma A_{t+1} - \frac{a_{i,t+1}^2}{2} \right) \qquad (21) \\ & \text{subject to } \Pi_t + \beta \Pi_{t+1}^E \leq \Pi_{t+1} \qquad (22) \\ & \max_{a_{i,t+1}} \Pi_{i,t+1} \\ = & \sum_i^n \left(\gamma A_{t+1} - \frac{a_{i,t+1}^2}{2} \right) \qquad (23) \end{aligned}$$

where the parameter β is the time preference which implies the level of the current generation's concerns about the future generation. β is in the range between 0 and 1. The larger β implies that the future generations are more treasured by the present generation. A smaller β means the decision makers are more myopic. The objective function for the present generation (21) contains the payoffs in the present and the future. It implies the spirit of sustainability that members in the coalition care about both the present and the future generations. In order to maximise the length of human development, the future payoff is therefore concerned by the present generation. Nevertheless, due to the decisions on abatement is irreversible, (23) shows that the total abatement in period t (A_t) would be fixed in the period $t + 1$ and the future generation could only care the future coalition payoff.

In the sustainability inequality (22), the left-hand-side shows the objective function of the present generation. The function contains the coalition payoff in present (Π_t) and the discounted expected coalition payoff ($\beta \Pi_{t+1}^E$). The right-hand-side is the objective function of the future generation (Π_{t+1}). Given the players are perfect foresight, the expected coalition payoff Π_{t+1}^E is equal to the future coalition payoff (Π_{t+1}). Following the concepts of sustainability, the future generation should not feel worse than how current generation feels. When this inequality (22) is violated, the status is called *unsustainability*. Otherwise, the status is called *sustainability*.

With the sustainability inequality (22), there will be two possible solutions as following.

3.2.1 Case 1. Inactive Sustainability Inequality

When the inequality is inactive, we solve (21), (19), (23) and (20), and yield the optimal abatements for a signatory and a nonsignatory in period t and $t + 1$ are

$$a_{i,t} = \gamma n (1 + \beta\delta) \tag{24}$$

$$a_{j,t} = \gamma \tag{25}$$

$$a_{i,t+1} = \gamma n \tag{26}$$

$$a_{j,t+1} = \gamma \tag{27}$$

Since the current generation take future payoff into her objective function, a signatory i would abate more than what in the BAU scenario. The optimal abatement $a_{i,t}$ is enlarged by the discounted marginal abatement times the number of signatories ($\gamma n\beta\delta$).

The aggregate abatements in period t and $t+1$ are

$$A_t = \gamma \left[(1+\beta\delta)\, n^2 + N - n\right] \tag{28}$$
$$A_{t+1} = \gamma \left(n^2 + N - n\right)(1+\delta) + \beta\delta^2\gamma\, n^2 \tag{29}$$

Each signatory receives payoffs in period t and $t+1$ are

$$\pi_{i,t} = \gamma^2 \left[(1+\beta\delta)\, n^2 + N - n\right] - \frac{\left[(1+\beta\delta)\,\gamma\, n\right]^2}{2} \tag{30}$$
$$\pi_{i,t+1} = \gamma^2 \left(n^2 + N - n\right)(1+\delta) + \beta\delta^2\gamma\, n^2 - \frac{\gamma^2 n^2}{2} \tag{31}$$

, and a nonsignatory receives a larger payoff than what she could get in the scenario of BAU

$$\pi_{j,t} = \gamma^2 \left[(1+\beta\delta)\, n^2 + N - n\right] - \frac{\gamma^2}{2} \tag{32}$$
$$\pi_{j,t+1} = \gamma^2 \left(n^2 + N - n\right)(1+\delta) + \beta\delta^2\gamma\, n^2 - \frac{\gamma^2}{2} \tag{33}$$

3.2.2 Case 2. Active Sustainability Inequality

The sustainability inequality is binding when the future generation would feel worse than the present generation. We then have a corner solution from the inequality constraint (22). Given that the future payoff is perfect foresighted by the present generation, the constraint can be rewritten as

$$\Pi_{i,t} \leq (1-\beta)\Pi_{i,t+1} \tag{34}$$

From (19), (23) and (20), for the optimal abatements for a nonsignatory in period t and $t+1$ and a signatory in period $t+1$ are derived as what the results in the BAU scenario.

$$
\begin{aligned}
a_{j,t} &= \gamma \\
a_{i,t+1} &= \gamma n \\
a_{j,t+1} &= \gamma
\end{aligned}
$$

By these results into (34), we can find the constrained abatement level for a signatory in period t.

$$
\begin{aligned}
a_{i,t} &= r\left[n+\sqrt{\Omega}+n\delta\left(-1+\beta\right)\right] \\
where\ \Omega &= \beta n^2\delta^2\left(\beta-2\right)+\beta n^2\left(2\delta+1\right) \\
&\quad +2\beta\left(N-n\right)\left(\delta+1\right)+n^2\delta\left(\delta-2\right)-2\delta\left(N-n\right)
\end{aligned}
$$

4 Simulation

In order to analyse the complicated effect of the sustainability criteria, simulation are called for.

Given $N = 100$ countries, the year gap between two periods is a decade because the international treaties are usually valid for a long term. The accumulated abatement rate is set as 1.00866 from the natural annual removal rate of CO2 stock given by Nordhaus (1994) [27]. Table 1 shows solutions to the stable size of an IEA in the BAU scenario for the marginal abatement benefit γ and the discount rate β. The marginal abatement benefit is set from 0.01 to 1, 000. The discount rate is usually assumed as the annual interest rate for a decade, the reasonable interest rate is between 0.1% to 5%. As the theoretical analyses, the simulation result shows that these two parameters will not change the fact of a small coalition with 2 or 3 members in the BAU scenario.

Table 1. Number of signatories out of 100
for parameters of β and γ in the BAU scenario

	γ					
β	0.01	0.1	1	10	100	1000
0.1%	2	2, 3	2, 3	2, 3	2, 3	2, 3
1%	2	2, 3	2, 3	2, 3	2, 3	2, 3
2%	2	2, 3	2, 3	2, 3	2, 3	2, 3
3%	2	2, 3	2, 3	2, 3	2, 3	2, 3
4%	2	2, 3	2, 3	2, 3	2, 3	2, 3
4.5%	2	2, 3	2, 3	2, 3	2, 3	2, 3
5%	2	2, 3	2, 3	2, 3	2, 3	2, 3

Table 2 reports the stable size of an IEA in the sustainability scenario for the marginal abatement benefit γ and the discount rate β. The result shows that the marginal abatement benefit does not change the stable size of the coalition. The higher discount rate means signatories have higher expectation on the future. Thus the incentive to participate into a IEA is stronger. When the discount rate is large enough, for example $\beta = 5\%$, a full cooperation is achieved.

Table 2. Number of signatories out of 100
for parameters of β and γ in the Sustainability scenario

	γ				
β	0.01	0.1	1	10	100
0.1%	4	4	4	4	4
1%	9	9	9	9	9
2%	13	13	13	13	13
3%	20	20	20	20	20
4%	34	34	34	34	34
4.5%	82	82	82	82	82
5%	100	100	100	100	100

Table 3 presents the country abatements. In each cell, numbers in the left side are abatements in the BAU scenario and ones in the right side are abatements in the SD scenario. From top to bottom, they are nonsignatory's abatement in period t, signatory's abatement in period t, nonsignatory's abatement in period $t+1$, and signatory's abatement in period $t+1$ respectively.

Signatories' always abate more than nonsignatories do in both scenario. In the BAU scenario, the abatements would not be changed over time, since the decisions on abatement are irreversible. In the SD scenario, signatories abate more in period t than that in period $t+1$ because the sustainability criteria requests the coalition in period t cares payoffs in both the present and the future. Compare the results in two scenario, signatories always do more in sustainability than they do in the BAU. Nevertheless, nonsignatories are not bound by the sustainability criteria, they abate at the same level in both scenarios.

When the marginal abatement benefit γ increases, the abatement grows by the same increasing proportion. The time preference β does not make the abatement different in the BAU scenario, but the abatements of signatories increases dramatically with β in the SD scenario. It implies that if the future is concerned more with higher β, the abatements of signatories are higher.

Table 4 shows the country payoffs in the BAU and SD scenarios. The numbers in the left side in each cell are the payoffs in the BAU scenario and those in the right side are the payoffs in the SD scenario. From the top to down are the payoffs a nonsignatory and a signatory in period t, and a nonsignatory and a signatory in period $t+1$ respectively. Because the abatement is accumulative, the payoffs in the future is always higher than those in the present. The sustainability inequality (34) is therefore hold in the most cases. The sustainability inequality aims to hold the intergenerational fairness. The simulation result shows that, we might have binding solution in several small coalitions when the time preference is high (e.g. $\beta = 4.5\%$). Within the small number coalitions, the present generation would feel better than the future does. However, these small coalitions are not stable because the higher time preference has motivated more countries to join the coalition. The equilibrium is a larger number coalition and this sustainability inequality does not matter to the formation of IEA. In other words, the coalition which cares both the present and the future has reached the goal of sustainability.

When the abatement benefit parameter γ increase by 10 times, the response payoffs increase by 100 times. When the time preference rate β is very small, payoffs in BAU scenario are similar to the results in the SD scenario. The payoffs in both periods increase when the time preference increases. By the abatement of signatories in period t, the higher time preference would more benefit to nonsignatories and signatories in the future period.

Proposition 1 *To summarise the simulation results in the BAU and the SD scenarios, we learnt that :*

(1) With the sustainability criteria, countries are more willing to participate in a coalition.

(2) Signatories abate more in the SD scenario, compare to they do in the BAU scenario.

(3) With the sustainability criteria, signatories abate more in the present period, compare to they would do in the future.

(4) Payoff of a signatory is always less than payoff of a nonsignatory. Payoffs in the future is expected no worse than those in the present. When the future time preference is high, payoffs would be increased in both periods.

Table 3. Country abatements of nonsignatory and signatory in different periods within the BAU and SD scenarios

	γ							
β	0.01		0.1		1		10	
0.1%	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.040	0.2 , 0.3	0.404	2 , 3	4.042	20 , 30	40.416
	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.04	0.2 , 0.3	0.4	2 , 3	4	20 , 30	40
1%	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.10	0.2 , 0.3	1.00	2 , 3	9.97	20 , 30	99.75
	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.09	0.2 , 0.3	0.9	2 , 3	9	20 , 30	90
2%	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.16	0.2 , 0.3	1.59	2 , 3	15.95	20 , 30	159.47
	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.13	0.2 , 0.3	1.3	2 , 3	13	20 , 30	130
4%	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.51	0.2 , 0.3	5.09	2 , 3	50.90	20 , 30	509.01
	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.34	0.2 , 0.3	3.4	2 , 3	34	20 , 30	340
4.5%	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	1.31	0.2 , 0.3	13.14	2 , 3	131.43	20 , 30	1314.3
	0.01	0.01	0.1	0.1	1	1	10	10
	0.02	0.82	0.2 , 0.3	8.2	2 , 3	82	20 , 30	820

*Given $N = 100$ and $\delta = 1.00866$. From left top to down in each cell are the abatements of a nonsignatory and a signatory in period t and a nonsignatory and a signatory in period $t+1$ respectively in the BAU scenario. From right top to down are those abatements in the SD scenario.

Table 4. Country payoffs of nonsignatory and signatory in different periods within the BAU and SD scenarios

β	γ = 0.01		0.1		1		10	
0.1%	0.01	0.01	1.02 , 1.06	1.12	101.5 , 105.5	111.68	10150 , 10550	11168
	0.01	0.01	1.00 , 1.02	1.04	100 , 101.5	104	10000 , 10150	10400
	0.02	0.02	2.13 , 2.21	2.34	212.69 , 221.05	233.78	21269 , 22105	23378
	0.02	0.02	2.11, 2.17	2.26	211.19, 217.05	226.28	21119, 21705	22628
1%	0.01	0.02	1.02 , 1.06	1.81	101.5 , 105.5	180.74	10150 , 10550	18074
	0.01	0.01	1.00 , 1.02	1.31	100 , 101.5	130.97	10000 , 10150	13097
	0.02	0.04	2.13 , 2.21	3.69	212.69 , 221.05	369.06	21269 , 22105	36906
	0.02	0.03	2.11, 2.17	3.29	211.19, 217.05	329.06	21119, 21705	32906
2%	0.01	0.03	1.02 , 1.06	3.28	101.5 , 105.5	328.29	10150 , 10550	32829
	0.01	0.02	1.00 , 1.02	1.78	100 , 101.5	178.42	10000 , 10150	17842
	0.02	0.06	2.13 , 2.21	6.40	212.69 , 221.05	639.90	21269 , 22105	63990
	0.02	0.05	2.11, 2.17	5.42	211.19, 217.05	542.40	21119, 21705	54240
4%	0.01	0.21	1.02 , 1.06	21.482	101.5 , 105.5	2148.2	10150 , 10550	215000
	0.01	0.06	1.00 , 1.02	5.5992	100 , 101.5	559.92	10000 , 10150	55992
	0.02	0.38	2.13 , 2.21	37.737	212.69 , 221.05	3773.7	21269 , 22105	377000
	0.02	0.31	2.11, 2.17	30.897	211.19, 217.05	3089.7	21119, 21705	309000
4.5%	0.01	1.08	1.02 , 1.06	107.95	101.5 , 105.5	10795	10150 , 10550	1079500
	0.01	0.22	1.00 , 1.02	21.585	100 , 101.5	2158.5	10000 , 10150	215850
	0.02	1.85	2.13 , 2.21	185.09	212.69 , 221.05	18509	21269 , 22105	1850900
	0.02	1.51	2.11, 2.17	151.47	211.19, 217.05	15147	21119, 21705	1514700

*Assumes $N = 100$ and $\delta = 1.00866$. From left top to down in each cell are the payoffs of a nonsignatory, a signatory in period t and a nonsignatory, a signatory in period $t + 1$ respectively in the BAU scenario. Numbers from right top to down are those payoffs in the sustainability scenario.

5 Conclusion

In this paper, we examine the sustainability criteria which are the principle goals of the international environmental agreements. To do so, we firstly build a myopic BAU model which is without the concern on the intergenerational fairness. The present generation only cares the current payoff. In this scenario, only a small number of coalition could possibly be formed. The simulation results show that the framework of a IEA would not be changed with the variety of the abatement benefit parameter and the time preference rate. The individual abatement and payoff would increase with either the increasing benefit parameter or the time preference rate. However, nonsignatories and signatories would abate the same amount over time. The future payoffs are higher than the present payoffs, because the abatement is accumulated.

The study has shown the importance of the sustainability on the framework of IEAs by building the sustainable development (SD) scenario with two sustainability criteria. Firstly, the members in the coalition care the payoffs not only in the present but also the future. Secondly, the sustainability inequality implies that the future generation shall not envy the present generation. For those nonsignatories, their objective functions are still myopic and care their individual payoffs. The simulation results imply that the coalition framework would increase with the higher time preference rate. When the future generation is more treasured, the higher incentive of participating in a IEA. Meanwhile, the marginal benefit of abatement would not make the framework different. When the marginal benefit of abatement or the time preference increases, the abatement levels and payoffs all increase. Compare to the results in two periods, the coalition would abate more in the present than that in the future. However, myopic nonsignatories would abate the same level over time. Also, a nonsignatory always yield higher payoffs than a signatory does, the future generation has higher payoff than the present generation.

In order to ensure the intergenerational fairness, the sustainability inequality is set in the model. The simulation result show that, only when the time preference is high, the sustainability inequality might be bound with small number coalitions. Nevertheless, these binding coalitions are not stable with the internal and the external constraints. The high time preference has motivated more countries to join the IEA, a large coalition has been formed with higher payoffs. In other words, the goal of sustainability could be reached.

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