Dynamic Effects on the Stability of International Environmental Agreements

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Summary

In terms of the number of signatories, one observes both large and small international environmental agreements. The theoretical literature, based on game theory, discusses different concepts and mechanisms for the stability of coalitions and has reached the conclusion that, under farsightedness, both large and small stable coalitions can occur. In the context of a repeated game, this implies that large stable coalitions can also be sustained over time by a simple trigger mechanism, for large enough discount factors. However, if changes in time implement changes in state, this conclusion does not hold anymore: only small stable coalitions can be sustained.

Keywords: IEA's, Coalitional stability, Dynamics

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1. Introduction

Global environmental problems such as ozone depletion and climate change require international cooperation by sovereign states to internalise the negative externalities of cross-border emissions. In the last decades, so-called International Environmental Agreements (IEA's) were signed, but the number of signatories varies considerably (see e.g. Finus (2003)). The Montreal Protocol (1987) with the purpose to phase out CFC's, that cause depletion of the ozone layer, has been signed and ratified by 181 countries. However, the Kyoto Protocol (1997) with the purpose to reduce greenhouse gas emissions, that cause climate change, is a different story. The number of countries that will reduce emissions in the first phase is much smaller, and especially after the withdrawal of the USA in 2001, the basis of this agreement is not very strong. It came only recently into force by the ratification of Russia. In the literature many arguments can be found to why IEA's are large or not. Barrett (1994), for example, argues that phase out of CFC's would probably also have occurred without such an international agreement, because cheap substitutes became readily available so that the issue was in fact resolved through technological development. This means that the agreement was probably redundant and the number of signatories does not say much. The theoretical literature has focused on stability concepts for IEA's, in order to shed some light on the size that can be expected, and this paper should be placed in that tradition.

Initially this literature produced two conflicting views. One is rooted in cooperative game theory and reached the conclusion that the grand coalition is stable, using the γ-core concept and implementing transfers to solve the heterogeneity of the countries involved (Chander and Tulkens (1995)). One can say that this leads to an optimistic view on the size of the stable coalition. The other view is rooted in non-cooperative game theory and became the dominant path in the literature (Hoel (1992), Carraro and Siniscalco (1993), Barrett (1994)). The idea is to check for which size of the coalition an individual country is indifferent between joining or leaving and to use that as the stability concept. This part of the literature reaches the conclusion that the size of a stable coalition is typically very small and one can say that this leads to a pessimistic view. The explanation for the opposing conclusions is the difference in behavioural assumptions. The γ-core concept assumes that in case a sub-coalition forms, the other countries play Nash against the sub-coalition and this threat prevents the sub-coalition to form. On the other hand, in the non-cooperative approach it is assumed that in case a country leaves the coalition, the other members continue as a coalition, which yields sufficient free-rider benefits to end up with only a small coalition.

Recent developments in game theory (see e.g. Ray and Vohra (1999)) advocate the concept of farsightedness. The behavioural assumptions in this model are in a sense midway between the models described above. Neither it is assumed that the coalition fully breaks down nor that the remaining coalition stays intact but it is assumed that if a country leaves, it may trigger other countries to leave as well until some new stable situation is reached. A country has to compare its initial position with its position at the end of the process and this makes both large and small stable coalitions possible. In a way the cooperative and non-cooperative approaches above are reconciled by this concept.

Not much attention is paid to the role of time in this literature. Reaction patterns take time, of course, but time is usually not explicitly modelled in the underlying economic models. IEA's, however, have a time dimension. An agreement usually states that a certain emission reduction has to be realized at a future point in time. For example, in the Kyoto Protocol the 15 countries of the European Union have to reduce greenhouse gas emissions with 8 % by 2008-2012, as compared to 1990 levels. A few papers exist in this area. Germain et al. (2003) extend the analysis of Chander and Tulkens (1995) to a model with stock pollutants and conclude that the grand coalition is still stable at each point in time, although the transfers needed to solve heterogeneity have to vary over time. Rubio and Casino (2001) extend the non-cooperative analysis to a similar model with stock pollutants and by applying the stability analysis to the values of the differential game, they get essentially the same result as in the static context. Rubio and Ulph (2002) formulate a model where the size of the stable coalition may depend on the level of the stock. In that case, the transition to the steady state also implies a transition of the stable coalition but the results on the size are essentially the same.

The concept of farsightedness has reset an optimistic view on the original issue: large stable coalitions are possible without relying on strong behavioural assumptions as in the γ-core. It also seems straightforward to solve the issue of compliance to an IEA. If a country deviates at some point in time, this will trigger a smaller stable coalition in the next period and onwards. The country is worse off as an outsider to that smaller stable coalition than it was as a member of the larger stable coalition. We know from the simple trigger mechanism in repeated games (Friedman, 1986) that regardless of the benefits of deviation in the first period, deviation is deterred if the discount factor is high enough.

This paper will show, however, that compliance remains an issue in the case that time is explicitly modelled, and a change in time means a change in state. A repeated game context does not take into account that the actions in the first period change the state of affairs and thus the game in the next periods. It will be shown that in that case the simple trigger mechanism does not work so that deviations are not deterred. Only the small stable coalition can be sustained and the pessimistic view prevails. We are back at the old conclusion that only strong reactions with a high level of punishment are a sufficient threat to prevent deviations and sustain large stable coalitions. The paper presents a simple abatement model with time and state, but starts with a static version in order to clarify the different concepts and mechanisms.

2. Stability concepts

The basic model is a very simple abatement model. In the initial state of the world the global emissions are at a level s. There are n countries ($n > 2$) that can choose to abate a_i, i = 1,2,..,n. It is costly to abate but the resulting level of emissions is damaging. A simple cost indicator can be represented by

$$(1) \qquad C_i = \tfrac{1}{2} a_i^2 + \tfrac{1}{2} p\left(s - \sum_{j=1}^{n} a_j\right)^2, i = 1,2,..,n, p > 0,$$

where p denotes the relative weight attached to the damage costs as compared to the abatement costs. The countries are assumed to be identical. This is, of course, not very realistic if one, for example, considers the climate change problem, but in this way we can abstract from issues like transfers between countries within the coalition and the relationship between types of countries and membership. We only want to focus on the number of countries that join. An extensive literature exists (e.g. Bloch (1997), Yi

(1997), Ray and Vohra (1999)) on general coalitional structures but we restrict the analysis to a structure with one coalition (and other countries as individual outsiders) because this corresponds to the current practice of the international environmental agreements. Suppose that *m* countries form the coalition. This implies that these *m* countries jointly minimize the sum of their costs above, whereas the other countries (outsiders) individually minimize their costs. It follows that the first-order conditions for the equilibrium levels of abatement are given by

$$(2) \qquad a_i - mp(s - \sum_{k=1}^{n} a_k) = 0, i = 1,.., m$$

$$(3) \qquad a_j - p(s - \sum_{k=1}^{n} a_k) = 0, j = m+1,.., n$$

Adding up and some simple manipulations yield the equilibrium abatement levels and the resulting level of global emissions:

$$(4) \qquad s - \sum_{k=1}^{n} a_k = \frac{1}{1 + (m^2 + n - m)p} s$$

$$(5) \qquad a_i = \frac{mp}{1 + (m^2 + n - m)p} s, i = 1,.., m$$

$$(6) \qquad a_j = \frac{p}{1 + (m^2 + n - m)p} s, j = m+1,.., n$$

It follows that the costs in equilibrium for a member of the coalition (C^c) and for an outsider (C^o), respectively, are given by

$$(7) \qquad C^c = \tfrac{1}{2} \frac{p + m^2 p^2}{(1 + (m^2 + n - m)p)^2} s^2$$

$$(8) \qquad C^o = \tfrac{1}{2} \frac{p + p^2}{(1 + (m^2 + n - m)p)^2} s^2$$

A few things are immediately clear: for $m = 0$ or $m = 1$ one gets the standard Nash equilibrium between individual countries and for $m = n$ one gets the full-cooperative outcome, with higher abatement levels and lower total costs. Note that for any size of the coalition $m > 1$ the costs of the outsiders are lower than the costs of the coalition members and also lower than the costs in the Nash equilibrium (free-rider benefits).

The usual approach to the theory on stable IEA's (e.g. Carraro and Siniscalco (1993), Barrett (1994)) is based on the ideas developed for cartel stability (d'Aspremont et al. ((1983)) and requires so-called *internal* and *external* stability. Internal stability means that a country does not have an incentive to leave the coalition of size m: the costs of an outsider to the coalition of size $m-1$ must be larger than (or equal to, to cover the border case) the costs of a member of the coalition of size m. External stability means that a country does not have an incentive to join the coalition of size m: the costs of a member of the coalition of size $m+1$ must be larger than the costs of an outsider to the coalition of size m. Note that this definition implies that if a country leaves or joins the coalition, all the countries adjust their abatement levels, so that the result is not a Nash equilibrium in the strict sense. Therefore, it is more precise to define the game as a so-called *open-membership* game: first the countries decide on whether they want to be a member of the coalition or not and then the abatement levels are chosen (see e.g. Bloch (1997), Yi (1997), Finus (2003)). The Nash equilibrium of this last game corresponds to the concepts of internal and external stability. It is straightforward to show:

<u>Proposition 1</u> Consider the abatement model defined above. The size of the coalition that is both internally and externally stable is *2* if the parameter for the relative weight between the cost components $p \# p_u$, $p_u = 1/(n-4+2\sqrt{(n^2-3n+3)})$. Otherwise, the size is *1* or, to put it differently, the Nash equilibrium between individual countries results.

<u>Proof</u> It is straightforward to check that

$$(9) \qquad C^c(m) > C^o(m-1)$$

for all p, n, and $m > 2$, so that all coalitions larger than *2* are not internally stable. The same inequality (for $m = 3$) also implies that a coalition of size *2* is externally stable.

Furthermore, straightforward calculations show that the condition on the parameter *p* is equivalent with

$$(10)\qquad \frac{p+4p^2}{(1+(2+n)p)^2} \le \frac{p+p^2}{(1+np)^2},$$

so that under the condition on *p* a coalition of size *2* is internally stable.
If the condition on the parameter *p* does not hold, a coalition of size *2* is not internally stable. A coalition of size *1* is always internally stable and if the condition on *p* does not hold, a coalition of size *1* is also externally stable. Q.E.D.

The general conclusion of this analysis is that the size of the stable coalition is small, which is in accordance with the previous literature. In this model the size is not larger than *2*. Furthermore, even a small coalition of size *2* falls apart if the relative weight of the damage costs as compared to the abatement costs is higher than p_u. The value of p_u depends on the total number of countries *n*, and this value decreases if the total number of countries *n* increases.

Carraro and Siniscalco (1993) show that the size of the coalition can be extended if the members offer a transfer to outsiders for their willingness to join. The transfer can be paid from the gains of enlarging the coalition. They have to assume, however, that the original members are committed to stay in the coalition, because these countries will have incentives to leave when new members join. They also point at the role of the slope of the best-reply function: the steeper the slope, the larger the incentive to deviate from the coalition. In our model, the slope of the best-reply function is given by the parameter *p*, so that the results above are also in accordance with this finding.

As mentioned in the introduction, Chander and Tulkens (1995) take a very different approach, based on the core concept in cooperative games. Their contribution mainly concerns the transfers between heterogeneous countries, but for identical countries the story boils down to the following. They employ the γ-core concept, which means that when a sub-coalition deviates from the grand coalition the so-called partial agreement Nash equilibrium results: the whole coalition falls apart and a game is played between this sub-coalition with size *m* and the other countries individually. This is exactly the game described above with the costs $C^c(m)$ and $C^o(m)$, respectively. This literature in fact states that the grand coalition is stable because no sub-coalition has an incentive to deviate, simply because $C^c(m) > C^c(n)$ for all $m < n$. The crucial element in this mechanism is the behavioural assumption that in case of deviation, the other countries switch to individual Nash equilibrium behaviour. This is different from the concept of internal stability above where it is assumed that the remaining coalition stays intact in case a country deviates. The threat that the remaining coalition falls apart is precisely what deters deviations and supports the grand coalition in the approach of Chander and Tulkens (1995).

Recently the concept of *farsightedness* was introduced (e.g. Chwe (1994), Ray and Vohra (1999)) and applied to the problem of IEA's (e.g. Diamantoudi and Sartzetakis (2002), Eyckmans (2003)). The idea is that deviations not only trigger adjustments of abatement, as for internal stability, but may also trigger further deviations and that the starting situation has to be compared with the outcome at the end of this process. In this perspective, the mechanism of internal stability is too weak, because it is assumed that no further deviations take place, but the mechanism of the γ-core is too strong, because in that case it is assumed that the initial coalition completely falls apart. In the context of IEA's we have restricted ourselves to a structure with one coalition and the other countries as individual outsiders. The idea of farsightedness effectively means that we should not check for one-step internal stability but that we have to compare the costs of a coalition member to the costs of an outsider after a series of deviations has come to an end. The situation can get rather complicated. If the parameter $p \# p_u$ in the model above, the coalition of size *2* is stable, the coalition of size *3* is not, but the coalition of size *4* is stable, in the sense that the costs of a member of the coalition of size *4* are lower than or equal to the costs of an outsider to the coalition of size *2*. However, if the parameter $p > p_u$, the coalition of size *2* is not stable, but the coalition of size *3* can be both stable and not stable, depending on the value of *p*.

<u>Proposition 2</u> Consider the abatement model defined in the beginning of this section.

(i) If $p \# p_u$, the coalition of size *4* is stable, in the sense of farsightedness as described above.

(ii) If $p_u < p \# p_v$, $p_v = 2/(n\text{-}12+3\sqrt{}(n^2\text{-}4n+12))$, the coalition of size *3* is stable in that sense, but if $p > p_v$, the coalition of size *3* is not stable.

<u>Proof</u> (i) From Proposition 1 we know that the coalition of size *2* is stable. Therefore we have to check that

$$(11) \qquad C^c(4) \leq C^o(2)$$

or

$$(12) \qquad \frac{1+16p}{(1+(12+n)p)^2} \leq \frac{1+p}{(1+(2+n)p)^2}$$

which holds for $p \# 1/(n\text{-}10+2\sqrt{}(n^2\text{-}3n+21))$, which is satisfied if $p \# p_u$.

(ii) From Proposition 1 we know that the coalition of size *2* is not stable. Therefore we have to check that

$$(13) \qquad C^c(3) \leq C^o(1)$$

or

$$(14) \qquad \frac{1+9p}{(1+(6+n)p)^2} \leq \frac{1+p}{(1+np)^2}$$

which holds for $p \# 2/(n\text{-}12+3\sqrt{}(n^2\text{-}4n+12))$. The result follows immediately. Q.E.D.

In order to keep the analysis transparent and since more general results are not needed to make our point in the sequel of the paper, we fix the total number of countries at *4*. A low number is not unrealistic if we realize that it is to be expected that international negotiations more and more take place between blocks of countries: e.g. the European Union represented its member countries in the Kyoto Protocol. In case that $n = 4$, the conclusion of Proposition 2 is that the grand coalition is stable if $p \# p_u$ and if $p > p_v$. Namely, if $p \# p_u$, Proposition 2(i) applies, and if $p > p_v$, Proposition 2(ii) states that the coalition of size *3* is not stable, so that the grand coalition of size *4* must be stable, because a deviation of one country now triggers the whole coalition to fall apart. Note that if $p_u < p \# p_v$, the grand coalition is not stable (but the coalition of size *3* is).

In a way, the concept of farsightedness reconciles the two approaches described in the first part of this section. For p small enough, for example, both the small coalition of size *2* and the grand coalition are stable. This concept also seems to solve the issue of compliance with the agreement. The countries may want to form the grand coalition but they want to be sure that when the agreement is implemented, no incentives arise to deviate. Detection of deviation takes time, so that deviation is initially beneficial. However, following the idea of the well-known trigger mechanism in repeated games (Friedman (1986)), a deviator knows that at some point in time the deviation will be detected and the small stable coalition will result from that time onwards. Since the costs of an outsider to this small stable coalition are higher than the costs of a member of the grand coalition, the initial benefits are outweighed by the extra future costs, if the discount factor is high enough. Therefore, deviation is deterred and compliance is to be expected.

This reasoning, however, ignores one crucial aspect. The abatement game presented in the beginning of this section starts from an initial level s for global emissions. If it is assumed that this game is repeated, it is in fact assumed that this level stays the same, but this is not realistic. Abatement efforts in previous periods affect the global emission level, so that the game changes over time. Especially, the game has changed before a deviation is detected. The question is how this affects the trigger mechanism.

3. A dynamic model

The static model in section 2 can easily be adapted to a dynamic model by introducing the following dynamics for the level of emissions

$$(15) \qquad s(t+1) = s(t) - \sum_{i=1}^{n} a_i(t), t = 0,1,...., s(0) = s_0$$

and by formulating the cost indicators as

$$(16) \qquad C_i = \sum_{t=0}^{\infty} \delta^t [\tfrac{1}{2} a_i^2(t) + \tfrac{1}{2} ps^2(t)], i = 1,2,..,n.$$

The idea is that initially the global level of emissions s is s_0 above some target level. Each country can abate a_i. It is costly to abate, and the costs are convex, but it is also costly to keep the level of global emissions above the target level. In the long run, it is always best to bring the level of emissions down to the target level. If the countries take account of the damage of emissions to other countries, this process goes faster and has lower total costs. Under an agreement to cooperate, the target is reached in a more efficient way, but such an agreement is vulnerable to free-rider behaviour. The model is very simple but it allows analysing coalition stability and compliance in case of a changing state. IEA's usually have a fixed time horizon, but the mathematics for an infinite horizon is more tractable and the mechanisms are the same.

Suppose again that m countries form a coalition and that a Nash equilibrium results between this coalition and the other countries individually. Because the parameters in the state transition and the cost indicators are not time-dependent, the solution of this difference game is stationary. The dynamic programming equations for the feedback Nash or Markov perfect equilibrium are given by

$$(17) \qquad \tfrac{1}{2} m k^c s^2 = \min[\sum_{i=1}^{m} \tfrac{1}{2} a_i^2 + \tfrac{1}{2} mps^2 + \tfrac{1}{2} \delta m k^c (s - \sum_{k=1}^{n} a_k)^2]$$

$$(18) \qquad \tfrac{1}{2} k^o s^2 = \min[\tfrac{1}{2} a_j^2 + \tfrac{1}{2} ps^2 + \tfrac{1}{2} \delta k^o (s - \sum_{k=1}^{n} a_k)^2],\ j = m+1,..,n$$

where $V^c(s) = ½k^c s^2$ and $V^o(s) = ½k^o s^2$ denote the value functions for a member of the coalition and for an outsider, respectively. It follows that the first-order conditions for the equilibrium levels of abatement are given by

$$(19) \qquad a_i - \delta m k^c (s - \sum_{k=1}^{n} a_k) = 0, i = 1,..,m$$

$$(20) \qquad a_j - \delta k^o (s - \sum_{k=1}^{n} a_k) = 0,\ j = m+1,..,n$$

Adding up and some simple manipulations lead to the next-period level of emissions and to the feedback equilibrium abatement levels:

(21) $$s - \sum_{k=1}^{n} a_k = \frac{1}{1 + \delta(m^2 k^c + (n-m)k^o)} s$$

(22) $$a_i = \frac{\delta m k^c}{1 + \delta(m^2 k^c + (n-m)k^o)} s, i = 1,.., m$$

(23) $$a_j = \frac{\delta k^o}{1 + \delta(m^2 k^c + (n-m)k^o)} s, j = m+1,.., n$$

Substitution in the dynamic programming equations above yields the following set of equations for the parameters of the value functions:

(24) $$k^c = p + \frac{\delta k^c (1 + \delta m^2 k^c)}{(1 + \delta(m^2 k^c + (n-m)k^o))^2}$$

(25) $$k^o = p + \frac{\delta k^o (1 + \delta k^o)}{(1 + \delta(m^2 k^c + (n-m)k^o))^2}$$

As in section 2, for $m = 0$ or $m = 1$ one gets the parameter of the value function for the standard Nash equilibrium between individual countries and for $m = n$ one gets the parameter of the value function for the full-cooperative outcome.

First, we check for internal and external stability. It is not easy to perform the analysis analytically but a numerical exercise already gives the insights that we need. We fix the number of countries $n = 4$ and we fix the parameter p at a level that is low enough to give a stable coalition of size *2* in the comparable static model of section 2: $p = 0.1$. Then the role of the discount factor becomes clear. Numerical calculations show that the dynamic model has a stable coalition of size *2* if the discount factor is low enough but for a large discount factor, even the small stable coalition falls apart. For example, $k^c(2) < k^o(1)$ for $\delta = 0.6$ but $k^c(2) > k^o(1)$ for $\delta = 1$ (see table 1). Second, if we employ the concept of farsightedness, we can conclude that for $\delta = 0.6$, besides the coalition of size *2*, also the grand coalition of size *4* is stable, because $k^c(4) < k^o(2)$. For $\delta = 1$, however, the coalition of size *3* is stable, because $k^c(3) < k^o(1)$, but the grand coalition is not (compare this to Proposition 2 in section 2 and the conclusions thereafter). We are now ready to investigate the trigger mechanism for the dynamic abatement model with a changing state.

4. Compliance with the large stable coalition

At some point in time, for some value of the level of emissions *s*, a coalition of size *m* has formed. Suppose that a member of the coalition considers deviating but the other countries in the coalition will not observe that before the next period. The deviating country can enjoy the free-rider benefits for one period of time but in the next period things have changed: the coalition structure changes to a smaller stable coalition and the level of emissions has changed. In the context of a repeated game, where the state of the world is assumed to remain the same, the change to a smaller stable coalition deters deviations because the free-rider benefits do not outweigh the increase in costs due to this change (if the discount factor is high enough). The question is whether this also holds in the model with a changing state.

When a country deviates, it knows that the future costs are given by the value function of an outsider to the coalition that will result in the next period. The parameter of this value function is denoted by k^{o+}. The first-order condition for the abatement level of the deviating country becomes

$$(26) \qquad a_i - \delta k^{o+}(s - a_i - \sum_{k \neq i} a_k) = 0$$

Because the other countries stick to their behaviour as a member or as an outsider to the coalition of size *m* in the current period, this leads to

$$(27) \qquad a_i = \frac{\delta k^{o+}}{1+\delta k^{o+}} \frac{1+\delta m k^c}{1+\delta(m^2 k^c + (n-m)k^o)} s$$

$$(28) \qquad s - \sum_{k=1}^{n} a_k = \frac{1}{1+\delta k^{o+}} \frac{1+\delta m k^c}{1+\delta(m^2 k^c + (n-m)k^o)} s$$

It follows that the value function of the country that deviates is given by $V_i(s) = ½ k_i s^2$, where

$$(29) \qquad k_i = p + \frac{\delta k^{o+}}{1+\delta k^{o+}} \frac{(1+\delta m k^c)^2}{(1+\delta(m^2 k^c + (n-m)k^o))^2}$$

It is again not easy to perform the analysis analytically but continuing the numerical exercise already gives the insights that we need. We fix the parameter p again at 0.1. In the previous section we have shown the effect of the discount factor. If $\delta = 0.6$, a deviation (from the grand coalition $m = n = 4$) triggers a stable coalition of size 2 in the next period, so that $k^{o+} = k^o(2)$. However, if $\delta = 1$, a deviation (but now from the coalition of size 3) triggers the Nash equilibrium between individual countries in the next period, so that $k^{o+} = k^o(1)$.

In both cases, deviations are not deterred, because $k_i(4) < k^c(4)$ and $k_i(3) < k^c(3)$ (see table 1). In the case that the discount factor is low, we may be tempted to think that the trigger mechanism does not work because future costs are too heavily discounted. However, this argument does not apply to the case where $\delta = 1$. Note that following the concept of farsightedness in listing the possible stable coalitions to start with, we looked at the coalition of size 3 here, but deviations from the grand coalition would also not be deterred, because $k_i(4) < k^c(4)$ (see table 1). The reason that the trigger mechanism does not work is a different one. The global level of emissions in the next period has decreased, due to the abatement efforts in the current period. Therefore all future costs and, more specifically, all extra future costs, when a deviation is detected, are lower. The result above shows that the extra future costs are so much lower, even if the discount factor is equal to 1, that deviations are not deterred, because the initial free–rider benefits are not outweighed. The typical finding in control theory, that the state is quickly adjusted in the initial periods, implies for our problem that deviations from the large stable coalition are not deterred so that this large stable coalition cannot be sustained (see also de Zeeuw, 2002).

This is bad news for the chance of success of international environmental agreements. The optimistic view on stability of IEA's with a large number of signatories is mainly based on trigger mechanisms that work fine in a static or a repeated game context, but do not work in the context of a difference game with a changing state.

5. Conclusion

Stability of international environmental agreements is a heavily debated issue. Some are optimistic and expect that the grand coalition can be sustained. Their arguments are based on the core concept in cooperative game theory or on trigger mechanisms in repeated games. Others are pessimistic and expect that only very small coalitions can be sustained. Their arguments are based on open-membership games and the concepts of internal and external stability.

The concept of internal stability is too weak. If a country considers deviating, it will realize that a deviation may trigger further deviations, which has inspired the concept of farsightedness. This concept sustains large stable coalitions, besides the small one that is found under internal and external stability requirements. This is good news for the optimists.

Establishing a coalition is one thing but compliance is another. Observing deviations and reacting to it takes time. In a repeated game context, the trigger mechanism with the threat to end up as an outsider to a small coalition is sufficient to deter deviations, provided that the discount factor is large enough. However, this paper shows that if the state of the world changes in the time that is needed to detect deviations, as is to be expected in a dynamic emission control model, this threat is not sufficient anymore and large coalitions cannot be sustained. Unfortunately, the pessimistic view prevails again. Note that we only looked at the simple trigger mechanism, as described above, since this is the type of reaction one can expect in the international arena. Of course, punishment strategies that deter deviations exist, as we know from the folk theorem, but this type of strategies is not observed in practice and it is hard to imagine that the countries can really employ such strategies.

The Montreal Protocol was a success in terms of the number of signatories, but from this we cannot conclude that establishing large coalitions is easy. As was argued in the introduction, special circumstances may have caused this to happen. In the Kyoto Protocol real benefits of cooperation are at stake and here we observe huge difficulties to form a large coalition. Theoretical research into stability concepts may not directly provide an answer to the challenge ahead of us, but insights into the mechanisms that enhance or threaten international cooperation are important, in my view. This paper ends with a pessimistic conclusion, but with the hope to inspire further research into the challenge of international cooperation.

Table 1

	$\delta = 0.6$	$\delta = 1$
$k^c(4)$	0.13531	0.14354
$k^c(3)$	0.14499	0.15944
$k^c(2)$	0.15357	0.17612
$k^o(2)$	0.13812	0.14070
$k^o(1)$	0.15377	0.17055
k^{o+}	0.13812	0.17055
$k_i(4)$	0.12541	0.13322
$k_i(3)$	0.13530	0.14875

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