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Dynamic Effects on the Stability of International Environmental Agreements

Aart de Zeeuw

Department of Economics and CentER

Tilburg University[1]

Abstract

In terms of the number of signatories, one observes both large and small international environmental agreements. The theoretical literature, based on game theory, produces results on the size of stable coalitions that can indeed go both ways. This paper first examines the different mechanisms in order to explain this controversy. Time plays a role in these mechanisms and time is usually also part of an agreement. It is therefore important to see how these mechanisms hold out in a dynamical setting. This paper shows that in that case the pessimistic view prevails: only small stable coalitions can be sustained.

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[1] P.O. Box 90153, 5000 LE Tilburg, the Netherlands, A.J.deZeeuw@uvt.nl, +31-13-4662065.

1. Introduction

Global environmental problems such as ozone depletion and climate change require international cooperation by sovereign states to internalise the negative transboundary externalities. In the last decades, International Environmental Agreements (IEA's) were established with a varying rate of success in terms of the number of signatories (see e.g. Finus (2003) for the most important IEA's). The Montreal Protocol (1987) with the purpose to phase out CFC's, that deplete the ozone layer, is a big success in this respect: it has been signed now by 181 countries. The Kyoto Protocol (1997), however, is a different story. The number of countries involved is much smaller and especially after the withdrawal of the USA in 2001, this IEA has a small basis. It only came into force recently with the support of Russia.

It can be argued whether the number of signatories is a good indicator for success. Barrett (1994) shows that a large number of signatories not necessarily means that large benefits of cooperation are realized. On the contrary, it probably means that the benefits are small and that the phase out of CFC's would also have occurred without international cooperation. The reason here is that cheap substitutes for CFC's became available, so that the issue was in fact resolved through technological development. The Kyoto Protocol is a different story. Part of the problem here is, of course, caused by the ongoing debate whether emissions of greenhouse gases really pose a big threat or not, but another part of the problem is caused by the characteristics of this IEA. On the basis of the current insights, benefits of cooperation would be high, technological developments do not seem to be able to produce cheap substitutes in a short period of time, and incentives to free ride on the agreement are substantial. This situation is the real challenge and it seems that in this case, IEA's with a large number of signatories have difficulty to emerge. It is therefore important to precisely understand why large coalitions are difficult and what mechanisms or design may improve that picture.

This paper fits in the literature on strategic mechanisms that determine the size of a coalition or, more precisely, the size of a *stable* coalition. The question is whether large coalitions can be stable in some sense but this literature is not conclusive and sometimes even contradictory. It starts out on two paths: one is rooted in cooperative game theory and the other one in non-cooperative game theory. Chander and Tulkens

(1995) use a core concept (the γ-core) and show that transfers between heterogeneous countries exist with the property that the grand coalition belongs to the core and is in that sense stable. One can say that this leads to an optimistic view on the size of the stable coalition. On the other hand, the dominant path in the literature (starting with Hoel (1992), Carraro and Siniscalco (1993), Barrett (1994)) builds on the idea to see when an individual country is indifferent between joining or leaving the coalition and to use that as the stability concept. This literature reaches the conclusion that the size of a stable coalition is typically very small. One can say that this leads to a pessimistic view on the size of the stable coalition. Recent developments in game theory (see e.g. Ray and Vohra (1999)) advocate the concept of farsightedness. The basic idea is that deviations may trigger further deviations, which have to be taken into account by the deviator. Both small and large stable coalitions can occur: in a way the cooperative and non-cooperative approaches above are reconciled by this concept. Furthermore, it is interesting to note that the stability mechanism in Chander and Tulkens (1995) is similar to the idea of trigger strategies in non-cooperative repeated games (Friedman (1986)). Both assume that in case of a deviation, other cooperation breaks down, and this threat may prevent such a deviation to occur. It has become clear by now that the discussion on the size of the stable coalition is not so much a controversy between the cooperative and non-cooperative approach, but that it boils down to the behavioural assumptions in case of a deviation from some initial agreement. If it is assumed that cooperation breaks down or that further deviations may occur, large stable coalitions can be sustained. In section 2 of this paper these issues are explained in more detail, using a simple static abatement model. Under the concept of farsightedness, both the grand coalition and a very small coalition are stable. At this point we may argue that the grand coalition can be sustained because a deviation will trigger further deviations until the small stable coalition arises, which deters deviation. This is also true if time passes by but then we have to add that the discount factor has to be high enough, as for trigger strategies in repeated games. The model is set up in a way that it can easily be adapted to a dynamic model in the sequel of the paper.

Not much attention is paid to the role of time in the literature. Implicitly time is there since reactions patterns require time, but time is not explicitly modelled. On the other hand, IEA's usually have a time dimension. An agreement usually states that a certain emission reduction has to be achieved at some 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. Each step in this process changes the state of affairs, and one may wonder what the effect is of such a changing state on the strategic mechanisms discussed above. To put it differently, when a deviation is detected, the state of affairs has changed and it is interesting to see how this affects the reactions and the initial incentives to deviate. This paper will show that, when time is taken into account, the pessimistic view prevails: only small stable coalitions can be sustained. The intuition is as follows. Without a state, a large stable coalition can be sustained, because deviations induce a smaller stable coalition, which is a sufficient threat (if the discount factor is high enough) to prevent deviation. However, when the state has changed, the threat may not be sufficient anymore. This paper will show that the equilibrium state trajectory indeed has this property.

A small part of the literature treats stability of coalitions in a dynamic context but the focus is different. Germain et al. (2003) extend the analysis of Chander and Tulkens (1995) to stock pollutants but their approach only affects the transfers over time and not the strategic conclusions: the full coalition forms at each point in time. Rubio and Casino (2001) extend the "non-cooperative" analysis to stock pollutants but they treat the coalitional game as a one-shot game: the strategy for the differential game with a stock pollutant is chosen at once and time does not play a role in the coalitional game. Rubio and Ulph (2002) formulate a model where the size of the stable coalition may depend on the level of the stock. The model in their paper resembles the one in Rubio and Casino (2001) but it is formulated in discrete time in order to be able to perform a trigger analysis. It focuses on the role of the discount factor and the relative weight between abatement costs and damage costs. The analysis confirms the earlier result that the stable coalition consists of two countries, but even that small coalition falls apart if the discount factor is high or a high weight is attached to the damage costs in comparison with the abatement costs.

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 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

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

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 a coalition and which countries will join a coalition. We 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 coalitional structures in general but we want to restrict the analysis to a structure with one coalition and the other countries as individual outsiders, because this is in line with the current practice of international environmental agreements. Suppose that *m* countries form this coalition. This implies that these countries jointly minimize the sum of their costs. It follows that the first-order conditions for the equilibrium levels of abatement are given by

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

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

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

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

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

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

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

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

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

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 a coalition with size m, that is the costs of an outsider of a coalition with size $m-1$ are larger than the costs of a member of a coalition with size m. External stability means that a country does not have an incentive to join a coalition with size m, that is the costs of a member of a coalition with size $m+1$ are larger than the costs of an outsider of a coalition with size m. Note that this definition implies that if a country leaves or joins a coalition, all countries adjust their abatement levels, so that the outcome is not an equilibrium in the strict sense. Therefore, it is more precise to define the game as an *open membership* game: first the countries decide whether they want to be a member of the coalition or not and then the abatement levels are chosen (e.g. Bloch (1997), Yi (1997), Finus (2003)). The Nash equilibrium of this open-membership game corresponds to the concepts of internal and external stability above. It is straightforward to check that for all $m > 2$

$$C^c(m) > C^o(m-1)$$

for all p and n, so that all coalitions larger than 2 are not internally stable. However,

$$\frac{p+4p^2}{(1+(2+n)p)^2} < \frac{p+p^2}{(1+np)^2}$$

for each (positive) weight p smaller than $(4-n+2\sqrt{(n^2-3n+3)})/(3n^2-4n-4)$. This implies that in this range a coalition with size 2 is internally stable. It is also externally stable because the previous inequality holds for $m = 3$. Note that the largest value of p for which we have a stable coalition of 2 decreases if the number of countries n increases. The conclusion is that the size of a 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 a certain value: this value decreases with the number of countries.

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. In fact, it is stated that the grand coalition is stable since no sub-coalition will deviate, simply because $C^c(m) > C^c(n)$ for $m < n$. The crucial element in this mechanism is the behavioural assumption that in case of a deviation, the other countries switch to Nash equilibrium behaviour. This is very 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 may be too weak, because it is assumed that no further deviations take place, but the mechanism of the γ-core may be 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 coalitional structure with one coalition and the other countries as individual outsiders. Then the concept of farsightedness implies that we should not check for one-step internal stability but that we should compare the costs of a coalition member to the costs of an outsider after a series of successive deviations has come to an end. In the model above, when starting from any coalition larger then 2, this process stops at the coalition with size 2, if the value of parameter p is smaller than $p_u = 4\text{-}n\text{+}2\sqrt{(n^2\text{-}3n\text{+}3))/(3n^2\text{-}4n\text{-}4)}$. Otherwise, the coalition completely falls apart. Starting from the grand coalition, if p is smaller than p_u, farsightedness implies that we should compare $C^c(n)$ to $C^o(2)$, instead of to $C^o(n\text{-}1)$ (as for internal stability) or to $C^o(1)$ (as for γ-core stability). For p larger than p_u, we are simply back at γ-core stability. It is easy to check that

$$\frac{p+n^2p^2}{(1+n^2p)^2} < \frac{p+p^2}{(1+(2+n)p)^2}$$

holds if $p < (n\text{-}3)/4$. Note that for $n = 3$, further deviations do not play a role so that we can conclude, as before, that the grand coalition is not internally stable. However, for $n > 3$, it follows that the grand coalition is stable in the sense of farsightedness. If

p is smaller than p_u, this follows because $p_u < (n\text{-}3)/4$. Note that if p is larger than p_u, stability of the grand coalition is obvious.

In a way, the concept of farsightedness reconciles the two basic approaches described above. Both the small coalition of size *2* (for p small enough) and the grand coalition are stable. The idea that deviations may trigger further deviations can also be used to construct an alternative to the well-known mechanism of trigger strategies in repeated games (Friedman (1986)). Players with a trigger strategy start to cooperate but punish deviations by switching to Nash equilibrium behaviour. If the discount factor is high enough, this threat is sufficient to sustain cooperation. For an IEA one may argue that countries start in a grand coalition but deviations trigger a smaller stable coalition. If the discount factor is high enough, the threat of ending up at the costs of an outsider of this small coalition deters deviations, so that the grand coalition can be sustained. The mechanism is similar but the behavioural assumptions are perhaps more in line with what one would expect of countries involved in an IEA. It is to be expected that the mechanism works, although we still have to prove that the benefits of deviation do not outweigh the costs of ending up with a small coalition. The purpose of this paper is, however, to take the issue one step further and to see if the mechanism still works in case the state of affairs is changing. By their abatement decisions, the countries are changing the level of emissions and therefore the parameters of the game. To detect a deviation and to react to it takes time, and in the meantime the level of emissions has changed due to the previous abatement decisions. In this situation is not so clear that the mechanism works and that the grand coalition can be sustained. In the next section the model is extended to a dynamic model in order to be able to answer this question.

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

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

and by defining the cost indicators as

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

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

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

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

where $V^c(s) = \tfrac{1}{2} k^c s^2$ and $V^o(s) = \tfrac{1}{2} k^o s^2$ 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

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

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

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

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

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

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

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

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

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

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 with size 2 in the comparable static model of section 2: $p = 0.1$. Then the role of the discount factor becomes clear. Calculations show that the dynamic model has a stable coalition with 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 use the concept of farsightedness, we can again conclude that, besides the coalition with size 2, also the grand coalition with size 4 is stable, because $k^c(4) < k^o(2)$ for $\delta = 0.6$. This means that deviations from the grand coalition are deterred, if it is assumed that the adjustments to the small stable coalition with size *2* occur instantaneously. However, the question remains whether deviations are also deterred if these adjustments take time and meanwhile the stock of pollutants has changed.

4. Deviations and a changing state

At some point in time, for some value of the level of emissions, a coalition with size m has formed. Suppose that a member of the coalition considers deviating but that the other countries in the coalition do not observe that before the next period. The country can enjoy 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 remains the same, the change in coalition size 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 of 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

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

Since the other countries stick to their behaviour as a member or an outsider of the coalition with size m in the first period, this leads to

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

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

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

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

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

In both cases, deviations are not deterred, because $k_i(4) < k^c(4)$ (see table 1). If the discount factor is low, the increase in future costs do not count so heavily as current free-rider benefits and the deviator can still enjoy the outsider position of the stable coalition with size 2 that results in the next period. Therefore, it is not a surprise that deviations are not deterred, because the negative consequences are not severe enough. However, if the discount factor is 1, costs and benefits are weighed equally over time and the coalition falls apart completely. In this case, based on the insights derived for repeated games, one would expect that deviations are deterred but the opposite is true. The reason is that the stock of pollutants has decreased in the next period, due to the abatement in the first period, which lowers future costs. The negative consequences are therefore not severe enough (despite the high discount factor and the loss of any cooperation) and deviations are deterred. Finally, it follows that the grand coalition with size 4 cannot be sustained, but may be a coalition with size 3 can. The answer is no, because it also holds that $k_i(3) < k^c(3)$ (see table 1). The intuition is the same.

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 in 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, so that it has to compare total costs without deviation to total costs after a series of deviations. This farsightedness sustains both the grand coalition and the small coalition that is found under internal and external stability requirements. This is good news for the optimists.

However, observing deviations and reacting to it takes time and the state of the world changes in that same time. This paper shows that the pessimistic view prevails again: the grand coalition cannot be sustained.

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

References

d'Aspremont, C., J. Jacquemin, J. Gabszewicz and J. Weymark (1983), On the stability of collusive price leadership, *Canadian Journal of Economics* 16, 17-25.

Barrett, S. (1994), Self-enforcing international environmental agreements, *Oxford Economic Papers* 46, 878-894.

Bloch, F. (1997), Non-cooperative models of coalition formation in games with spillovers, in: C. Carraro and D. Siniscalco (eds.), New Directions in the Economic Theory of the Environment, Cambridge University Press, Cambridge, 311-352.

Carraro, C. and D. Siniscalco (1993), Strategies for the international protection of the environment, *Journal of Public Economics* 52, 309-328.

Chander, P. and H. Tulkens (1995), A core-theoretic solution for the design of cooperative agreements on transfrontier pollution, *International Tax and Public Finance* 2, 279-293.

Chwe, M. (1994), Farsighted coalitional stability, *Journal of Economic Theory* 63, 299-325.

Diamantoudi, E. and E. Sartzetakis (2002), International environmental agreements – the role of foresight, *mimeo*.

Eyckmans, J. (2003), On the farsighted stability of international climate agreements, *mimeo*.

Finus, M. (2003), Stability and design of international environmental agreements: the case of transboundary pollution, in: H. Folmer and T. Tietenberg (eds.), The International Yearbook of Environmental and Resource Economics 2003/2004, Edward Elgar, Cheltenham, 82-158.

Friedman, J. (1986), Game Theory with Applications to Economics, Oxford Economic Press, New York.

Germain, M., Ph. Toint, H. Tulkens and A. de Zeeuw (2003), Transfers to sustain dynamic core-theoretic cooperation in international stock-pollutant control, *Journal of Economic Dynamics and Control* 28, 79-99.

Hoel, M. (1992), International environmental conventions: the case of uniform reductions of emissions, *Environmental & Resource Economics* 2, 141-159.

Ray, D. and R. Vohra (1999), A theory of endogenous coalition structures, *Games and Economic Behaviour* 26, 286-336.

Rubio, S. and B. Casino (2001), International cooperation in pollution control, *mimeo*.

Rubio, S. and A. Ulph (2002), An infinite-horizon model of dynamic membership of international environmental agreements, *mimeo*.

Yi, S.-S. (1997), Stable coalition structures with externalities, *Games and Economic Behaviour* 20, 201-237.

Zeeuw, A. de (2002), Highlighting the acid rain game, in: B. Kriström, P. Dasgupta and K.-G. Löfgren (eds.), Economic Theory for the Environment, Edward Elgar, Cheltenham, 317-330.