# Insights from Game-Theoretic Analysis on the Design of International Climate Agreements*

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**Abstract**

Game-theoretic approaches have been widely used to examine interactions between countries in the negotiations on climate change, and have emphasized difficulties in designing such a voluntary agreement. This paper presents the current status of international negotiation on climate change control and the observed scientific evidence, and provides an overview of literature on game-theoretic analysis of climate coalition formation. The role of some flexible mechanisms and potential extensions will be discussed to promote participation in the international agreement on climate change.

**Keywords**： International environmental agreement, Applied game theory

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## 1. Introduction

Global warming has been considered one of the major environmental challenges that the world is facing to date. International cooperation is vital to achieve a large amount of reductions of the greenhouse gases (GHGs) emissions. The United Nations Framework Convention on Climate Change (UNFCCC) entered into force in 1994 with an aim to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In 1997, the Kyoto Protocol was signed, which mandated that by the period from 2008 to 2012, Annex I countries (composed of developed countries and economies in transition) should reduce their GHGs emissions by approximately 5% compared to their 1990 levels. The Protocol came into force in 2005, although the U.S.A., one of the major emitters of $CO_2$, had not ratified the Protocol. Upon the expiration of the Kyoto Protocol, the Parties to the UNFCCC continue to strive to negotiate on the post-Kyoto international framework. The negotiation at the Conference of the Parties (COP) to the UNFCCC in Copenhagen revealed how difficult it was to achieve full cooperation on climate change control.

The Intergovernmental Panel on Climate Change (IPCC), an intergovernmental scientific body, states in its Fourth Assessment Report (AR4) that 'Warming of the climate system is unequivocal' by quoting the observation of changes in the climate system, such as rise in the global average surface temperature and global average sea level (IPCC, 2007a). The global average surface temperature has increased by about 0.74±0.18 ˚C over the period 1906 to 2005, and global average sea level has risen by 3.1±0.7 mm per year from 1993 to 2003 (IPCC, 2007a). Furthermore, AR4 shows that precipitation increased considerably over the period from 1900 to 2005 in eastern parts of North and South America, northern Europe and northern and central Asia, while it declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. There is associated observable evidence of extreme climate events, such as tropical cyclones and increase in the frequency of hot days and heat waves (IPCC, 2007a). The main cause of global warming is considered to be greenhouse gas forcing over the last 50 years and it is 'very likely' that human activities, such as burning of fossil fuels, significantly contributed to the rise in temperature over the last 50 years (IPCC, 2001; IPCC, 2007a). In the absence of additional climate policy, the baseline global emissions of greenhouse gases (GHGs)[1)] are projected to increase by values in the range between 9.7 Gigaton of carbon dioxide-equivalent ($GtCO_2$-eq) and 36.7 $GtCO_2$-eq (25% - 90%) between 2000 and 2030 (IPCC, 2000; IPCC, 2007b). Especially, the fossil fuel originated $CO_2$ emissions are projected to grow by any rate between 40% and 110% from 2000 to 2030 (IPCC, 2007b).

1) Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrous oxide ($N_2O$), Sulfur hexafluoride ($SF_6$), Hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs) are the greenhouse gases listed in Kyoto Protocol (United Nations, 1998).

Controlling $CO_2$ emission encompasses the characteristics of a public good.[2)] Benefits derived from abatement by one region are freely available to other countries (non-excludability) and the benefits enjoyed by one region do not diminish the benefits that other countries may obtain (non-rivalry). These features give rise to a free-riding problem, a situation in which regions have few incentives to contribute to the protection of global commons, while they can enjoy benefits derived from abatement efforts by others. It has been widely acknowledged that cooperation on abatement is likely to be difficult to achieve, because of the existence of free-riding. The main obstacle to an implementation of a successful agreement is that the agreement must be ratified on a voluntary basis. There are no international institutions and international laws that implement binding International Climate Agreements (ICAs) for all countries involved. Thus, we have to rely on individual voluntary participation in an ICA. It remains a crucial research topic how such a voluntary agreement could be established and how regional incentives to participate in the agreement would change according to different forms and designs of the agreement. This paper provides an overview of recent analysis on ICAs with game-theoretic approach and of some flexible mechanism suggested to induce participation in ICAs, especially focusing on the cost-benefit analysis using the non-cooperative games to analyze the success of ICAs.

## 2. Game-theoretic approaches

Game-theoretic approaches have been widely used to examine an interaction between countries in the negotiation on climate change, and have emphasised difficulties in designing such a voluntary agreement. This section introduces the basic theoretical framework of the non-cooperative game theory of climate cartel coalition formation, which is often used to analyze the success of ICAs. Following this approach, a two-stage game of coalition formation is considered. In the first stage, regions decide to join a coalition or not (membership decision). Regions announcing not to join a coalition, the non-signatories, remain singleton players, and those announcing to join, the signatories, form a unique coalition. In the second stage, regions adopt their abatement strategies over the planning horizon. The strategies are based on the payoff function which is composed of regional benefits from global abatement and cost of abatement. Non-signatories choose their abatement level by maximizing their own payoffs, taking the other regions' abatement levels as given. On the other hand, signatories choose the abatement levels that maximize the sum of the payoffs of the signatories (joint welfare maximization), taking the abatement levels of non-signatories as given. In this setting, all regions decide simultaneously in both stages.

A coalition is stable if the coalition satisfies both internal and external stability: cf. d'Aspremont et al. (1983). Internal stability of a coalition requires that no signatories have an incentive to withdraw from the coalition as

2) For the theory of public goods, see Cornes and Sandler (1996).

a lower payoff is obtained by changing their strategies to not join the coalition. Similarly, external stability of a coalition means an equilibrium where no non-signatories have an incentive to participate in the coalition as a lower payoff is achieved by changing their strategies to join a coalition. In a definition of external stability, it is implicitly assumed that non-signatories can join the coalition freely whenever they can obtain the higher payoffs by joining the coalition, without the approval of other signatories. This is called an open membership which is in line with the procedures of the Kyoto Protocol.

A number of studies on ICAs have investigated the formation of climate coalitions in a theoretical framework with symmetric or asymmetric countries (e.g., Hoel, 1992; Barrett, 1994, 1997; Carraro and Siniscalco, 1993; Hoel and Schneider, 1997). These studies show that self-enforcing ICAs can be successful only when the difference between the non-cooperative outcome and the full-cooperative outcome is sufficiently small. The studies with asymmetric countries reveal that it is hard to achieve self-enforcing agreements with a large number of signatories because of asymmetries among countries in the context of benefits and costs from abatement (Carraro, 1999). Other studies, such as Fankhauser and Kverndokk (1996), Tol (2001) and Finus et al. (2006) derive similar results from game-theoretic models with stylized integrated assessment model. There are substantially larger global net benefits achieved in the full-cooperative case than in the non-cooperative case, but some countries are worse off because they contribute more to reduce emissions than is in their own interest. This will eventually lead to free-riding. Given the fact that each region's net benefits derived from abatement depend heavily on the arrangements enacted by the ICAs and the design of mechanisms, ICAs should be individually rational (Carraro and Siniscalco, 1993; Finus, 2002) for participants in the agreement, i.e., each member of an ICA is at least as well off as in the non-cooperative case.

## 3. Flexible mechanism to promote participation

This section reviews the role of some flexible mechanisms, namely transfer schemes and issue linkages, which may promote participation in the ICAs.

### 3.1 Transfer scheme

To lower the free-riding incentives, some of the policy regimes apply the concept of transfer schemes between countries in the form of side payments, emission permit trading or surplus sharing (e.g., Carraro and Siniscalco, 1993; Edmonds et al., 1995; Rose et al., 1998; Altamirano-Cabrera and Finus, 2006; Weikard et al., 2006). Transfer schemes are especially suitable to compensate regions that contribute relatively more to abatement in the coalition, but that have relatively low benefits from abatement. Carraro and Siniscalco (1993) conclude in an analytical framework that transfer schemes may successfully increase the number of signatories. In a model with five asymmetric regions, Botteon and Carraro (1997) confirm the results obtained by Carraro and Siniscalco (1993) that ICAs can consist of at most three countries, and conclude that transfer schemes exist that may succeed in stabilizing larger coalitions. Tol (2001) empirically investigates the impact of side payments and suggests that with side payments, the largest stable coalitions do not include either the large emitters or the most vulnerable countries from climate change.

In the literature on coalition formation it has been shown that transfer schemes will be effective when regions have different structures of costs and benefits of abatement, and the design of the transfer schemes will highly affect the incentives to join the agreement. Both cost-effectiveness and equity issues have been treated as focal points when abatement burdens are distributed among regions. Rose et al. (1998) investigate the impacts of rules for allocating emission permits on the abatement costs of achieving the targeted emission level. They categorize transfer schemes into two types: (i) allocation-based rules and (ii) outcome-based rules. In allocation-based rules, emission permits are initially distributed to the coalition members according to certain criteria. In outcome-based rules, on the other hand, net benefits from cooperative abatement efforts are distributed to the coalition members based on certain criteria. For allocation-based rules, such as permit trading, Altamirano-Cabrera and Finus (2006) examine the impact of different allocation schemes on the success of ICAs, focusing on what they call 'pragmatic schemes' and 'equitable schemes'. In the pragmatic schemes, emission permits are allocated based on certain baseline emission levels, either in the form of Business as Usual (BAU) emissions or emissions in the absence of cooperation (Nash equilibrium).[3)] In the equitable schemes, emission permits are allocated by considering equity aspects, such as ability to pay for abatements, historical responsibility for accumulated emissions, and the level of technology. They conclude that pragmatic schemes perform better than equitable ones in terms of the success of self-enforcing agreements. For outcome-based rules, Weikard et al. (2006) explore the impact of surplus sharing rules where net benefits from cooperating are distributed to the coalition members either on an equitable basis or on an emission basis. They find that equitable sharing rules are inferior to emission-based sharing rules in terms of global net benefits of controlling climate change.

The findings of previous studies, have established that the success of ICAs with transfer schemes largely depends on how emission permits or net benefits are allocated among coalition members. To improve the design of transfer further, another type of transfer scheme called 'optimal sharing' has been explored. Optimal sharing, suggested by Carraro et al. (2006), McGinty (2007), Weikard (2009) and Fuentes-Albero and Rubio (2010), offers two main advantages. These are: (i) if the coalition payoff is sufficiently large and distributed in such a way that each member obtains at least its outside-option payoff, no incentives to leave a given coalition remain and (ii) all coalitions that are possibly internally stable under some sharing rule are internally stabilized. By taking a systematic approach to examine the role of transfer schemes, Carraro et al. (2006)

3) Under a Business as Usual (BAU) scenario, no additional climate policy or measure is taken for each region to abate emissions, while in a Nash equilibrium, each region chooses the best abatement strategy domestically, taking abatement in other countries as given.

attests that an 'appropriate' transfer scheme (optimal transfer scheme) can maximize cooperation on abatement. Furthermore, Nagashima et al. (2009) provide a comparison of different transfer schemes and relate these to results for an optimal sharing scheme and also conclude that optimal sharing rule can stabilize larger coalitions.

Another problem concerns the design of transfer schemes that influences incentives to cooperate on abatement. As discussed above, a number of studies have explored various flexible mechanisms to increase the environmental effectiveness and stimulate cooperation on global abatement. Some of the regimes apply transfer schemes to affect burden-sharing for abatement efforts among countries based on criteria such as equity or efficiency. In most of the studies transfer schemes for allocation of abatement burdens are based on a single year. In reality, abatement targets for Annex I countries in the Kyoto protocol are assigned according to the emission level in 1990. As Germain and Steenberghe (2003) pointed out, a grandfathering rule based on the emission level in 1990 does not always satisfy the individual rationality requirement along the time path. The static schemes do not take into account that the future growth paths of emissions are expected to diverge substantially between regions. This leads to assignments where historically large emitters obtain a relatively large share of the permits or surplus, while fast-growing developing countries, such as China or India, obtain relatively small shares, resulting in increasing burdens on these developing countries to reduce their emissions; an issue brought forward by many developing countries in their argumentation on why they do not agree on any reduction targets in the Kyoto protocol. To enhance participation of developing countries, some alternative allocation schemes are necessary to set incentives to join an agreement especially for those regions whose economies are expected to grow faster in the future. This problem can be solved by transfer schemes in which the allocation of emission permits generates benefits for these developing countries.

A general observation from the literature on the transfer scheme in a coalition formation game is that rather inefficient partial coalitions tend to emerge and the coalition with all the members may not be attained. De Zeeuw (2008) widens the scope to a dynamic context and confirms that large stable coalitions can only emerge when the gains from cooperation are small. Thus, even with transfers, full cooperation on emission abatement is hard to establish.

### 3.2 Issue linkage

Another mechanism, known as issue linkage, that has been proposed may reduce incentives to free-ride and expand coalitions in the global warming game. The main idea of issue linkage is that countries negotiate not only on emission reductions (public good), but also negotiate on another economic issue which is often exclusive to signatories (club good). If the benefits from the club good outweigh the incentive to free-ride, the incentives to stay in a coalition will increase. Carraro and Siniscalco (1994), Cesar and De Zeeuw (1996) and Barrett (2003) show that the linkage of the IEAs on climate change control and technological cooperation may stabilize an ICA, as payoffs for signatories will increase due to increased technological spillovers from other signatories. Furthermore, Carraro and Siniscalco (1997) show that linkage of the environmental agreement with an agreement on technological cooperation may overcome free-riding problems due to the fact that the negotiation on both climate change control and technology is more profitable to signatories when benefits from technological cooperation are exclusive to them than the negotiation on climate control only. In their setting, cooperative R&D generates spillovers which influence production costs.

Similarly, Kemfert (2004) combines cooperation on abatement and technological innovation to explore the possibility of inducing participation from non-cooperative countries, such as the USA. This approach suggests that an increase in R&D expenditures will lead to technological innovation through technology spillovers and an increase in energy efficiency through technology spillovers and trade in goods among signatories.

On the other hand, Nagashima and Dellink (2008) introduce the technological spillovers which influence marginal abatement costs. They investigate how technology spillovers can influence the region's incentive structure to join the coalition, in which technological change through the spillovers is directed to lower abatement costs. They show that technology spillovers exclusive to signatories do increase their incentive to stay in the coalition and their efforts to reduce emissions, which leads to increased stability. However, as the gap between full cooperation and no cooperation also increases with the size of coalitional spillovers, the relative success of a coalition, measured in terms of the percentage of the gap between full cooperation and no cooperation that is closed by the coalition, mostly decreases with the level of coalitional spillovers.

As shown in the above empirical literature, the type of spillovers, e.g., whether concerning production costs or concerning abatement costs, tends to bring the different implication.

Linking the negotiation on emission reductions to other economic issues, such as technology cooperation seems to be in line with reality. Under the UNFCCC framework, the Parties have been negotiating on four key issues: emission reductions, adaptation, technology and finance, simultaneously. The outcome of negotiation on one issue may influence the ones on other issues. The issue linkage will describe the real negotiation and the analysis of such a multiple negotiation will provide useful implications to policy makers.

## 4. Limitation of game theory for the analysis of ICAs

Although the game theoretic approaches are useful to examine interactions between regions in the negotiations on climate change, there are limitations of game theory for the analysis of ICAs. This section presents some limitations and extensions Finus (2008) suggested. One of the extensions is to relax the assumption of maximizing the 'material' payoffs which are based on costs and benefits from abatement, and to consider non-material payoffs which reflects the fact that regions' decisions of participation might be based on their reputation or ethical consideration, or which may include the notion of punishment for non-signatories. General observation from the cost-benefit analysis in a coalition formation game is that larger coalition provides larger global payoffs not only to signatories but also non-signatories due to the public good nature of climate change control. For example, Hoel and Schneider (1997) introduce the regional-specific ‘non-environmental costs’ of breaking the agreement for non-signatories. Their theoretical model finds that implementation of the non-environmental costs increases the number of participating countries in the case of no transfer schemes significantly. In an empirical analysis, as such a region-specific non-material payoff is hard to be quantified, this will be challenging for modelers to analyze how non-material payoffs affect the success of ICAs.

Another critique is related to the determination of abatement levels within a coalition. The common assumption used in a coalition formation model is to derive abatement within a coalition from joint welfare maximization among coalition members. One of the problems with this assumption Finus (2008) pointed out is that this does not reflect abatement level in the observed international negotiation; the coalitional abatement is not allocated in a cost-effective way. This critique will be improved if the concept of bargaining theory is applied. For example, potential signatories negotiate on a uniform emission abatement level (quota). Although the uniform allocation is not necessarily ‘fair’ when considering the regions’ circumstances, this is often applied in international environmental agreements, such as Montreal Protocol on substances that deplete the ozone layer.[4)]

Furthermore, the reader should be aware that a central assumption in the game-theoretical analysis applied in the literature is that regions act on the basis of self-interest. An interesting research question is how elements of altruistic behavior would affect the outcomes.

## 5. Concluding Remarks

Global warming is one of the crucial challenges that the world is facing now. The allocation of abatement efforts among regions has long been negotiated and it will not be an easy task to achieve a full cooperation with stringent targets in an ongoing international negotiation under UNFCCC framework. Game-theoretic approaches have been widely used to examine interactions between countries in the negotiations on climate change, and have emphasized difficulties in designing such a voluntary agreement. To curtail the free-riding incentive, some of the policy regimes apply the concept of transfer schemes between regions and the issue linkage, which highly affects the incentives to join the agreement. Although there are some limitations of game theory for the analysis of ICAs, useful policy implication can be derived from these studies and further contribution will be expected to improve the current international negotiation on climate change.

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4) Other examples are shown in Finus (2001).

## Reference

Altamirano-Cabrera, J. C., and M. Finus (2006). “Permit trading and stability of international climate agreements,” *Journal of Applied Economics* 9(1), 19-47.

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

Barrett, S. (1997). “Towards a theory of international cooperation,” In C. Carraro and D. Siniscalco (eds.), *New directions in the economic theory of the environment,* pp.239-280. Cambridge: Cambridge University Press.

Barrett, S. (2003). *Environment and statecraft: The strategy of environmental treaty making*. Oxford: Oxford University Press.

Botteon, M., and C. Carraro (1997). “Burden sharing and coalition stability in environmental negotiations with asymmetric countries,” In C. Carraro (ed.), *International environmental negotiations: strategic policy issues,* pp. 26-55. Cheltenham: Edward Elgar.

Carraro, C. (1999). “The structure of international agreements,”. In C. Carraro (ed.), *International environmental agreements on climate change*, pp. 9-25. Dordrecht: Kluwer Academic Publisher.

Carraro, C., J. Eyckmans, and M. Finus (2006). “Optimal transfers and participation decisions in international environmental agreements,” *The Review of International Organizations* 1(4), 379-396.

Carraro, C., and D. Siniscalco (1993). “Strategies for the international protection of the environment,” *Journal of Public Economics* 52(3), 309-328.

Carraro, C., and D. Siniscalco (1994). “Technical innovation and environmental protection Environmental policy reconsidered: The role of technological innovation,” *European Economic Review* 38(3-4), 545-554.

Carraro, C., and D. Siniscalco (1997). “R&D cooperation and the stability of international environmental agreements,” In C. Carraro (ed.), *International environmental negotiations: Strategic policy issues,* pp. 71-96. Cheltenham: Edward Elgar.

Cesar, H., and A. De Zeeuw (1996). “Issue linkage in global environmental problems,” In A. Xepapadeas (ed.), *Economic policy for the environment and natural resources,* pp. 158-173. Cheltenham: Edward Elgar.

Cornes, R., and T. Sandler (1996). *The theory of externalities, public goods and club goods*. Cambridge: Cambridge University Press.

d’ Aspremont, C., A. Jacquemin, J. J. Gabszewicz, and J. A. Weymark (1983). “On the stability of collusive price leadership,” *The Canadian Journal of Economics* 16(1), 17-25.

De Zeeuw, A. (2008). “Dynamic effects on the stability of international environmental agreements,” *Journal of Environmental Economics and Management* 55(2), 163-174.

Edmonds, J., M. Wise, and D. W. Barns (1995). “Carbon coalitions: The cost and effectiveness of energy agreements to alter trajectories of atmospheric carbon dioxide emissions,” *Energy Policy* 23(4-5), 309-335.

Fankhauser, S., and S. Kverndokk (1996). “The global warming game – Simulations of a $CO_2$ reduction agreement,” *Resource and Energy Economics* 18(1), 83-102.

Finus, M. (2001). *Game theory and international environmental cooperation*. Cheltenham: Edward Elgar.

Finus, M. (2002). “Game theory and international environmental cooperation: Any practical application?” In C. Böhringer, M. Finus, and C. Vogt (eds.), *Controlling global warming: Perspectives from economics, game theory and public choice,* pp. 9-104. Cheltenham: Edward Elgar.

Finus, M. (2008). “Game theoretic research on the design of international environmental agreements: insights, critical remarks, and future challenges," *International Review of Environmental and Resource Economics* 2, 29-67.

Finus, M., E. van Ierland, and R. Dellink (2006). "Stability of climate coalitions in a cartel formation game," *Economics of Governance* 7(3), 271-291.

Fuentes-Albero, C., and S. J. Rubio (2010). "Can international environmental cooperation be bought?" *European Journal of Operational Research* 202(1), 255-264.

Germain, M., and V. van Steenberghe (2003). "Constraining equitable allocations of tradable $CO_2$ emission quotas by acceptability," *Environmental and Resource Economics* 26(3), 469-492.

Hoel, M. (1992). "International environment conventions: The case of uniform reductions of emissions," *Environmental and Resource Economics* 2(2), 141-159.

Hoel, M., and K. Schneider (1997). "Incentives to participate in an international environmental agreement," *Environmental and Resource Economics* 9(2), 153-170.

Intergovernmental Panel on Climate Change (IPCC) (2000). "Emissions Scenarios," [N. Nakicenovic and R. Swart (eds.)]. *Special Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC) (2001). *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson (eds.)]. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC) (2007a). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller (eds.)]. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC) (2007b). *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, and L. A. Meyer (eds.)]. Cambridge: Cambridge University Press.

Kemfert, C. (2004). "Climate coalitions and international trade: Assessment of cooperation incentives by issue linkage," *Energy Policy* 32(4), 455-465.

McGinty, M. (2007). "International environmental agreements among asymmetric nations," *Oxford Economic Papers* 59(1), 45-62.

Nagashima, M., and R. Dellink (2008). "Technology spillovers and stability of international climate coalitions," *International Environmental Agreements: Politics, Law and Economics* 8(4), 343-365.

Nagashima, M., R. Dellink, E. van Ierland, and H.-P. Weikard (2009). "Stability of international climate coalitions – A comparison of transfer schemes," *Ecological Economics* 68(5), 1476-1487.

Rose, A., B. Stevens, J. Edmonds, and M. Wise (1998). "International equity and differentiation in global warming policy: An application to tradeable emission permits," *Environmental and Resource Economics* 12(1), 25-51.

Tol, R. S. J. (2001). "Climate coalitions in an integrated assessment model," *Computational Economics* 18(2), 159-172.

United Nations (1998). "Kyoto Protocol to the United Nations Framework Convention on Climate Change."

Weikard, H.-P. (2009). "Cartel stability under an optimal sharing rule," *The Manchester School* 77(5), 575-593.

Weikard, H.-P., M. Finus, and J.-C. Altamirano-Cabrera (2006). "The impact of surplus sharing on the stability of international climate agreements," *Oxford Economic Papers* 58(2), 209-232.