AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.

The Importance of Pre-commitment in International Environmental Agreements

Prepared for The 45th Annual Conference of the Australian Agricultural and Resource Economics Society

Ian MacDonald
Lincoln University
Canterbury, New Zealand

Abstract

In the face of transboundary pollution externalities, cooperation in regulatory efforts between countries is required to move the economy towards the efficient outcome. Existing research in this field concludes that such cooperation is unlikely to occur because of the free-rider problem. This paper introduces the institution of international treaties and shows that a cooperative outcome supported by a treaty is sustainable. One effective treaty structure requires countries to reduce their pollution levels by a common percentage from the non-cooperative benchmark level, but only if all countries sign it. Under such a treaty arrangement, welfare improvements are generally significant.

Key Words: game theory, international environmental agreements, pre-commitment.

1. Introduction

Many of the environmental problems that countries face today are international in scope. That is to say, pollution from one country can have serious detrimental impacts on other countries. The reciprocal nature of these environmental externalities implies that a country's own measures to reduce pollution may have little impact on the pollution level within its own borders and countries must therefore co-ordinate their behaviour in order to reach efficient outcomes. Cooperation to reduce the global level of pollution has the potential to increase the well-being of all countries concerned. Moreover, the benefits of reduced pollution are, in general, realised across the entire population within each country making it politically viable for governments to openly undertake such collusive behaviour[1]. Of course, cooperation between countries can be fragile because free-riding off others' efforts can increase any individual country's welfare even further. For this reason, much of this cooperative effort is undertaken within the institution of treaties.

An international treaty is a formal agreement between nations which is governed by certain rules and regulations. Treaties outline the obligations that each signee must live up to. Treaties also put forth conditions that must be met before any individual party is bound by the agreement. A treaty usually enters into force only after a specific number of countries have made a pre-commitment to their actions by signing and ratifying it. Before the required number have made this pre-commitment, the actions of no country are constrained. In addition to a number requirement, treaties often do not become binding unless the countries who have signed are responsible for a certain proportion of the total activity that is to be controlled[2]. Enforcement of the treaty may be explicit in the sense that clear penalties for deviant behaviour are included and rules for arbitrating disputes are set out in the agreement. Enforcement may also be indirect in that countries who do not fulfil their treaty requirements can be subjected to indirect costs of non-compliance. For example, many treaties have a mechanism through which interested parties and non-governmental organisations can monitor and report on a country's compliance status. In turn, non-compliant countries and governments can be subjected to political pressure and international shunning[3]. Non-compliance may also result in specific financial penalties in the form of a country's exclusion from access to funding or entry into markets. Whatever the specific design, all treaties have in common the fact that countries must pre-commit to their actions before any constraints on their actions are binding.

Existing literature in the field of environmental negotiations (for example Barrett (1994, 1997), Carraro and Siniscalco (1993), Chander and Tulkens (1992), Heal (1994), and Sandler and Sargent (1995)) focuses on the incentives countries face to form coalitions and the stability of these coalitions. Welfare of individual countries is assumed to be a function of a pollutant which imposes an externality on all other countries and negotiations between

---

[1] This is in contrast to the way benefits from cooperation accrue in oligopolistic collusion for example. Here, a small number of producers prosper at the expense of the broader population of consumers. As a result, government effort is usually directed at stopping such behaviour rather than fostering it.
[2] For example, the Montreal Protocol came into power only after it was ratified by 11 countries controlling at least two thirds of the global consumption of clorofluorocarbons.

countries over emission control is modelled using game theoretic tools. Once formed, coalitions act to maximise the joint welfare of the group. The benefit from cooperating for an individual country from cooperation is calculated as the difference in welfare it receives inside and outside the coalition. Stability of the coalition requires that no country within the coalition has an incentive to defect and no country outside the agreement has an incentive to join. The standard conclusion of these papers is that self-enforcing international environmental agreements have little potential for welfare improvement unless side-payments or issue linking is introduced.

The research on self-enforcing international agreements has produced many insights into the problem of global pollution control. Nevertheless, the application of the self-enforcement concept to environmental problems is flawed because it has grown out of the oligopoly literature (in particular D'Aspremont and Gabszewicz (1986)) where cooperation between firms is not carried out under the institution of treaties. Given that treaties allow countries to costlessly pre-commit to cooperation, they have the potential to significantly enhance the size and effectiveness of the environmental coalition. The main contribution of this paper is to re-examine the issue of international environmental agreements in one such treaty context.

In this paper I construct a model which incorporates a treaty institution that captures many of the components of the 'real' treaty process. As has already be discussed, one key component of the treaty process is the fact that if a country signs the treaty, it is not obligated to alter its polluting activities unless a specific number of other countries sign as well. In other words, the treaty allows countries to costlessly pre-commit to their cooperative actions. In the absence of the treaty institution, countries are playing what amounts to a prisoners' dilemma game in which the dominant strategy Nash equilibrium is not to cooperate. The treaty transforms the choice of a representative country into one of choosing between either the cooperative treaty outcome, by signing the treaty and allowing for its potential entry into force, or the non-cooperative outcome, by not signing the treaty and ensuring its non-ratification. Unlike in the prisoners' dilemma game, however, the choice to sign the treaty only commits a country to cooperation if others likewise commit. Therefore, the treaty effectively eliminates any incentive or possibility to free-ride. As long as a country is better

---

[3] EB Weiss labels an enforcement mechanism which relies on the 'reputation' factor a "sunshine strategy".

off in the treaty agreement than out, signing is a weakly dominant strategy. If an agreement that leaves all parties better off in than out can be designed, the Nash equilibrium will be for all parties to sign the agreement and, as a result, act cooperatively.

The effectiveness of treaties is illustrated by employing a model in which countries receive benefits from polluting activities and incur costs associated with the global level of pollution. The objective of a country acting alone is to maximise its own net benefits. When cooperating with others, a country can increase its own welfare by acting in a way that maximises the welfare of the group. In this paper I use numerical simulations to show that treaties are potentially an effective way in ensuring that countries will, in fact, act in a way which is for the collective good.

In a world where countries are asymmetric, the gains from cooperation may not accrue equally to all countries. In such a situation, an agreement which requires all countries to play an equal role in pollution reduction may not be desirable for all countries. In fact, it is quite possible that such an agreement would make some countries worse off than if there was no cooperation at all. That is not to say, however, that an agreement between asymmetric countries is not possible. There will be potential gains from cooperation, but the treaty that supports this cooperation, and the obligations of each country within the treaty, may be somewhat more complicated than that outlined above. In this paper I propose a treaty, that I call the constrained cost-benefit optimal (CCBO) treaty, which requires each country within the group included in the treaty to reduce pollution by a common percentage from the non-cooperative benchmark equilibrium. The percentage decrease in pollution will be constrained such that it is always desirable for those countries include in the treaty to sign.

In some situations, the treaty group will be made up of all countries in the economy. However, with some types of asymmetries between countries, it will be in the best interest of all to omit some countries from the treaty process and allow them to free-ride. When countries are symmetric, the treaty outcome will directly correspond to the first-best planner's or the unconstrained cost-benefit optimal (UCBO) outcome. With asymmetries, the CCBO treaty outcome will fall short of the first-best outcome, because the treaty agreement will not include all countries and/or because the mix of pollution will not ensure that the marginal benefit of pollution is equated across all countries.

Within the framework, it is possible to address two important issues. First, when is it best to exclude a set of countries from the treaty agreement and which countries are should be excluded? Second, how close to the first-best level of global welfare can the treaty agreement move the economy? Although the answers to these questions depends on the magnitude of the asymmetries, in general the answer to the first question is that it is best to omit countries with extremely low costs of pollution or extremely high benefits of pollution or both. The answer to the second question is that treaty outcomes can come very close to the first-best outcome and certainly much closer than self-enforcing agreements of the type traditionally examined in the field.

The paper is organised as follows. In the next section the general framework of the treaty institution is outlined in more detail and the structure of the game is defined. In section 3 a generic model along with one particular functional form are presented. In section 4, numerical results for a limited range of parameter values are discussed. The focus in this section will be on the impact of asymmetries across countries. The paper finishes with conclusions and suggested areas of further research.

2. The Treaty Framework

2.1 The Institution of Treaties

There are a number of multilateral agreements in force today designed to control transboundary pollutants[4]. Although each treaty is to some extent unique, there are a number of characteristics which are common to many. For example, treaties usually enter into force only after an explicit number of countries have ratified it. Treaties also often require countries to reduce the amount of pollution they emit by some common percentage from a benchmark level. Most importantly, however, no country, whether they have signed or not, is bound by the treaty until it enters into force.

The design of the treaty institution is extremely important in ensuring its effectiveness. Specifically, the ability of a treaty to overcome the free-rider problem is directly related to its structure. This can be illustrated most clearly in a simple game-theoretic framework. The treaty proposed in this paper is binding only if all countries have signed it. If binding, the treaty requires all countries to cooperate in the control of pollution. With the inclusion of this treaty process, a representative country is faced with what amounts to an all or nothing choice. By signing the treaty, a country allows for the possibility of moving to the cooperative outcome if all other countries sign as well. By not signing the treaty, a country ensures that the non-cooperative outcome is attained. Given the specific nature of the treaty process outlined above, countries are able to costlessly commit to their actions before they are undertaken. Additionally, there is no possibility for countries to free-ride off the actions of others because by not cooperating, a country ensures that the treaty fails to enter into force.

It is useful to look more closely at the strategies and payoffs of the countries in a symmetric two-player simultaneous move game[5]. In the absence of the treaty process, the countries are playing what amounts to a prisoner's dilemma game. The fully cooperative outcome is strictly preferred to the non-cooperative outcome, but it is not a Nash equilibrium because the payoff for each country is even greater when it free-rides off the cooperative efforts of the other country. Figure 1 shows the prisoner's dilemma game with arbitrary payoff values. If Country *B* is cooperating, Country *A*'s best response is to not cooperate. If Country *B* is not cooperating, again *A*'s best response is to not cooperate. The same holds for Country *B* in response to Country *A*'s actions. Therefore, *{Don't Cooperate, Don't Cooperate}* is the strictly dominant strategy equilibrium and the unique Nash equilibrium of the game. This equilibrium is clearly sub-optimal to the first-best outcome.

Figure 1 – Prisoner's dilemma game with arbitrary payoff values

		Country B	
		Cooperate	Don't Cooperate
Country A	Cooperate	(100,100)	(70,120)
	Don't Cooperate	(120,70)	(80,80)

payoffs:(country A, country B)

[4] The Montreal Protocol for chlorofluorocarbons is but one example.
[5] A two player sequential move game with similar payoffs results in the same equilibrium.

With the addition of a treaty process, the countries must decide whether they wish to sign the treaty or not. If both countries sign the treaty, it becomes binding and the strategy *'Don't Cooperate'* is eliminated from the strategy set. If at least one country decides not to sign, the treaty is not binding and we revert to the prisoner's dilemma game outlined in Figure 1 above. It has already been established that the only possible outcome of the prisoner's dilemma game is one in which there is no cooperation. If the treaty is signed by both, the outcome will be full cooperation. The payoff matrix facing the two countries in the treaty game is shown in Figure 2. The strategy *'Don't Sign'* is strictly dominated by the strategy *'Sign'* in this case. Therefore, both countries will always choose to sign the treaty.

Figure 2 – Treaty game with arbitrary payoff values

		Country B	
		Sign	Don't sign
Country A	Sign	(100,100)	(80,80)
	Don't sign	(80,80)	(80,80)

payoffs:(country A, country B)

Extending the analysis to a game between *N* countries is straight forward. Facing any set of decisions made by the other *N-1* countries, the *N*th country faces the same type of decision as either of the two countries in Figure 2. If the decision is to sign the treaty, it has the potential to enter into force. If the decision is to not sign the treaty, it certainly does not enter into force. In the case when all countries are identical, the weakly dominant strategy for all of them is *'Sign'*[6]. Therefore, the weakly dominant Nash equilibrium of the game is one in which all countries sign the treaty. In effect, the introduction of the treaty institution allows a country to play the strategy *'cooperate if all other countries cooperate, do not cooperate otherwise'*. A country is certainly never made worse off if it signs and lives up to its obligations of the treaty.

[6] In this case, if the players move sequentially, *'Sign'* is a dominant strategy in all sub-games and all countries signing is the dominant strategy equilibrium of the game.

Figure 3 – Payoffs facing a representative country in the *N*-country treaty game

Number of other countries

	0	1	…	*N*-2	*N*-1
Sign	80	80	…	80	100
Don't Sign	80	80	…	80	80

It is important that all countries are obligated to sign the treaty before it enters into force. If this requirement was relaxed, to say *N-1* countries, *'Sign'* would no longer be a weakly dominant strategy. In particular, when faced with *N-2* other countries signing, the marginal country's best response is to sign the treaty and cause it to become binding. However, if *N-1* other countries had signed the treaty, the marginal country's best response is to not sign the treaty so that it could free ride off the actions of those bound by the agreement. In this situation, there is no longer a unique dominant strategy equilibrium and a coordination problem is introduced[7].

Figure 4 – Payoffs facing a country in the *N*-country treaty game when it enters into force after *N-1* countries sign

Number of other countries

	0	1	…	*N*-2	*N*-1
Sign	80	80	…	100	100
Don't Sign	80	80	…	80	120

2.1 The Implications of Asymmetries Across Countries

When all countries receive the same benefits from polluting activities and incur the same costs from global pollution levels, a treaty that improves the welfare of one country improves the welfare of all countries. In other words, if it is in the best interest of any individual country to sign the treaty, it is in the best interest of all countries to sign it. When countries vary in their net benefit functions, this is no longer necessarily be the case and the problem of designing a treaty that is attractive to all parties becomes important.

[7] In this situation, countries would be best to play mixed strategies. For example, a treaty that becomes binding after only 50% of the countries sign it would, on average, become binding if countries played the optimal strategy of signing the treaty 50% of the time. Of course, the actual outcome that would result if this game was played is indeterminate.

In the analysis above, the treaty moves countries to the fully cooperative outcome. This outcome is one in which the joint welfare across all countries is maximised and in that process, the allowable emission level in each country under the treaty is determined. Introducing asymmetries across countries does not prohibit one to solve the same joint welfare maximising problem. However, it might be the case that a sub-set of the countries will be worse off being bound by the treaty than in a world with no treaty agreement at all. In such cases, it would be individually irrational for these countries to sign the treaty and therefore, given the structure of the treaty, the agreement would never enter into force.

One way to overcome this problem is to constrain the choice of pollution in such a way as to ensure that all countries are individually better off in the treaty outcome than in the non-cooperative outcome. While there are many conceivable structures for such a treaty, perhaps the simplest way to do this is to require all countries to decrease pollution by some percentage from some historical non-cooperative benchmark level[8]. Rather than solving an unconstrained joint maximisation problem, countries would be maximising joint welfare subject to two constraints. First, the relative quantity of pollution in each country will be predetermined by the non-cooperative equilibrium levels of pollution. Second, the size of the percentage decrease is limited by the requirement that the treaty must be attractive to all countries.

The introduction of asymmetries also introduces another concern in the design of treaties. When all countries are identical, global welfare within the treaty agreement can only be maximised when all countries cooperate. With the presence of asymmetries it is possible, however, that global welfare can be increased by omitting one or more countries from the treaty process altogether. Cross-country differences in both costs and benefits of pollution might drive this result. By way of introduction imagine a situation in which a country benefits from being able to pollute, but incurs no costs associated with global pollution levels. A treaty that required this country to reduce its emissions by any amount would necessarily leave the country worse off than in the non-cooperative outcome. In this case, the only treaty that could enter into force would be one in which only a zero percent reduction in pollution is

[8] A somewhat similar solution would be to require countries to reduce pollution by some percentage from the historical non-cooperative level, but to allow this percentage to vary across countries (or groups of countries).

required. However, if this country is omitted from the treaty process, an agreement between the remaining countries that increases global welfare might be possible.

3. The Model

3.1 The Analytical Framework

Let the welfare of each of $i = 1, \ldots, N$ countries be determined as the difference between the benefit and cost of pollution. It is natural to suppose, for country *i*, a benefit function which depends on the level of emissions within the country:

$$B_i(q_i).$$

It is also assumed that the benefit function is increasing in its argument, over some relevant range of emissions[9], and strictly concave:

$$\frac{\partial B_i(q_i)}{\partial q_i} > 0, \ \frac{\partial^2 B_i(q_i)}{\partial q_i^2} < 0.$$

The cost of pollution is a function of total global emissions:

$$C_i(q_i, q_{-i}).$$

The cost function is assumed to be increasing in the quantity of pollution at either a constant or increasing rate:

$$\frac{\partial C_i(q_i, q_{-i})}{\partial q_i} > 0, \ \frac{\partial^2 C_i(q_i, q_{-i})}{\partial q_i^2} \geq 0.$$

In the absence of cooperation, countries will choose their own level of pollution emissions so as to maximise their net benefits:

$$\max_{\{q_i\}} \quad NC_i = B_i(q_i) - C_i(q_i, q_{-i}).$$

The familiar Nash equilibrium solution to this problem involves each country simultaneously choosing a level of emission, q_i^{NC}, which equates their private marginal benefit and marginal

[9] It is possible that the benefit function first increases and then decreases as the level of pollution emissions is increased. This would certainly be the case if benefits from pollution are generated as a by-product of the production and sale of some other good. However, a country would never find it in its best interest to emit at a level where marginal benefits of pollution are negative, and thus the relevant range of emissions is that for which the marginal benefit is positive.

cost of pollution. If the marginal cost of pollution for country *i* is independent of the quantity of pollution emitted in other countries then

$$\frac{\partial^2 C_i(q_i, q_{-i})}{\partial q_i \partial q_j} = 0$$

and the reaction functions are orthogonal. In this situation, the choice of pollution level in country *i* will in no way be influenced by other countries' emission levels. If instead, the marginal cost of pollution for country *i* is increasing in the emission levels in other countries then

$$\frac{\partial^2 C_i(q_i, q_{-i})}{\partial q_i \partial q_j} \rangle 0$$

and pollution levels across countries are strategic substitutes. Given the assumption of diminishing marginal benefit, this implies that country *i*'s non-cooperative level of pollution increases as other countries decrease their emissions.

The fully cooperative, or planner's, solution involves choosing a level of pollution in each country so as to maximise joint net benefits subject to the constraint that each country must emit a non-negative level of pollution

$$\max_{\{q\}} \quad P = \sum_{i=1}^{N} \left[B_i(q_i) - C_i(q_i, q_{-i}) \right]$$

$$st \quad q_i \geq 0 \vee i.$$

The solution to this problem involves equating the marginal benefit of pollution in each country with the global marginal cost of pollution. As a consequence, the level of global pollution is be allocated in such a way as to equate the marginal benefit of pollution across all countries. Given the reciprocal nature of the pollutant and diminishing marginal benefit, the global marginal cost of a country's emissions is higher than the private marginal cost and therefore the quantity emitted in each country is lower in the planner's solution than in the non-cooperative solution.

If countries are homogenous, each would be better off in the fully cooperative outcome than in the non-cooperative Nash equilibrium. Under such circumstances, a treaty that required all countries to pollute at a level set out by the planner's outcome would be supportable. In the face of asymmetries between countries, however, this result does not necessarily hold and an alternative treaty agreement may be required[10]. The treaty structure that is proposed in this paper is one that requires all countries to reduce their emissions by a common percentage from their non-cooperative benchmark levels[11]. The percentage reduction that is supportable under such a treaty arrangement can be found by solving the constrained maximisation problem:

$$\max_{\{x\}} \quad T = \sum_{i=1}^{N}\left[B_i\left(q_i^{NC}(1-x)\right) - C_i\left(q_i^{NC}(1-x), q_{-i}^{NC}(1-x)\right)\right]$$

$$st \quad \begin{array}{l} B_i\left(q_i^{NC}(1-x)\right) - C_i\left(q_i^{NC}(1-x), q_{-i}^{NC}(1-x)\right) \geq \\ B_i\left(q_i^{NC}\right) - C_i\left(q_i^{NC}, q_{-i}^{NC}\right) \end{array} \quad \vee i .$$

3.2 A Specific Functional Form

The benefit function used in the numerical simulations that follow takes the form:

$$B_i(q_i) = b_i\left[q_i - \frac{q_i^2}{2}\right]$$

where q_i is the quantity of pollution emitted by country *i* and b_i is a positive, country specific parameter that determines the slope of each country's marginal benefit function. Marginal benefit for country *i* is thus:

$$MB_i = b_i[1 - q_i]$$

which takes on positive values for all emission levels below one unit. It is assumed that the pollution cost function increases linearly in global pollution:

$$C_i(q_i, q_{-i}) = c_i\left(q_i + \sum_{-i} q\right).$$

Marginal cost for country *i* is constant and equal to the country specific parameter c_i.

In the fully cooperative outcome, each country emits at a level that equates private marginal benefit to global marginal cost:

[10] In the planner's solution, the marginal benefits of pollution are equated across all countries. If, for example, a country's benefit parameter is relatively small, in order to achieve equal marginal benefits, the country will be allowed to emit a relatively small amount of pollution compared to other countries. For a constant level of total pollution, a country is better off the greater its share of emissions. Therefore, it is conceivable that as the emission mix moves to a country's disadvantage, it can become worse off in the planner's outcome than in the non-cooperative outcome.

[11] Note that in the absence of asymmetries, the planner's outcome and the treaty outcome will be equivalent.

$$q_i^P = 1 - \frac{\sum_{j=1}^{N} c_j}{b_i}.$$

In so doing, each country pollutes at a level that equates marginal benefit to the sum of the cost parameters across all countries. In the non-cooperate outcome, each country will choose to emit at a level that equates private marginal benefit and private marginal cost:

$$q_i^{NC} = 1 - \frac{c_i}{b_i}.$$

4. Results

In this section, I present a number of numerical results for various parameter values. There are three import issues to be investigated. First, I examine whether the UCBO treaty can be supported in the face of asymmetries in the benefit and cost functions across countries will be answered. Second, I examine how close to the UCBO treaty outcome can a CCBO treaty get. In particular, I am interested in how close in terms of global welfare measures the two treaty outcomes are when the UCBO treaty outcome is not supportable. Third, I examine if and when it is in the best interest of all countries, individually and jointly, to exclude one or more countries from the treaty process altogether. If excluded, a country is able to choose its level of pollution so as to maximize its own welfare. As such, the excluded country is able to free-ride off the collective actions of the others.

Throughout the numerical simulations I will restrict the number of countries to three. This is a sufficient number of countries for a detailed analysis of the issues introduced above, but small enough to avoid needless complication. For the same reasons, I will limit the asymmetry to only one of the countries. Finally, I will separate the analysis into two parts; one where countries differ only in the benefits they receive from producing pollution, and one where the countries differ only in the costs they incur from pollution. This allows for a more transparent analysis of the impacts of the two types of asymmetries.

4.1 Asymmetry in the Benefit Function

Here I present the numerical results when one country's benefit parameter, b_i, is different from that of the other countries. The countries are identical in every other respect. I assume that there are only three countries, such that country 3 differs from identical countries 1 and 2. I present the results for two different simulations; one for which the benefit parameters are relatively small compared to the cost parameters, and one for which the benefit parameters are relatively large compared to the cost parameters. The first simulation has parameter values of $b_1=b_2=200$, $c_1=c_2=c_3=25$ and the second has values of $b_1=b_2=1000$, $c_1=c_2=c_3=25$, the parameter b_3 ranges in each. These numbers are presented only to illustrate the different situations that may arise when asymmetries in the benefit functions are present. The actual numbers are meaningless beyond this role.

Figure 5: Global welfare measures as a percentage of the UCBO levels under different treaty arrangements: $b_1=b_2=200$, $c=25$.

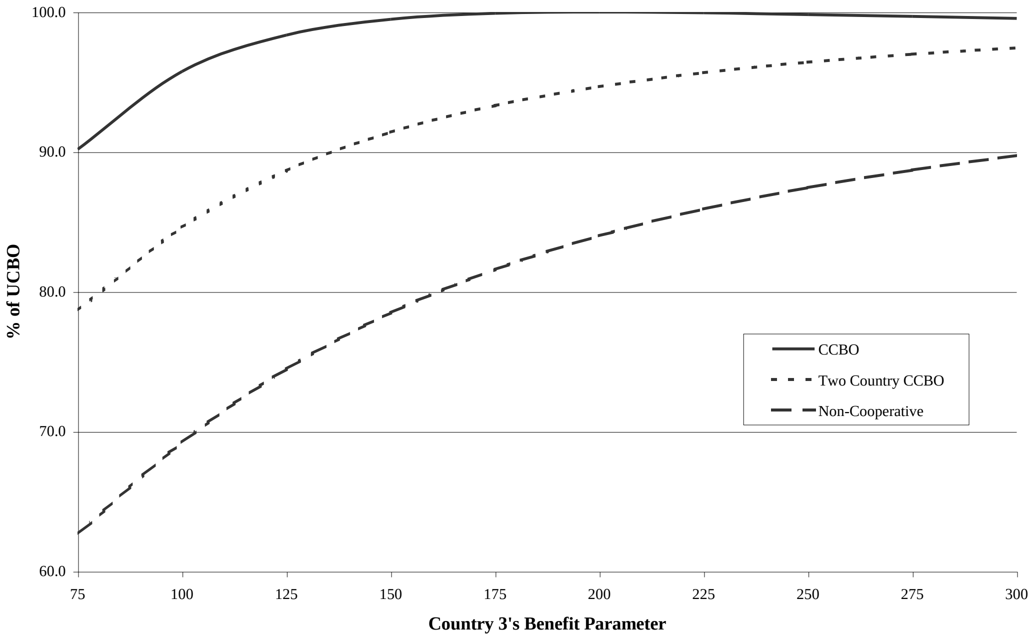
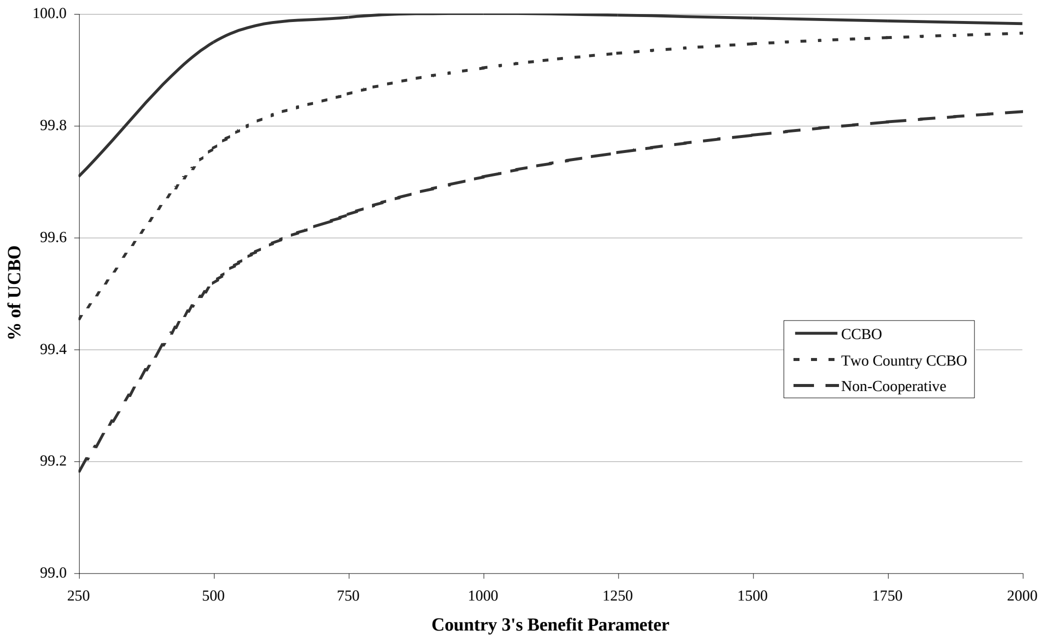


Figure 5 presents a plot of the total global welfare measure under the non-cooperate, CCBO treaty, and two country CCBO treaty outcomes, for b_3 ranging from 75 to 300. Total global welfare is measured as a percentage of the welfare that is obtained in the UCBO outcome. For this simulation, the percentage decrease in pollution is not limited by the welfare requirement of any one country in the CCBO treaty. Instead, the decrease in pollution and the increase in total welfare is constrained only by the initial levels of emissions in each country and the requirement that all countries reduce pollution by the same percentage. In other words, the total welfare attained in the CCBO treaty falls short of that attained in the UCBO treaty only because the equilibrium levels of pollution are not in the correct ratio to ensure that the marginal benefit of pollution is equated across all countries. Even in the face of this problem, the CCBO treaty performs well and is able to increase global welfare significantly over the non-cooperative outcome. The two-country treaty, in which country 3 is acting as a free-rider, is also able to achieve a total welfare level far in excess of the non-cooperative outcome. As country 3's benefit parameter is allowed to increase substantially, the CCBO treaty's effectiveness becomes limited by the unwillingness of country 3 to reduce its emissions. When this occurs, the total welfare generated in the two country CCBO treaty will exceed that of the treaty consisting of all countries.

Figure 6 shows a similar pattern of results for the case of the larger benefit parameters. The key difference here is that because the benefits of pollution far outweigh the costs of pollution, the fully cooperative outcome results in little pollution reduction and little increase in total welfare. In fact, the non-cooperative outcome has a total welfare measure that is more than 99% of that generated by the fully cooperative outcome and the treaty outcomes improve on this by less than 0.4%.

Figure 6: Global welfare measures as a percentage of the UCBO levels under different treaty arrangements: $b_1=b_2=1000$, $c=25$.

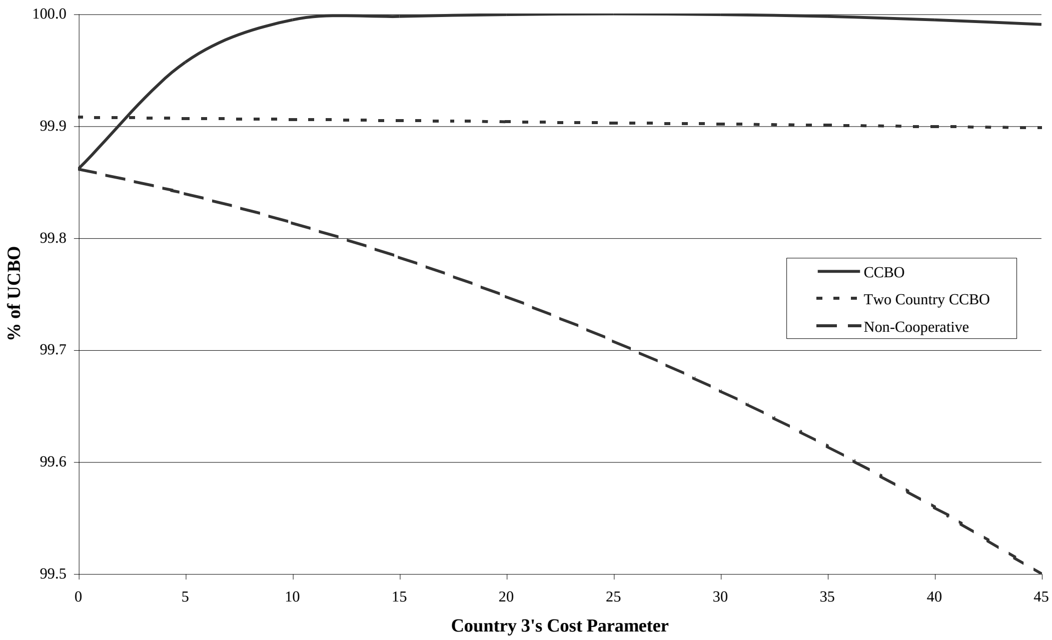


4.2 Asymmetry in the Cost Function

The asymmetry now enters through the cost function. Let country 3 differ from countries 1 and 2 in its parameter c_3. The first simulation has parameter values of $b_1=b_2=b_3=1000$, $c_1=c_2=25$ and the second has values of $b_1=b_2=b_3=1000$, $c_1=c_2=200$.

Figure 7 shows results that correspond closely to those found in Figure 6. Because the cost of pollution is relatively small compared to the benefit of pollution, the externality problem is not as significant and the gains from cooperation are minor. Note, however, that the externality grows in importance rather rapidly as the sum of the cost parameters increases. In addition, the measure of the total welfare in the non-cooperative equilibrium decreases quickly with the fall of welfare in country 3. In the cooperative outcome, all countries are required take into account the external effect their pollution is having on country 3.

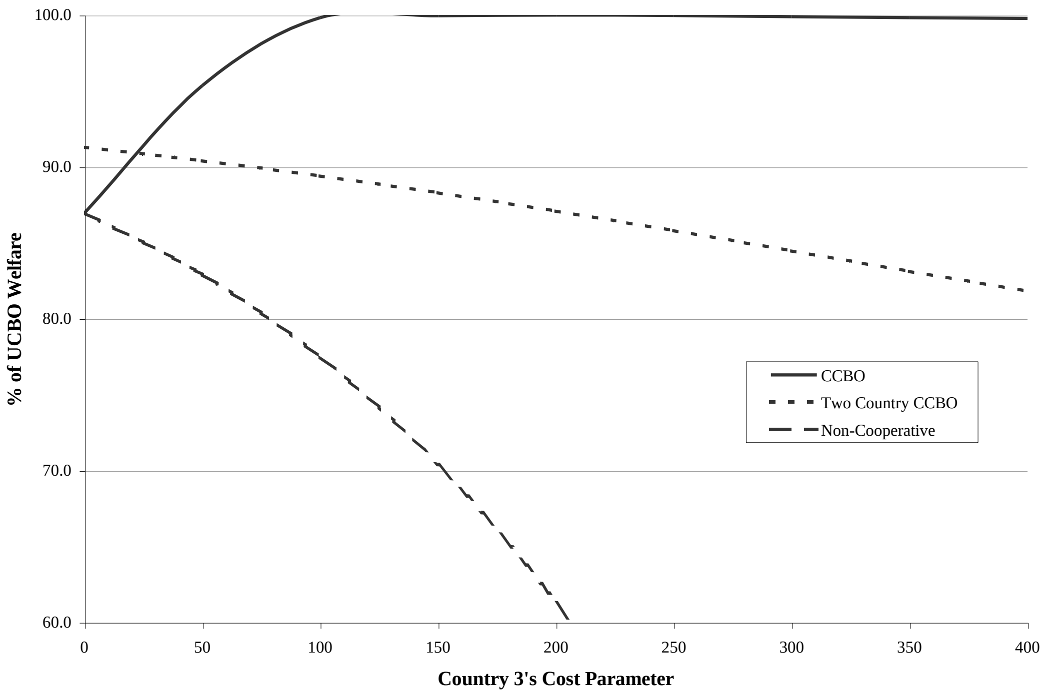
Figure 7 : Global welfare measures as a percentage of the UCBO levels under different treaty arrangements: $b=1000$, $c_1=c_2=25$.



For very small values of c_3 it is found that the ability of the CCBO treaty to increase total welfare is limited because of the requirement that country 3 is better off in the treaty outcome than in the non-cooperative outcome. Specifically, country 3 has little incentive to reduce pollution on their own, and gains little from the reduction of pollution in other countries. Therefore the effectiveness of the treaty is limited. In such cases, a treaty which excludes country 3 and its substantial constraint on the maximum percentage reduction in pollution leads to higher total welfare measures[12]. When the percentage reduction constraint is not binding, the CCBO treaty is able to attain total welfare levels that are extremely close to the unconstrained levels and far in excess of the non-cooperative numbers.

Figure 8 shows that with the exception of the magnitude of the gains, the pattern of results does not change appreciably when looking at relatively large cost parameters compared to benefit parameters. Of significance, it remains the case that it is still optimal to eliminate a country from the treaty process if it incurs low costs of pollution.

Figure 8**:** Global welfare measures as a percentage of the UCBO levels under different treaty arrangements: *b = 1000*, $c_1=c_2=200$.



[12] Recall that the functional form chosen in this study yields reaction functions that are orthogonal between countries. Therefore, even though country 3 is allowed to free-ride off the collective actions of the other two countries, it will not react by increasing its level of emissions. If it was assumed that countries do react to lower emissions elsewhere by increasing their own levels, it would still be the case that the two-country treaty would be more effective over some range of parameter values. However, this range would be smaller.

5. Conclusions

This paper has addressed the importance of the institution of treaties in the control of transboundary pollutants. Because treaties are able to effectively legislate cooperation between countries, they are able to move the global economy towards the first-best outcome. The model presented in this paper takes into account the presence of asymmetries across countries, and is able to identify a number of characteristics that are important in treaty design. The results of this research are significantly different than those offered by existing works in the field.

The treaty process modelled in this paper is one in which commitment to cooperation is only binding if all other countries included in the negotiations likewise commit. In a symmetric model, all countries are better off in the fully cooperative or UCBO outcome than in the non-cooperative outcome and a treaty is always able to move the economy to the first-best outcome. When countries are asymmetric this is no longer the case. A CCBO treaty, in which each country within the treaty must reduce their emissions by a common percentage from their non-cooperative levels, can lead to significant increases in global welfare over the non-cooperative equilibrium. In the absence of asymmetries, the CCBO treaty achieves the first-best level of global welfare, but as the magnitude of the asymmetry increases, the gap between the constrained and unconstrained outcomes grows. In general, cooperation of any kind is most useful when countries incur high costs and/or receive low benefits of pollution. If only a subset of the countries in the economy have this characteristic, however, it might be welfare improving for all to eliminate them from the treaty process altogether.

The analysis offered in this paper is by no means complete and further work must be done in order to help policy makers in the design and implementation of new agreements. In particular, I believe that research into how the addition of tradable permits and other market incentive mechanisms to the treaty process would impact on the potential for improving welfare and the size of the cooperating group could prove insightful. I also feel that a clearer understanding of the domestic issues of treaty ratification would be helpful. Some thought should be put into the question of how technological change and the sharing of information about new technologies, specifically those that reduce the costs of achieving treaty obligations, affects the treaty process. Of course the use of treaties is not limited to environmental problems, and this analysis could easily be applied to other issues such as international trade agreements.

6. References

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

Barrett, S. “Towards a theory of international cooperation”, in C. Carraro and D. Siniscalco (eds), *New Directions in the Economic Theory of the Environment*, Cambridge University Press, 1997.

Brown Weiss, E. “Strengthening national compliance with international environmental agreements”. *Environmental Policy and Law*, 27, 1997, 297-303.

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

Chander, P. and H. Tulkens. “Theoretical foundations of negotiations and cost sharing in transfrontier pollution problems”. *European Economic Review*, 36, 1992, 388-398.

D’Aspremont, C. and J. Gabszewicz. “On the stability of collusion”, in G. Matthewson and J. Stiglitz (eds), *New Developments in the Analysis of Market Structure*, Macmillan, 1986.

Heal, G. “The formation of environmental coalitions”, in C. Carraro (ed), *Trade, Innovation, Environment*, Kluwer Academic Publisher, 1994.

Sandler, T. and K. Sargent. “Management of transnational commons: coordination, publicness, and treaty formation”. *Land Economics*, 71, 1995, 145-162.