INTERNATIONAL TREATIES ON GLOBAL POLLUTION: A DYNAMIC TIME-PATH ANALYSIS

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March 1998

Abstract

In this paper we show that the formation of coalitions by subsets of countries might diminish the likelihood of a successful world- wide treaty on global pollution. Non-member countries may be less willing to sign a world-wide treaty than they would be in the absence of such coalitions. In fact, the coalition formation may raise the reservation utility of non-member countries above the world-wide treaty level and thus take away their incentives to sign it.

1. INTRODUCTION

In recent years there has been a trend towards the formation of preferential trading areas (PTAs) such as the European Union (EU) and the North American Free Trade Agreement (NAFTA). An important implication of the formation of such coalitions is that they create externalities on non-members. For example, the abolition of tariffs on trade among member countries and the readjustment of external tariffs may worsen non-member countries' terms of trade with member countries.[1]

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[1]See Srinivasan (1996) for a comparative analysis of the alternative approaches to determining the impact on non-member countries' welfare.

Two opposing views have persisted regarding the formation of PTAs. On the one hand, it is claimed that the ever-expanding PTAs may lead progressively to the state of non-discriminatory free trade for all and therefore as policy-makers we must encourage their formation. This has been, however, debated and it has been argued that free trade for all may not come about as the PTAs, once formed, may lead to a stagnant state in which the world remains divided into various trading blocks. This argument has given the theory of PTAs what Bhagwati (1993) has called, a dynamic time-path dimension.

In this paper we analyze a conceptually similar dynamic time-path dimension in an international economic-ecological setting. In particular, we examine the question whether expanding coalitions can lead progressively to the formation of the grand coalition and therefore to a world wide treaty on global pollution (typically climate change).[2]

In a recent paper, Chander and Tulkens (1997) examine the likelihood of a world-wide treaty on global pollution. They present the contents of a feasible treaty which not only satisfies optimality but also group rationality, which they call the γ-core property. The negotiations for the conclusion of such a treaty, as in the case of international trade, might proceed via the emergence of coalitions of subsets of countries with common views and aims coming together who may on their own reduce their pollution levels. Such coalitions might be easier to form, more efficient, and more certain and might seem to be a quick, even if a half-way, solution to the global pollution problem. It has been also argued that the formation of such coalitions can act as a catalyst and lead eventually to the conclusion of a world-wide treaty. See, for example, Heal (1993).

[2] This is a different kind of dynamics than the one considered in Chander and Tulkens (1992) and Chander (1993). There the time-path is defined in the space of feasible allocations – here it is in the space of coalitions.

In this paper, we show that the formation of coalitions by subsets of countries might diminish the likelihood of a successful world-wide treaty. Non-member countries may be less willing to sign a world-wide treaty than they would be in the absence of such coalitions. In fact, the coalition formation may raise the reservation utility of non-members above the world-wide treaty level and thus take away their incentives to sign it.

The paper proceeds as follows: in Section 2 we state the economic-ecological model. In Section 3 we consider the idea of coalition formation and show that though formation of a coalition may be Pareto-improving, it might lead to a situation from which the non-members have no incentives to sign the world-wide treaty. We also relate our results with the literature on stable coalitions.

2. THE ECONOMIC-ECOLOGICAL MODEL

We adopt the model most commonly used for the economic analysis of global pollution problems. A set $N = \{1, 2, \ldots, n\}$ of countries share a common environmental resource. Each country i's preferences over the consumption of some private good ($x_i \geq 0$) and of some environmental good ($z \leq 0$) are described by the utility function $u_i(x_i, z)$. Define $\pi_i = (\partial u_i/\partial z)/(\partial u_i/\partial x_i) \geq 0$ as country i's willingness to pay (in terms of commodity x) for the environmental good z. We assume the utility function u_i to be of the quasi-linear form, *i.e.*, $u_i(x_i, z) = x_i + v_i(z)$ with v_i concave and increasing. Furthermore, let $y_i = g_i(p_i)$ denote country i's production function, linking its output $y_i \geq 0$ of the private good with its emissions $p_i \geq 0$ of pollutant in the environment. We assume that g_i is strictly concave and $\gamma_i(p_i) = dg_i(p_i)/dp_i > 0$. The derivative γ_i, when taken to the left, is country i's marginal cost (in terms of y_i) of abatement.

The *transfer function* $z = -\sum p_i$ specifies how the pollutant emissions of all countries are diffused and transformed by ecological processes into the ambient quantity z.

A *feasible state* of the economy is a vector $(x, p, z) = (x_1, \ldots, x_n; p_1, \ldots, p_n; z)$ such that

$$\sum_{i \in N} x_i = \sum_{i \in N} g_i(p_i)$$

and

$$z = -\sum_{i \in N} p_i.$$

A *Pareto-efficient state* of the economy is a feasible state $(x^*, p^*, z^*) = (x_1^*, \ldots, x_n^*; p_1^*, \ldots, p_n^*; z^*)$ that maximizes

$$\sum_{i \in N} [x_i + v_i(z)].$$

Given the quasi-linearity of preferences, it is easily seen that in all Pareto-efficient states the emission levels are the same, only the private good consumption levels might be different across Pareto-efficient states.

A Pareto-efficient state $(x_1^*, \ldots, x_n^*; p_1^*, \ldots, p_n^*; z^*)$ is characterized by the following first order conditions for maximization:

$$\sum_{j \in N} \pi_j(z^*) = \gamma_i(p_i^*) \qquad i = 1, 2, \ldots, n. \tag{1}$$

A *disagreement equilibrium* is a feasible state $(\bar{x}_1, \ldots, \bar{x}_n; \bar{p}_1, \ldots, \bar{p}_n; \bar{z})$ such that for each i,

$(\bar{x}_i, \bar{p}_i)$ maximizes $x_i + v_i(z)$ subject to $x_i = g_i(p_i)$ and $p_i + z = -\sum_{j \neq i} \bar{p}_j$. A disagreement equilibrium describes the state of autarky in which there is no agreement. Each country acts on its own and decides its pollution level without taking into account the welfare impact of its pollution on other countries. A disagreement equilibrium $(\bar{x}_1, \ldots, \bar{x}_n; \bar{p}_1, \ldots, \bar{p}_n; \bar{z})$ is characterized by the following first order conditions for maximization:

$$\pi_i(\bar{z}) = \gamma_i(\bar{p}_i) \qquad\qquad i = 1, 2, \ldots, n. \tag{2}$$

It is easily seen from these conditions that a disagreement equilibrium is not a Pareto-efficient state.[3] The environmental efficiency at the world level can be therefore achieved only through some form of cooperation among the countries.

Chander and Tulkens (1997) demonstrate the theoretical possibility of such cooperation. For this purpose, they introduce the new concept of γ-core as distinct from the α- and β-cores. That concept is described as follows: if a coalition $S \subset N$ forms, the highest payoff it can achieve for its members is given by the function:

$$w^{\gamma}(S) = \sum_{i \in S} [\hat{x}_i + v_i(\hat{z})],$$

[3]The existence and uniqueness of a disagreement equilibrium follow from the standard arguments for the existence and uniqueness of a Nash equilibrium.

where $(\hat{x}_1, \ldots, \hat{x}_n; \hat{p}_1, \ldots, \hat{p}_n; \hat{z})$ is the solution to the problem:

$$\begin{aligned} &\max_{(x_i,p_i)_{i\in S}} \sum_{i\in S}[x_i + v_i(z)] \\ \text{subject to} \quad &\sum_{i\in S} x_i = \sum_{i\in S} g_i(p_i) \\ \text{and} \quad &\sum_{i\in S} p_i + z = -\sum_{j\in N\setminus S} g_i(\hat{p}_i), \end{aligned}$$

where for each $j \in N \setminus S$

$$\begin{aligned} &(\hat{x}_j, \hat{p}_j) \text{ maximizes } x_j + v_j(z) \\ &\text{subject to} \quad x_j = g_j(p_j) \\ &\text{and} \quad p_j + z = -\sum_{i\neq j} \hat{p}_i. \end{aligned}$$

We shall refer to the solution $(\hat{x}_1, \ldots, \hat{x}_n; \hat{p}_1, \ldots, \hat{p}_n; \hat{z})$ as the *partial agreement equilibrium* with respect to S. Thus, $w^\gamma(S) = \sum_{i\in S}[\hat{x}_i + v_i(\hat{z})]$ is the payoff of S corresponding to the partial agreement equilibrium with respect to S. The partial agreement equilibrium $(\hat{x}_1, \ldots, \hat{x}_n; \hat{p}_1, \ldots, \hat{p}_n; \hat{z})$ is characterized by the following first order conditions:

$$\sum_{i\in S} \pi_i(\hat{z}) = \gamma_i(\hat{p}_i), \qquad i \in S,$$

and

$$\pi_j(\hat{z}) = \gamma_j(\hat{p}_j), \qquad j \in N \setminus S. \tag{3}$$

For the grand coalition N, the highest payoff is given by $w^{\gamma}(N) = \sum_{i \in N}[x_i^* + v_i(z^*)]$ where (x^*, p^*, z^*) is a Pareto optimum. Since the emission levels p_i^*'s are the same across Pareto-efficient states, the aggregate private good output, $\sum_{i \in N} x_i^*$ $(= \sum_{i \in N} g_i(p_i^*))$ is also the same. The stability of an environmentally efficient world-wide treaty therefore depends on how the aggregate world output $\sum_{i \in N} x_i^*$ is distributed among the countries. Chander and Tulkens (1997) show that the following distribution rule is sufficient:

$$x_i^* = g_i(\bar{p}_i) - \frac{\pi_i(z^*)}{\sum_{j \in N} \pi_j(z^*)} \left(\sum_{j \in N} g_j(\bar{p}_j) - \sum_{j \in N} g_j(p_j^*) \right), \qquad i \in N. \tag{4}$$

Given this distribution rule, N is stable in the sense that for each $S \subset N$, $w^{\gamma}(S) \leq \sum_{i \in S}[x_i^* + v_i(z^*)]$ where x_i^*'s are as defined in (4).[4]

As seen from above, the definition of $w^{\gamma}(S)$ involves the assumption that there are no non-singleton coalitions except possibly S.

In order to consider the dynamic time-path question, we may define the payoff of S in the presence of another (possibly non-singleton) coalition T. Given coalitions S and T, a *coalitional equilibrium* with respect to S and T is the state $(\tilde{x}_1, \ldots, \tilde{x}_n; \tilde{p}_1, \ldots, \tilde{p}_n; \tilde{z})$ such that:

$$\begin{aligned} \text{(i)} \qquad (\tilde{x}_i, \tilde{p}_i)_{i \in S} \text{ maximizes } \quad & \sum_{i \in S}[x_i + v_i(z)] \\ \text{subject to } \quad & \sum_{i \in S} x_i = \sum_{i \in S} g_i(p_i), \\ & \sum_{i \in S} p_i + z = - \sum_{j \in N \setminus S} \tilde{p}_j; \end{aligned}$$

[4]The allocation (x^*, p^*, z^*) can be given a similar interpretation as the Lindahl equilibrium in public good economies or the Walrasian equilibrium in exchange economies.

$$\text{(ii)} \qquad (\tilde{x}_j, \tilde{p}_j)_{j\in T} \text{ maximizes} \qquad \sum_{j\in T}[x_j + v_j(z)]$$

$$\text{subject to} \qquad \sum_{j\in T} x_j = \sum_{j\in T} g_j(p_j),$$

$$\sum_{j\in T} p_j + z = -\sum_{j\in N\setminus T} \tilde{p}_j;$$

and (iii) for each $k \in N \setminus S \setminus T, (\tilde{x}_k, \tilde{p}_k)$ maximizes $x_k + v_k(z)$

$$\text{subject to} \qquad x_k = g_k(p_k),$$

$$p_k + z = -\sum_{j\neq k} \tilde{p}_j.$$

A coalitional equilibrium with respect to S and T defines the payoff of S when there is a pre-existing coalition T. Let $w^\gamma(S|T)$ denote this payoff, that is:

$$w^\gamma(S|T) = \sum_{i\in S}[\tilde{x}_i + v_i(\tilde{z})],$$

where $(\tilde{x}_1, \ldots, \tilde{x}_n; \tilde{p}_1, \ldots, \tilde{p}_n; \tilde{z})$ is the coalitional equilibrium with respect to S and T. The coalitional equilibrium with respect to S and T is characterized by the following first order conditions:[5]

[5]The existence and uniqueness of a coalitional equilibrium follow from similar arguments as in the case of partial agreement equilibrium.

$$
\begin{aligned}
\sum_{i\in S}\pi_i(\tilde z) &= \gamma_i(\tilde p_i) && \text{for all } i\in S,\\
\sum_{j\in T}\pi_j(\tilde z) &= \gamma_i(\tilde p_i) && \text{for all } i\in T,\\
\pi_j(\tilde z) &= \gamma_j(\tilde p_j) && \text{for all } j\in N\setminus S\setminus T.
\end{aligned}
\tag{5}
$$

Theorem : *For each coalition $S \subset N$, the payoff $w^\gamma(S|T)$ corresponding to the coalitional equilibrium with respect to S and T is at least as large as the payoff $w^\gamma(S)$ corresponding to the partial agreement equilibrium with respect to S.*

The Theorem implies that coalition formation T creates positive externalities for S. By raising the reservation utility of S, it may reduce the incentives of S to sign the world-wide treaty.

Proof of the Theorem : We first show that $\tilde z \geq \hat z$, where $\tilde z = -\sum_{i\in N}\tilde p_i$, $\hat z = -\sum_{i\in N}\hat p_i$, and $(\tilde p_1,\ldots,\tilde p_n)$ and $(\hat p_1,\ldots,\hat p_n)$ are the emission levels corresponding to the coalitional equilibrium and the partial agreement equilibrium.

Suppose contrary to the assertion that $\tilde z < \hat z$. We must then have $\pi_i(\tilde z) \geq \pi_i(\hat z)$ for each $i \in N$. From the characterization of coalitional equilibrium (see (5) above), partial agreement equilibrium with respect to S (see (3) above) and disagreement equilibrium (see (2) above), it follows that:

$$\gamma_i(\tilde p_i) = \sum_{j\in S}\pi_j(\tilde z) \geq \sum_{j\in S}\pi_j(\hat z) = \gamma_i(\hat p_i) \text{ for all } i \in S,$$

$$\gamma_i(\tilde{p}_i) = \sum_{j \in T} \pi_j(\tilde{z}) \geq \sum_{j \in T} \pi_i(\hat{z}) = \gamma_i(\hat{p}_i) \text{ for all } i \in T,$$

and

$$\gamma_i(\tilde{p}_i) = \pi_i(\tilde{z}) \geq \pi_i(\hat{z}) = \gamma_i(\hat{p}_i) \text{ for all } i \in N \setminus S \setminus T.$$

From these inequalities and the strict concavity of each g_i, it follows that $\tilde{p}_i \leq \hat{p}_i$ for each $i \in N$. But this contradicts our supposition that $\tilde{z} < \hat{z}$. Hence we must have $\tilde{z} \geq \hat{z}$.

Now since $\tilde{z} \geq \hat{z}$,

$$\gamma_i(\tilde{p}_i) = \sum_{j \in S} \pi_j(\tilde{z}) \leq \sum_{j \in S} \pi_j(\hat{z}) = \gamma_i(\hat{p}_i) \text{ for all } i \in S.$$

Which from concavity of each g_i, means $\tilde{p}_i \geq \hat{p}_i$ for all $i \in S$. Therefore,

$$\sum_{i \in S} \tilde{x}_i = \sum_{i \in S} g_i(\tilde{p}_i) \geq \sum_{i \in S} g_i(\hat{p}_i) = \sum_{i \in S} \hat{x}_i.$$

Since $\tilde{z} \geq \hat{z}$ and $\sum_{i \in S} \tilde{x}_i \geq \sum_{i \in S} \hat{x}_i$,

$$w^\gamma(S|T) = \sum_{i \in S} [\tilde{x}_i + v_i(\tilde{z})] \geq \sum_{i \in S} [\hat{x}_i + v_i(\hat{z})] = w^\gamma(S).$$

This completes the proof.

We have shown that for any S and T, $w^\gamma(S|T) \geq w^\gamma(S)$ in general. From this it does not follow that $w^\gamma(S|T) > \sum_{i\in S}[x_i^* + v_i(z^*)]$, where $(x_1^*, \ldots, x_n^*; p_1^*, \ldots, p_n^*; z^*)$ is the world-wide treaty as defined in (4), which is clearly a stronger requirement since $\sum_{i\in S}[x_i^* + v_i(z^*] \geq w^\gamma(S)$. Though it need not be satisfied in general, we construct an illustrative example to show that this might indeed be the case in certain circumstances.

There are three identical countries, *i.e.* $N = \{1, 2, 3\}$ with $u_i(x_i, z) = x_i + z$ and $g_i(p_i) = p_i^{\frac{1}{2}}$. For this economy, the disagreement equilibrium is given by $\bar{x}_i = \frac{1}{2}$; $\bar{p}_i = \frac{1}{4}$, $\bar{z} = -\frac{3}{4}$, and $\bar{u}_i = u_i(\bar{x}_i, \bar{z}) = -\frac{1}{4}$. The coalitional equilibrium with respect to $S = \{3\}$ and $T = \{1, 2\}$ implies

$$\tilde{x}_1 + \tilde{x}_2 = \frac{1}{2}, \qquad \tilde{p}_1 = \tilde{p}_2 = \frac{1}{16},$$
$$\tilde{x}_3 = \frac{1}{2}, \tilde{p}_3 = \frac{1}{4}, \qquad \tilde{z} = -\frac{1}{8} - \frac{1}{4} = -\frac{3}{8}, \text{ and}$$
$$\tilde{u}_3 = u_3(\tilde{x}_3, \tilde{z}) = \frac{1}{2} - \frac{3}{8} = \frac{1}{8}.$$

Thus $w^\gamma(\{3\}|\{1, 2\}) = \frac{1}{8}$. The Pareto- efficient emission levels are $p_i^* = \frac{1}{36}$, $z^* = -\frac{1}{12}$. The payoff of $\{3\}$ corresponding to the world-wide treaty (see (4)) is

$$u_3^* = u_3(x_3^*, z^*) = \frac{1}{6} - \frac{1}{12} = \frac{1}{12}.$$

Since $w^\gamma(\{3\}|\{1, 2\}) = \frac{1}{8} > \frac{1}{12}$, country 3 will not be willing to sign the treaty if countries 1 and 2 were to form a coalition. Country 3 would, however, be willing to sign the treaty, if countries 1 and 2 do not form a coalition, since $w^\gamma(\{3\}) = -\frac{1}{4} < \frac{1}{12} = u_3^*$. Note that

$$w^{\gamma}(\{1,2\}) = -\frac{1}{4} \geq w^{\gamma}(\{1\}) + w^{\gamma}(\{2\}) = -\frac{1}{2},$$
$$w^{\gamma}(\{3\}|\{1,2\}) = \frac{1}{8} \geq w^{\gamma}(\{3\}) = -\frac{1}{4}.$$

This means that formation of coalition $T = \{1,2\}$ is Pareto- improving compared to the disagreement equilibrium. Yet it is bad for T in a dynamic time-path sense, since country 3 will then be no longer willing to sign the world-wide treaty under which the payoff of T ($=\frac{1}{6}$) is still higher. We may summarize the result in terms of the following diagram, which is a suitable adaptation from Bhagwati (1993) in the context of PTAs.

[Figure 1: cf. page 16]

The figure illustrates metaphorically the dynamic time-path considered in the example. The formation of the coalition $T = \{1,2\}$ may Pareto-improve world welfare immediately from $\bar{u}$ $(= \sum \bar{u}_i)$ to $\tilde{u}$ $(= \sum \tilde{u}_i)$, but not thereafter and it may never reach u^* - the maximum world welfare - as country 3 will then have no incentive to sign the world-wide treaty. Since $u_1^* + u_2^* = \frac{1}{6} > w^{\gamma}(\{1,2\}) = -\frac{1}{2}$ and $u_3^* = \frac{1}{12} > -\frac{1}{4}$, if no such coalition forms the dynamic time-paths would eventually lead to u^*, since each group of countries, including $S = \{3\}$ and $T = \{1,2\}$ would then find it advantageous to sign the world-wide treaty.

Carraro and Siniscalco (1993) and Barrett (1994) also analyze the possibility of cooperation among countries on global pollution. Their approach is based on the concept of coalition stability (see d'Aspremont and Gabszewicz (1986)) borrowed from the industrial organization literature on cartels. They assert that only small subset of countries can ever emerge as coalitions and sign a treaty among themselves.[6]. More specifically, as can be shown, in terms of their approach $T = \{1, 2\}$ in the example considered above is a stable coalition. Our analysis above clarifies that this might be so if coalition T is assumed to be concerned only with its immediate (static) payoff and not with the payoff it can achieve in the dynamic time-path sense.[7]

It should however be clarified that all coalition formations are not bad. For example, in the three countries case considered above if $u_3(x_3, z) = x_3$, that is country 3 does not care about the environmental quality, then formation of $T = \{1, 2\}$ is not bad even in the dynamic time-path sense.

3. CONCLUSION

In this paper we have shown that in an international economic-ecological setting, the formation of a coalition by a subset of countries can imperil the emergence of a world-wide treaty. Such a coalition formation can upset the balance of gains and losses from a world-wide treaty and make it unacceptable to some countries.

Finally, it may be noted that the sign of externalities created by coalition formation on non-members is positive in our context which is the opposite of that in the case of PTAs in the trade context. Accordingly, coalition formation in our case reduces the incentives of non-members to join the coalition whereas in the case of PTAs, it must reduce the incentives of member countries to let new members join the coalition.

[6] See Tulkens (1997) for a candid criticism of this view *vis-a-vis* the one in Chander and Tulkens (1997).

[7] It is interesting to note in this context that an international treaty which has been recently under negotiations, namely the so-called Comprehensive Test Ban Treaty or CTBT, can come into force *only* if *all* the current and potential nuclear powers sign it by a specific date. This is perhaps a case of practice running ahead of our theory.

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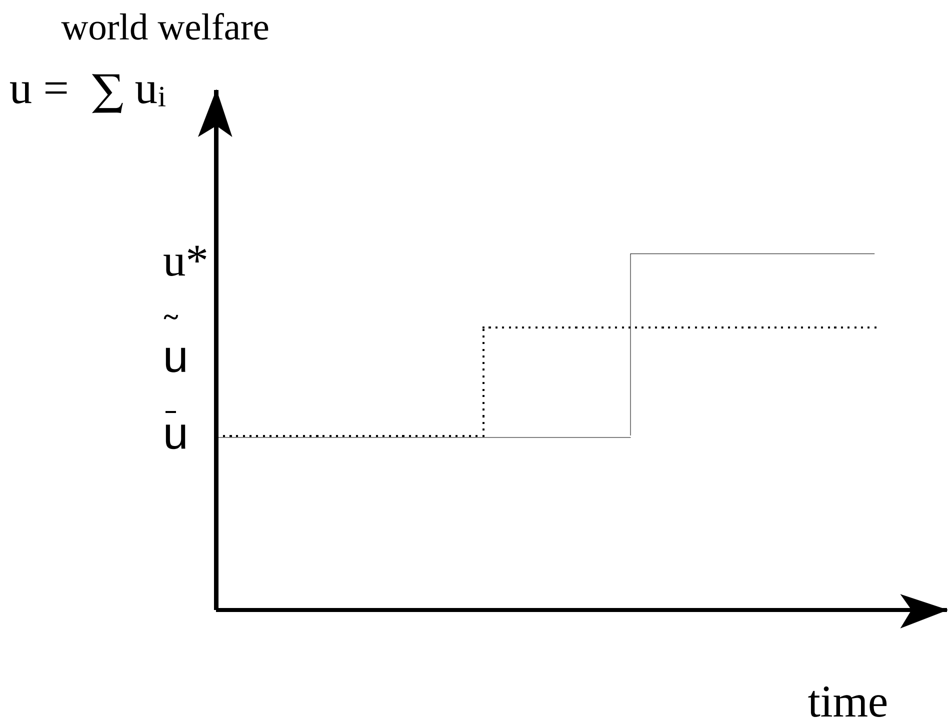
world welfare
$u = \sum u_i$
u^*
$\tilde{u}$
$\bar{u}$
time