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Enforcing ‘Self-Enforcing’ International Environmental Agreements

DAVID M. McEVOY*
Department of Resource Economics
University of Massachusetts-Amherst

JOHN K. STRANLUND
Department of Resource Economics
University of Massachusetts-Amherst

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* Correspondence to: David M. McEvoy, 80 Campus Center Way, 404 Stockbridge Hall, Amherst, MA 01003, USA, Phone: 617-671-8147, Fax: 413-545-5853, E-mail: dmcevoy@resecon.umass.edu.

Enforcing 'Self-Enforcing' International Environmental Agreements

Abstract: Theoretical analyses of international environmental agreements (IEAs) have typically employed the concept of *self-enforcing agreements* to predict the number of parties to such an agreement. The term *self-enforcing*, however, is a bit misleading. The concept refers to the stability of cooperative agreements, not to enforcing these agreements once they are in place. Most analyses of IEAs simply ignore the issue of enforcing compliance. In this paper we analyze a static IEA game in which parties to an agreement finance an independent enforcement body with the power to monitor the parties' compliance to the terms of an IEA and impose penalties in cases of noncompliance. This approach is broadly consistent with the enforcement mechanism of the Kyoto Protocol under the Marrakesh Accords. We find that costly enforcement limits the circumstances under which international cooperation to protect the environment is worthwhile, but when IEAs are expected to form they will involve greater participation than IEAs that do not require costly enforcement. Consequently, costly enforcement of IEAs is associated with higher international environmental quality. Moreover, under certain conditions, aggregate welfare is higher when IEAs require costly enforcement.

Keywords: International environmental agreements, self-enforcing agreements, compliance, enforcement.

JEL Codes: Q50, H41, C72, F53, L5

1. Introduction

International environmental agreements (IEAs) made between sovereign nations seeking to manage shared environmental and natural resources are susceptible to two sources of free-riding behavior. First, because participation in an IEA is voluntary, countries can decide at will whether to become a party to an agreement. If an IEA only requires a subset of countries to join before entering into force, as is typically the case, then incentives exist for some countries to stay out of the agreement and free-ride off the provision of the cooperating others. Second, if compliance with the terms of the agreement is not enforced, parties to an IEA will have incentives to violate the terms of their agreement and free-ride off those countries that do comply.

Conceptually, IEAs have typically been modeled using the equilibrium concept of a *self-enforcing agreement*. A self-enforcing agreement made between agents, as first proposed by D'Aspremont et al. (1983) and later coined by Barrett (1994), is defined as a single coalition from which no member wishes to withdraw (the coalition is *internally stable*) and no nonmember wishes to join (the coalition is *externally stable*). Often in this framework, parties to a self-enforcing IEA are assumed to comply fully with the terms of the agreement, thus avoiding altogether the problem that parties to an IEA have an incentive to not comply (e.g. Barrett 1994, 2003; Carraro and Siniscalco 1993, 1998; Hoel 1992). The objective of this paper is to introduce a more complete model of a static self-enforcing IEA by directly addressing the enforcement issue. Specifically, this paper analyzes an IEA game in which nations have the opportunity to self-finance an independent enforcement body that is capable of monitoring and penalizing noncompliant parties.

The fact that countries may fall short of their commitments to an IEA is well documented. For example, the Convention on International Trade in Endangered Species (CITES) has witnessed hundreds of infractions every year since its inception in 1979 (Swanson and Johnston 1999; Finus 2004). Similarly, customs officers throughout the world frequently intercept flows of CFC products even though these substances have been banned under the Montreal Protocol since 1991 (Finus 2004). As a more recent example, although performance with the Kyoto Protocol cannot formally be evaluated until the end of the first commitment period (2008-2012), many countries are currently not on track to meeting their commitments (Friends of the Earth 2006).

To discourage noncompliance, many existing IEAs include provisions for enforcement within the treaty. These enforcement mechanisms must be negotiated and included as part of a

treaty. As Hovi and Areklett (2004, pg 3) point out, “In practice, enforcement must either be carried out by the parties themselves, or by some institution erected, accepted and empowered by the parties”. The Montreal Protocol, for example, enforces compliance by threatening the use of trade sanctions on defecting parties (Benedick 1998; Heister 1997). It is one of an estimated 19 IEAs that uses trade sanctions as a mechanism for motivating compliance (United States International Trade Commission 1991).¹ Arguably one of the most ambitious provisions for enforcing compliance with an IEA has been implemented within the Kyoto Protocol under the Marrakesh Accords. An independent Compliance Committee, consisting of members elected by the parties, has been formed to oversee the monitoring of members actions and the sanctioning of noncompliant behavior. If a party to the Kyoto Protocol is found in violation, the Compliance Committee has the power to impose a penalty in the form of a reduction in next period’s greenhouse gas emissions quota (UNFCCC 2002). Although it is too early to evaluate the effectiveness of this type of enforcement mechanism, its structure is unique in the sense that parties have agreed to invest in an institution with the power to monitor and sanction noncompliance.

Despite the reality that noncompliance with IEAs is a genuine concern and that any provision for enforcement must be determined endogenously, the established theoretical literature has largely avoided the issue.² The majority of studies model agreements as one-shot games, and these universally assume compliance is perfect and costless to enforce. Adopting this assumption allows for a focused investigation into the effects of nonparticipation free-riding

¹ Barrett (2003) estimates that a much larger number of IEAs make provisions for trade sanctions, however, many of those agreements use bans on traded items as part of the agreement’s goal, not its method of enforcement.

² Although it is universally accepted that some level of noncompliance with IEAs exists, there remains debate as to the magnitude and effect of noncompliance. On one end of the debate, Chayes and Chayes (1991) argue that high levels of compliance are often observed in IEAs without formal enforcement mechanisms and therefore enforcement is not a real concern. On the other end, Downs et al. (1996) argue that high levels of compliance may result because the lack of enforcement motivates parties to form shallow agreements to begin with.

but avoids the equally pressing question on how costly enforcement potentially affects international cooperation.³ On the other hand, a few studies do include costly enforcement mechanisms within the framework of a repeated game. These models use reciprocal punishment strategies in which parties to an agreement may punish violators in future rounds by jointly reducing the level of the public good (Barrett 1994, 2003; Finus and Rundshagen 1998).

The model developed in this paper explicitly incorporates a mechanism to enforce compliance within a one-shot IEA game. Our game is fashioned using elements of the compliance mechanism developed for the Kyoto Protocol, and features an endogenously determined enforcement apparatus. Specifically, parties to an IEA are given the opportunity to finance the creation of a third party enforcement body that is capable of monitoring (albeit imperfectly) and penalizing noncompliance.

Our efforts yield three new results. First, the range of international environmental problems within which an IEA can form is smaller when enforcing cooperation is necessary and costly. This follows because enforcement effectively increases the cost of cooperation, which, in turn, limits the set of situations under which cooperation can actually increase aggregate welfare is smaller than when cooperation can be enforced without cost. Second, when an IEA is expected to form, it will have more members when enforcement is costly. Consequently, costly enforcement of IEAs is associated with higher environmental quality. Greater participation in IEAs that are costly to enforce occurs because the additional cost of being party to an IEA must be offset with an increase in the level of environmental quality, which is realized through an increase in the number of parties to the agreement. Finally, provided that the number of

³ To encourage greater participation levels, the basic model has been extended to include provisions for trade sanctions (Barrett 1997a; 1997b), side payments (Carraro and Siniscalco 1993; Carraro and Botteon 1997 and Hoel and Schneider 1997), issue linkage (Folmer 1993; Carraro and Siniscalco 1997; Botteon and Carraro 1998) and minimum participation requirements (Barrett 1998a; 2003 and Carraro et al. 2003). For a review of these extensions see Wagner 2001.

countries involved is sufficiently large, social welfare will be greater under an IEA that is costly to enforce. If the number of countries involved is large enough, the aggregate benefit from increased participation levels offsets the parties' costs of enforcing their agreement.

The paper proceeds as follows; section 2 presents the basic model of a self-enforcing IEA with costless enforcement; section 3 introduces the endogenous enforcement mechanism; section 4 draws conclusions from the self-enforcing IEA model with costly enforcement, and section 5 provides some concluding remarks.

2. The basic model of a self-enforcing IEA

Following Barrett (2003), consider a situation where N identical countries each emit a uniformly mixed transboundary pollutant. Country i 's welfare is

$$w_i = A + b(q_i + q_{-i}) - cq_i, \quad [1]$$

where q_i is equal to one if i abates its emissions and is zero if it does not, q_{-i} is the sum of the abatement decision by all other countries, b is the constant marginal benefit of abatement, c is the constant marginal cost of abatement, and A is a positive constant. Assume that the underlying structure of the countries' interactions with each other is an N -player prisoners' dilemma. That is, all countries have a dominant strategy to not abate in a noncooperative Nash equilibrium. This will be true when $b < c$. However, when all the countries abate their emissions their joint welfare will be maximized. This requires $Nb > c$.

Recognizing the benefits from joint determination of their decisions, the countries have the incentive to form an international environmental agreement. Because participation in an IEA is voluntary, countries can join or not join the agreement at will. Parties to an IEA maximize their joint payoffs by agreeing to abate their emissions. In this section of the paper, we maintain

the common assumption in the literature that this agreement is enforced perfectly and without cost.

Let s denote the number of parties to an IEA. Moreover, let $w^p(s)$ denote the common payoff of each of the parties to the IEA, and let $w^{np}(s)$ denote the common payoff of each of the countries that are not party to the agreement. Then,

$$\begin{aligned} w^p(s) &= A + bs - c ; \\ w^{np}(s) &= A + bs . \end{aligned} \quad [2]$$

Let s^{nc} denote the equilibrium number of parties to an IEA. (The superscript nc identifies s^{nc} as the equilibrium number of parties when the terms of an IEA are costlessly enforced). Formally, the notion of a *self-enforcing voluntary agreement* applied in this setting is:

Definition: An IEA consisting of s^{nc} countries that can enforce the IEA without cost is self-enforcing if and only if:

$$\begin{aligned} (i) \quad & w^p(s^{nc}) \geq w^{np}(s^{nc} - 1) \\ (ii) \quad & w^{np}(s^{nc}) \geq w^p(s^{nc} + 1) .^4 \end{aligned} \quad [3]$$

Requirement (i) of a self-enforcing agreement is that no party to the agreement wishes to leave the agreement; that is, the agreement is *internally stable*. Requirement (ii) is that no country that is not a party to the agreement wishes to join; that is, the agreement is *externally stable*. The equilibrium value of s^{nc} follows easily from these two conditions.

⁴ Although the concept of self-enforcing agreements is most often adopted for analyses of international environmental agreements, it was first developed to study the stability of cartels by D'Apremont et al. [(1983); see Diamontoudi (2005) for a recent contribution], and has been used to model voluntary domestic environmental policies by Dawson and Segerson (2003).

Using the payoff functions [2] and the external stability condition (ii), $w^{np}(s) - w^p(s+1) = c - b \geq 0$. Since we have assumed that $b < c$, the external stability condition is always satisfied. Determining the values of s that satisfy the internal stability condition (i) involves examining the consequences of two possible outcomes of a single country that must decide whether to defect from an IEA. The first is when this single defection does not cause all the other parties to the IEA to also defect. In this case, using the payoffs [2] and the internal stability condition (i), $w^p(s) - w^{np}(s-1) = b - c \geq 0$, which violates our assumption that $b < c$. This implies that if the number of parties to an IEA is such that it would remain intact if one party defected, then the IEA is not internally stable. Thus, the self-enforcing number of parties to an agreement, if greater than zero, must be such that one defection would make the agreement collapse. In this case, the internal stability condition (i) is written as $w^p(s) - w^{np}(0) = bs - c \geq 0$. The self-enforcing number of parties, s^{nc} , to an agreement that is enforced without cost is the minimum size coalition that satisfies this inequality. Formally:

$$s^{nc} = \min s \mid w^p(s) - w^{np}(0) \geq 0 = \min s \mid s \geq c / b. \quad [4]$$

Our assumption that $b < c$ implies that $s^{nc} > 1$, while the assumption that $Nb - c > 0$ implies that [4] will be satisfied for some $s^{nc} \leq N$. Barrett's (1994, 2003) claim that international cooperation to protect the environment will be greatest when it is needed least is easy to verify with [4], which indicates that participation with an IEA is increasing in the cost of abatement, c , and decreasing in the individual benefit of abatement, b .

It is clear the concept of a self-enforcing agreement applies to the stability of a cooperating coalition, not to parties' decisions to comply with the terms of the agreement once they've joined. However, Barrett (1998b, pg 36) claims: "The binding constraint on international cooperation is free-rider deterrence, not compliance enforcement. Once free-riding

[nonparticipation] can be deterred, compliance can be enforced free of charge.” In fact, this is true if countries are able to observe each others’ compliance decisions perfectly and without cost. In this setting a country has no incentive to join an agreement and then not comply with its requirements, because all the other participating nations would automatically observe this violation and would realize that they would then be worse off if they stayed with the agreement. In these circumstances a party to an IEA would not violate the terms of the agreement, because the agreement would then collapse.

Realistically, however, nations cannot observe each other’s abatement perfectly and without cost, nor can a country’s abatement decision be directly inferred from an aggregate measure (e.g., the global concentration of a pollutant). In these cases, a country may be motivated to join an agreement and then decide to violate its terms. If the other participating countries cannot observe this act of noncompliance, they will not automatically defect as they would if they could observe this violation. The violator, therefore, is able to escape the cost of compliance with the agreement while enjoying the benefit of cooperation of those that remain with the agreement. Asymmetric information among parties to an IEA about their compliance decisions motivates the implementation of some enforcement mechanism to counteract the incentive to violate the terms of the agreement.

3. Endogenous enforcement of compliance to an IEA

We now give parties to an IEA the opportunity to violate the terms of the agreement, and the opportunity to invest in a third party enforcement body designed to maintain compliance to the agreement. The enforcement mechanism works as follows; each party to the agreement pays x

dollars (to be determined endogenously) to a third party enforcement body that is capable of monitoring the parties with probability π and penalizing noncompliant parties with a fine f .

The monitoring capability of the enforcer is a monotonically increasing function of the amount of funding provided by the parties. That is, because monitoring the actions of the parties to an IEA is costly, the more funding available to the enforcer the more complete the monitoring. Suppose that monitoring consists of random audits of the parties. Audits are perfectly accurate in the sense that an audit always uncovers a violation if one has occurred and does not ‘discover’ a violation when one hasn’t occurred. Each dollar of additional enforcement funding allows the number of random audits to increase by α ; that is, α is the constant marginal productivity of resources devoted to monitoring. If s parties to an agreement each provide x to fund the enforcer, then the number of random audits the enforcer conducts is $sx\alpha$, and the probability that any party is audited is

$$\pi = sx\alpha / s = x\alpha . \quad [5]$$

Clearly, constraining π to be between zero and one requires $\alpha \in [0, 1/x]$. We will maintain this assumption throughout. The expected penalty for noncompliance is $\pi f = x\alpha f$, and the fine, f , is constrained (by convention, norm, or law) to be no more than \bar{f} .

Assume that the countries are risk neutral and that they comply with an IEA if they are indifferent between compliance and noncompliance. Then, given an agreement consisting of s countries, a country will comply with the terms of the agreement if its payoff from doing so is not less than its expected payoff from noncompliance. A country’s payoff from compliance is $w^p(s) - x$, and its expected payoff from noncompliance is $w^{np}(s-1) - x - x\alpha f$, where recall that $w^p(s)$ and $w^{np}(s-1)$ are defined by [2]. Therefore, a party to an IEA complies with the terms of the agreement if and only if $[w^p(s) - x] - [w^{np}(s-1) - x - x\alpha f] = x\alpha f - (c - b) \geq 0$. If the

expected penalty, $x\alpha f$, is less than the gain from noncompliance, $c - b$, then all parties to an IEA will violate its terms and no self-enforcing agreement is possible. On the other hand, if $x\alpha f$ is no less than $c - b$, each party to an IEA will comply with its requirements. Clearly, $x\alpha f - (c - b) \geq 0$ is a necessary condition for a viable IEA. Indeed, a self-enforcing IEA that is costly to enforce (with a (positive number of members) is not internally stable unless $x\alpha f - (c - b) \geq 0$.

Now let us determine each party's contribution to the third party enforcer of an IEA. Clearly, each would like to contribute as little as possible while providing the enforcer with sufficient resources to maintain compliance to the agreement. This requires a payment x so that $x\alpha f - (c - b) \geq 0$ binds, yielding $x = (c - b) / \alpha f$. Moreover, since x is monotonically decreasing in the fine for noncompliance, the parties to the agreement will choose the fine to be as high as possible; that is, $f = \bar{f}$.⁵ Thus, the contribution to the enforcer of an IEA that is required of all parties to the agreement is

$$x = (c - b) / \alpha \bar{f}. \quad [6]$$

Note that the payment required of each party to an agreement decreases with the maximal fine, \bar{f} , and the marginal productivity of resources devoted to monitoring, α , but is increasing in the gain from noncompliance, $c - b$.

4. Self-enforcing IEAs with costly enforcement

We are now ready to analyze the consequences of costly enforcement of international environmental agreements. The first effect of costly enforcement is that it changes the set of

⁵ The idea that the penalty for noncompliance should be set as high as possible to conserve on monitoring costs is common in the literature on the economics of law enforcement. See Polinsky and Shavell (2000) for a review of this literature.

circumstances under which cooperation increases aggregate welfare. Given s parties to an agreement that each earn $w^p(s) - x = A + bx - c - x$, and $N - s$ free-riding countries that each earn $w^{np}(s) = A + bs$, aggregate welfare when cooperation is costly to enforce is

$$\begin{aligned} W^c(s) &= s(A + bs - c - x) + (N - s)(A + bs) \\ &= NA + s(Nb - c - x). \end{aligned} \quad [7]$$

(The superscript ‘ c ’ identifies variables and functions when cooperation is costly to enforce).

Note that $W^c(s)$ is linearly decreasing in s if $Nb - c - x < 0$ and linearly increasing (weakly) if $Nb - c - x \geq 0$. Therefore, the efficient size coalition is either $s = 0$ if $Nb - c - x < 0$, or $s = N$ if $Nb - c - x \geq 0$. Use [6] to substitute for x in the latter inequality and rearrange the result to obtain

$$N \geq \frac{c}{b} + \frac{c - b}{b\alpha f}. \quad [8]$$

If the inequality in [8] is strict, then any coalition of countries that cooperate to abate their emissions will increase aggregate welfare. Moreover, aggregate welfare is maximized if all countries cooperate to abate their emissions. If [8] does not hold, then the costs of enforcing a cooperative agreement are high enough to make cooperation by any subset of countries inefficient. Recall that we assumed $N \geq c/b$ under costless enforcement of a cooperative agreement so that any coalition of cooperating countries would increase aggregate welfare, and the grand coalition of cooperating countries maximized their joint welfare. Since $c > b$, the second term on the right side of [8] is strictly positive, which yields the following proposition:

Proposition 1: The set of values of N , b , and c for which international environmental agreements increase aggregate welfare is smaller when enforcement of these agreements is costly.

Since enforcing cooperation entails an additional cost of forming cooperative agreements, the set of circumstances under which cooperation will increase aggregate welfare is smaller than when cooperation can be enforced without cost. It is straightforward to show that $c/b + (c-b)/b\alpha\bar{f}$ is increasing in c and decreasing in b . Thus, the set of circumstances under which cooperation is worthwhile is larger when cooperation is needed least; that is when abatement costs are high relative to the benefits of abatement. Moreover, $c/b + (c-b)/b\alpha\bar{f}$ is decreasing in α and \bar{f} . Increasing either of these parameters decreases the payment cooperators pay to enforce an agreement, leading to an enlargement of the set of opportunities for welfare-enhancing cooperation.

Now let us determine the equilibrium coalition size when IEAs are costly to enforce. As in the case of costless enforcement, a self-enforcing equilibrium is the minimum size coalition of cooperating countries for which the welfare of each of these countries is no less than if no country abated their pollution. That is, letting s^c denote the size of a self-enforcing IEA with costly enforcement, $s^c = \min s \mid w^p(s) - x \geq w^{np}(0)$. Using the welfare functions [2] and substituting for x from [6], the equilibrium condition under costly enforcement that is the analogue to [4] is:

$$s^c = \min s \mid s \geq \frac{c}{b} + \frac{c-b}{b\alpha\bar{f}}. \quad [9]$$

An IEA with costly enforcement will form if and only if $N \geq c/b + (c-b)/b\alpha\bar{f}$, because then there exists a coalition $s^c \leq N$ that satisfies [9]. On the other hand, when enforcement is costless the term $(c-b)/b\alpha\bar{f}$ disappears so that an IEA without costly enforcement will form as long as $N \geq c/b$. Since $(c-b)/b\alpha\bar{f} > 0$, we have the following proposition:

Proposition 2: If compliance to IEAs is costly to enforce, then the set of values of N , b , and c for which an IEA will form is smaller than when enforcement is costless.

The condition under which an IEA with costly enforcement would be expected to form is identical to the condition under which cooperative management of the international environmental resource will increase aggregate welfare (equation [8]). This implies that when cooperation among nations is worthwhile, a cooperative agreement among some subset of countries can be expected to form.

In fact, when an IEA is expected to form, costly enforcement implies that the equilibrium number of parties to the agreement will typically be higher. When an IEA with costly enforcement forms, [9] indicates that the equilibrium size of the coalition s^c is the least s for which $s \geq c/b - (c-b)/b\alpha\bar{f}$. When an IEA is not costly to enforce, [4] indicates that the equilibrium coalition s^{nc} is the least s for which $s \geq c/b$. Again, since $(c-b)/b\alpha\bar{f} > 0$, $s^c \geq s^{nc}$. Therefore:

Proposition 3: If an IEA that is costly to enforce forms, membership in the IEA will be no less, and will typically be greater, than if the IEA could be enforced without cost.

The intuition behind this result is straightforward. Since contributing to enforcement is an additional cost of joining an IEA, more countries need to participate in an IEA to make the agreement worthwhile. Note that if an IEA forms, then costly enforcement is associated with increased environmental quality because more countries agree to abate their emissions.

Generally speaking, participation in an IEA increases with the costs of participation and decreases with the benefit that participation provides to all the countries. Thus, participation with an IEA that is costly to enforce increases with a country's abatement cost, c , and decreases with individual benefit of some country's abatement, b . Moreover, participation decreases as the cost of enforcement is reduced because either the marginal productivity of monitoring resources, α , increases or the maximal penalty for noncompliance, \bar{f} , increases.

Finally, we examine possible difference in aggregate welfare under self-enforcing IEAs that are costly to enforce and under those that are not costly to enforce. From [7] and [9], social welfare when a self-enforcing IEA requires costly enforcement is $W^c(s^c) = NA + s^c(Nb - c - x)$. For convenience, let us assume that s is continuous. Then, from [9], $s^c = c/b + (c - b)/b\alpha\bar{f}$.

Substitute this and $x = (c - b)/\alpha\bar{f}$ from [6] into $W^c(s^c)$ to obtain

$$W^c(s^c) = NA + \left(\frac{c}{b} + \frac{c - b}{b\alpha\bar{f}} \right) \left(Nb - c - \frac{c - b}{\alpha\bar{f}} \right). \quad [10]$$

Welfare when a self-enforcing IEA does not require costly enforcement is $W^{nc}(s^{nc}) = NA + s^{nc}(Nb - c)$, which upon substitution of $s^{nc} = c/b$ from [4] becomes

$$W^{nc}(s^{nc}) = NA + (c/b)(Nb - c). \quad [11]$$

Subtract [11] from [10] to obtain

$$W^c(s^c) - W^{nc}(s^{nc}) = \left(\frac{c - b}{\alpha\bar{f}} \right) \left[N - \left(\frac{2c}{b} + \frac{c - b}{b\alpha\bar{f}} \right) \right].$$

Since the first term of $W^c(s^c) - W^{nc}(s^{nc})$ is positive, $W^c(s^c) > W^{nc}(s^{nc})$ if and only if the term in hard brackets is positive. Therefore, we have our final proposition.

Proposition 4: Aggregate welfare is higher when IEAs are costly to enforce if and only if

$$N > \frac{2c}{b} + \frac{c-b}{b\alpha f}. \quad [12]$$

Figure 1 illustrates how $W^c(s^c)$ and $W^{nc}(s^{nc})$ vary with the number of potential parties to an IEA. To draw this graph we have assumed, without loss of generality, that $A = 0$. Aggregate welfare when an IEA does not require costly enforcement, $W^{nc}(s^{nc})$, is zero for $N \leq c/b$. For $N > c/b$, $W^{nc}(s^{nc})$ increases linearly at rate c (from equation [11]). The size of a self-enforcing IEA does not change as N increases—it remains constant at c/b —but aggregate welfare increases with N because increasing N means we are increasing only the number of free-riding countries, each of which benefits from the abatement efforts of the c/b parties to the agreement.

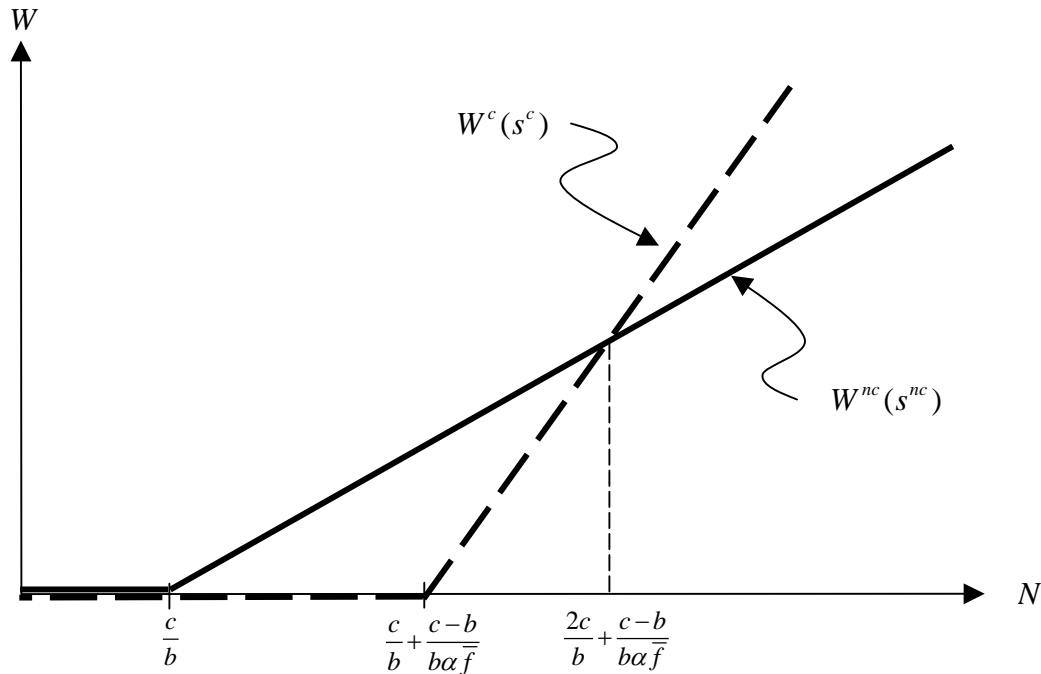


Figure 1: Aggregate welfare from self-enforcing international environmental agreements when they are costly to enforce and when they are not costly to enforce.

The bold dashed function in Figure 1 is aggregate welfare for a self-enforcing IEA that is costly to enforce. Note that $W^c(s^c)$ is equal to zero for a larger range of N than $W^{nc}(s^{nc})$; that is, up to $c/b - (c-b)/b\alpha\bar{f}$. This follows because cooperative abatement efforts that are costly to enforce increase aggregate welfare under a smaller set of circumstances than when cooperation can be enforced without cost (Proposition 1), and consequently, IEAs will only form under this smaller set of circumstances (Proposition 2). When, $N \geq c/b - (c-b)/b\alpha\bar{f}$, the coalition $s^c = c/b + (c-b)/b\alpha\bar{f}$ forms and aggregate welfare increases with N at rate s^c (from equation [10]). It is important to reiterate, however, that the increase in aggregate welfare that comes from increasing N goes entirely to the free-riding countries, and not to the members of s^c .

For $N > c/b - (c-b)/b\alpha\bar{f}$, the relationship between $W^c(s^c)$ and $W^{nc}(s^{nc})$ depends on two countervailing factors, the positive welfare effect of higher abatement when an IEA must be enforced (because $s^c > s^{nc}$ from Proposition 3) and the negative welfare effect of the costs of this enforcement. For $N \in [c/b - (c-b)/b\alpha\bar{f}, 2c/b - (c-b)/b\alpha\bar{f}]$, the enforcement-cost effect dominates the higher-abatement effect so that aggregate welfare is lower when the equilibrium IEA requires enforcement. However, when N exceeds $2c/b - (c-b)/b\alpha\bar{f}$ the higher-abatement effect dominates the enforcement-cost effect so that aggregate welfare is higher when compliance to an agreement requires costly enforcement than when compliance can be enforced without cost.

5. Concluding Remarks

We have analyzed a game of self-enforcing international environmental agreements when parties to such an agreement finance an independent enforcement body to insure that members comply with their commitments. We have shown that costly enforcement limits the circumstance under which international cooperation to control a transboundary pollutant will increase aggregate welfare. Consequently, the circumstances under which an IEA can be expected to form are limited by costly enforcement. However, when an IEA is expected to form, participation with the agreement will typically be greater than when an IEA does not require costly enforcement. Hence, costly enforcement is associated with higher international environmental quality. In fact, under some circumstances, costly enforcement of an IEA is associated with higher aggregate welfare—not for the participants with an IEA, however, but for the countries that choose to free-ride on the agreement.

Our results have important implications for multilateral management of environmental externalities. By assuming away enforcement problems related to IEAs, the scope of mutually beneficial agreements between countries will be artificially enlarged and the minimum required coalition of countries will be artificially reduced. In other words, for some international environmental problems, once enforcement costs are included, IEAs will either require more members before coming into effect or may not be worthwhile at all. Further, the increased participation requirement of IEAs with enforcement costs may pose an additional problem for multilateral cooperation. The formation of an IEA is largely a problem of coordination among the countries involved. Although the simple model proposed in this paper assumes countries can perfectly coordinate their actions, in reality coordination problems typically increase when more countries need to be involved. Therefore, the increased membership requirement resulting from

positive enforcement costs may present an additional coordination problem that could jeopardize a welfare-enhancing IEA.

Additionally, when IEAs require costly enforcement, the benefits to nonparticipation free-riding are augmented. Nonmembers escape both the cost of providing the public good and the additional cost of financing enforcement of cooperation. If countries involved in forming an IEA have a strong aversion to inequity, the large benefits captured by the free-riders may prevent the agreement from materializing. Greater payoff inequity may motivate countries to sacrifice individual gains to prevent a self-enforcing agreement from forming in order to block potential free-riders.

A logical next step in analyzing how costly enforcement and free-rider incentives affect the stability of international environmental agreements is to observe how people actually play these games. It is well known that insights derived from theory are limited in that they abstract from a number of other potential influences on behavior. The coordination and inequity problems previously described are just two examples. Jason Shogren (2006) argues for using economics experiments to analyze strategic interactions among players involved in forming self-enforcing agreements. Conducting controlled experiments may provide useful empirical evidence about the performance of these agreements.

Finally, although the model developed in this paper offers new and interesting insights by introducing costly enforcement into the standard IEA game, it could easily be extended to include more complicated features. For example, we assume throughout that the auditing of a party's abatement choice is perfectly accurate. An interesting extension would be to allow errors in the monitoring technology of the third party enforcer. Additionally, the payoff functions could be constructed to better reflect the real heterogeneity of countries involved in a particular

environmental externality. Obviously, there are a host of other extensions that can and should be addressed to gain a more complete picture of how costly enforcement affects voluntary coalition formation to protect the international environment.

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