The Problem of Maintaining Compliance within Stable Coalitions: Experimental Evidence

David M. McEvoy*
Department of Economics
Appalachian State University

James J. Murphy
Department of Economics
University of Alaska Anchorage

John M. Spraggon
Department of Resource Economics
University of Massachusetts, Amherst

John K. Stranlund
Department of Resource Economics
University of Massachusetts, Amherst

Acknowledgements: Funding for this project was provided from the Center for Public Policy and Administration, University of Massachusetts, Amherst. The authors would like to thank Emily Caffrey and Glenn Caffrey for their help with designing and programming the experimental software for this research. The authors also gratefully acknowledge the helpful comments of Erin Baker and David Dickinson.

* Correspondence to: David M. McEvoy, Economics Department, Appalachian State University, Raley Hall, 416 Howard Street, ASU Box 32051, Boone NC 28608. Phone: 828-262-6126. Email: mcevoydm@appstate.edu.

1. Introduction

The analysis of stable coalitions is important in many contexts including the formation of cartels (D'Aspremont et al. 1983; Diamantoudi 2005), international environmental agreements (Carraro and Siniscalco 1993; Barrett 1994; Kolstad 2007), voluntary agreements with industries (Dawson and Segerson 2008), the provision of threshold public goods (Van de Kragt 1983; Dawes et al. 1986; Marks and Croson 1998) and industry mergers (Vasconcelos 2006). Although many definitions of coalitional stability exist, the concept initially proposed by D'Aspremont et al. (1983) is frequently adopted. According to D'Aspremont et al. (1983), a coalition is considered stable if no existing member wishes to leave (*internal stability*) and no non-member wishes to join (*external stability*).[1] With identical agents, these two conditions ensure that a stable coalition is unique in size, consisting of the minimum number of members such that each are better off than in the absence of any cooperation. In other words, a stable coalition is the minimum sized profitable coalition. Most economic analyses of these types of coalitions are concerned primarily with individual agents' incentives to participate in, or defect from, a group of cooperating members. As a result, the term 'stable' is somewhat narrow as it refers exclusively to defining the number of members in a coalition, not with their decisions to cooperate after joining.

Without enforcement, however, individuals may first join a coalition to make certain that it satisfies a minimum membership requirement for formation, and then later renege on their commitments in an attempt to free ride off those members that continue to cooperate. For example, nations may become party to an international environmental agreement (e.g., the Kyoto Protocol) with the sole intention of satisfying a minimum membership requirement so that an

[1] These two stability conditions are used to define the *self-enforcing* agreement size within the theoretical literature on international environmental agreements (Barrett 1994; Ulph 2004; Rubio and Santiago 2006, 2007; McGinty 2007).

agreement can enter into force. Later, if compliance is not adequately enforced, nations may find it in their interest to violate the terms of the agreement. In general, inadequate enforcement within coalitions can undermine the objectives of cooperative agreements and even prevent them from forming at all.

Despite the fact that the commitments of coalition members need to be enforced, little attention has been paid to this problem. In fact, most authors who examine stable coalitions simply assume that their members will comply fully with the terms of a cooperative agreement (e.g. D'Aspremont et al. 1983; Carraro and Siniscalco 1993; Barrett 1994; Kolstad 2007; Dawson and Segerson 2008). In contrast, this study evaluates the performance of coalitions in which all members have the opportunity to violate their commitments and, consequently, to fund a third-party enforcer to maintain compliance. Our study consists of a theoretical analysis of the impact of member-financed enforcement on the size of stable coalitions and their provision of a public good, as well as laboratory experiments to test the main hypotheses of the theoretical model.

Our theoretical model suggests that member-financed enforcement of compliance within coalitions can lead to greater participation and greater provision of a public good than when compliance is assured without cost. This is intuitive because more cooperation is necessary to offset the additional costs of enforcement to make a coalition profitable. To test this theoretical result we conducted a series of experiments that utilize a threshold public good framework similar to those of Van de Kragt et al. (1983), Dawes et al. (1986), Bagnoli and McKee (1991), and Marks and Croson (1999), but with the added compliance and enforcement dimensions. However, our experimental results flatly reject the hypothesis that member-financed enforcement within stable coalitions leads to greater provision of a public good. Relative to the theoretical predictions, as well as to baseline experiments that did not allow subjects the opportunity to be noncompliant, requiring member-financed enforcement actually decreased the average provision of the public good.

Our experimental design allows us to explain the poor performance of stable coalitions with member-financed enforcement in terms of the two factors that change when giving coalition members the opportunity to violate their commitments while requiring them to finance an enforcer to maintain compliance. The first is the compliance decision itself and the second is the theoretical outcome that the individual cost of financing enforcement leads to a higher participation threshold if coalitions with member-financed enforcement are to form. We demonstrate that both factors contributed to the poor showing of stable coalitions with member-financed enforcement. Like other authors (Van de Kragt et al. 1983; Dawes et al. 1986; Suleimen and Rapoport 1992; Rapoport and Suleimen 1993; Cadsby and Maynes 1999) we find that increasing the participation threshold lowered the average provision of a public good because coalitions formed less frequently. Moreover, even though we structured the compliance incentives so that each member of a coalition had the financial motivation to comply, a significant number did not.

Because theoretically stable coalitions with member-financed enforcement performed so poorly, we conducted another set of experiments with which we abandoned the restrictive internal and external stability requirements of stable coalitions and examined the performance of a coalition that was costly to enforce, but required full participation to form. This requirement did not change average compliance rates within coalitions, but it significantly increased both the frequency of coalition formation and the overall provision of the public good. Our results suggest important lessons for the determination of threshold rules for coalition formation and for enforcing compliance within coalitions. Improving coalition formation and compliance within coalitions requires a higher participation threshold, perhaps full participation, and more stringent enforcement than suggested by theory.

2. Stable coalitions to provide a public good

In this section we present a model of the formation of coalitions to provide a public good that form the basis for our experiments. In particular we derive equilibrium levels of participation in these coalitions when they require member-financed enforcement and when they do not. Comparing these participation levels provides the main hypothesis of this paper: member-financed enforcement of compliance within stable coalitions leads to greater participation than when compliance is assured without cost. Since our theoretical development and experiments have individuals deciding whether to provide a single unit of a public good, increased participation in coalitions also implies increased provision of the good.

2.1 Stable coalitions without the need for costly enforcement

Consider *n* homogeneous players with payoff functions

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

where q_i is equal to one if player *i* contributes to the public good and is zero if she does not, q_{-i} is the sum of the contributions by all other players, *b* is the constant marginal benefit of public good contributions, *c* is the cost of contributing to the public good, and *A* is a positive constant. The structure of the players' interactions is an *n*-player prisoners' dilemma, requiring $b < c$ and $nb > c$. That is, all players have a dominant strategy to not contribute to the public good in a noncooperative Nash equilibrium, but their joint payoffs will be maximized when they all contribute. Thus, the players have an incentive to form a cooperative agreement to provide the good.

Suppose at first that compliance with such an agreement is assured without cost. Following Ulph (2004) and Kolstad (2007), we model coalition formation as a two-stage game. In the first stage, each player decides whether or not to join a coalition to provide the public good. We deviate slightly from the coalition models of Ulph and Kolstad by having each player make this decision sequentially. When a player makes a choice whether or not to join a coalition, she knows all of the choices of those who decided before her. This type of sequential decision-making better represents the participation process in many voluntary coalitions (e.g., international environmental agreements). We will demonstrate shortly that this feature does not change the equilibrium coalition structure from the traditional simultaneous decision games.

In the second stage, all players decide whether to contribute their unit of the good. The players that do not join the coalition in the first stage maximize their individual payoffs by not contributing to the public good in the second. Those that do join in the first stage commit to decisions in the second stage that maximize the joint payoffs of the coalition members, given that the non-members will not contribute.

The members of a coalition commit to contributing to the public good in the second stage as long as each of them is at least as well off with all members contributing as they would be if no player contributed to the public good. That is, a coalition must be profitable for its members. Let s denote the number of members of a coalition who all agree to contribute to the public good; let $\pi^{m}(s)$ denote the payoff of each of the coalition members if they decide to contribute to the public good, and let $\pi^{nm}(s)$ denote the payoff of each of the non-members. (The superscript *m* signals that the player in question is a member of the coalition, while the superscript *nm* signals that the player is not a member of the coalition). From [1], the payoff functions for each coalition member and for each non-member are:

$$\pi^{m}(s) = A + bs - c;$$

$$\pi^{nm}(s) = A + bs. \qquad [2]$$

Since $b < c$, $nb > c$, and $\pi^{m}(s)$ is increasing in *s*, there exist coalition sizes that are strictly greater than one and weakly less than *n* that are profitable. The smallest of these profitable coalitions is

$$s^{nc} = \min s \mid \pi^{m}(s) \geq \pi^{nm}(0) = \min s \mid s \geq c/b. \qquad [3]$$

Throughout, the superscript *nc* denotes values when the decisions of the coalition members do not require costly enforcement. If the number of joiners in the first stage of the game is greater than or equal to s^{nc}, they will agree that each of them will contribute to the public good in the second stage. If the number of joiners in the first stage is less than s^{nc}, they will agree to not contribute to the public good in the second stage because it would be unprofitable to do so.

The equilibrium coalition size in this game is called a self-enforcing coalition in the theoretical literature on cartels and international environmental agreements (e.g., D'Aspremont et al. 1983; Barrett 1994). At the self-enforcing coalition size no member of the coalition wants to leave the coalition (the coalition is internally stable) and no non-member wants to join the coalition (the coalition is externally stable). The only internally and externally stable coalition size is the smallest profitable coalition, s^{nc}. To see why, note that for a coalition size $s > s^{nc}$ any member could leave the coalition and the remaining members would still find it profitable to contribute to the public good. Using the payoff functions [2], the defector's payoff would be $\pi^{nm}(s-1) = A + b(s-1)$, which is greater than its payoff if it stayed in the coalition,

$\pi^m(s) = A + bs - c$, by the amount $c - b > 0$. Since individuals are motivated to leave a coalition of any size $s > s^{nc}$, these coalitions are not internally stable. On the other hand, a coalition of size $s = s^{nc}$ is internally stable, because if one member leaves the coalition it is no longer profitable for the remaining members to contribute to the public good. Since no individual would provide the public good in this case, a defector's payoff would simply be $\pi^{nm}(0) = A$, which is weakly less than its payoff if it stayed in the coalition, $\pi^m(s^{nc}) = A + bs^{nc} - c$. Finally, a coalition with s^{nc} members is externally stable because no non-member would want to join. To see why calculate $\pi^m(s^{nc}+1) - \pi^{nm}(s^{nc}) = b - c < 0$, which indicates that an individual who joins the smallest profitable coalition is worse off than staying out of the coalition.

Demonstrating that s^{nc} is the self-enforcing coalition size is normally accomplished under the assumption that players make their decisions to join or not join a coalition simultaneously. We now demonstrate that the subgame-perfect equilibrium in a sequential decision making game is the self-enforcing coalition size, because, in our experiments, the order in which subjects make their participation decisions is endogenous. That is, players decide when, relative to others, to join or not join a coalition. Given identical players we cannot predict the order in which each player will move. Therefore, we assume that the order of players' decisions in this game is determined randomly by nature. Given the order of moves, we are able to predict the order of join/not join decisions.

Define a *critical* player as one that is required to join a coalition if that coalition is to meet the profitability requirement [3]. Thus, a player is critical if and only if $n - s^{nc}$ players have already opted out of the coalition. Moreover, a critical player would always prefer to join a coalition, because not joining would prevent a profitable coalition from forming and all players prefer to be part of a profitable coalition than have no coalition form at all (i.e., $\pi^m(s^{nc}) \geq \pi^{nm}(0)$). Since all critical players will join a coalition, a noncritical player would never join, because it is always more profitable to stay out of a profitable coalition (i.e., $\pi^m(s^{nc}) < \pi^{nm}(s^{nc})$ from [2]). Therefore, in equilibrium there will be s^{nc} coalition members and $n - s^{nc}$ non-members. Since non-members earn strictly higher payoffs than members, the first $n - s^{nc}$ players to choose will decide to opt out of the coalition, and the last s^{nc} players to decide will join. In the second stage of the game, all members of the coalition make their contributions to the public good, while the remaining players contribute nothing. [2]

2.2 Stable coalitions with member-financed enforcement

We now give coalition members the opportunity to violate their commitment to provide the public good. To counteract this, coalition members fund an independent enforcer who monitors the behavior of coalition members and applies a sanction when one is found not contributing to the public good. Following McEvoy and Stranlund (2009), this game is played in four stages. In the first stage, players decide sequentially whether to join a cooperative coalition. In the second stage, members of the coalition jointly agree on whether to contribute to the public good. If they do agree to contribute to the public good, each member is required to contribute funds to the independent enforcer. If the coalition members decide not to contribute to the public good in

[2] Although our experiments have an endogenous sequencing of participation decisions, we are focused on aggregate measures of coalition formation and public good provision. Others have examined the sequencing of participation decisions. Erev and Rapoport (1990) and Cooper and Stockman (2002) derive similar equilibria to ours in threshold public good games in which players are assigned the order in which they must decide whether to contribute to a public good. A threshold is specified, which is referred to as the "minimum contributing set" (MCS). The subgame-perfect Nash equilibrium in these games is that the first n – *MCS* players choose not to contribute to the public good, while the remaining players choose to contribute. Note that the decision order is exogenous in these games, while it is endogenous in our experiments. McEvoy (2009) explores the endogenous order of decisions using a subset of the data used in this experiment and finds that the timing of participation decisions is sensitive to the threshold in these games. In particular, he finds that subjects are more likely to rush to opt out of voluntary coalitions when the free-riding payoff is larger.

stage 2, they do not fund the enforcer and the game ends with no contributions to the public good. If the coalition members agree to contribute to the public good in stage 2, they move onto stage 3 in which all players make their contribution decisions independently. Finally, in stage 4 the enforcer randomly audits the coalition members and applies a sanction when a member is found not contributing to the public good. Because the game is solved by backward induction we begin by describing the last stage.

2.2.1 Enforcement stage

If the game reaches this stage, a coalition of s members has formed, each member has agreed to contribute to the public good, each member has provided x dollars to fund the enforcer, and all players have made their contributions. In this stage, the enforcer randomly audits the decisions of the coalition members with a probability that is an increasing function of the amount of funding the members provide. Each additional dollar of funding allows the number of random audits to increase by $\alpha > 0$. Thus, if s coalition members each provide x to fund the enforcer, then the number of random audits conducted is $sx\alpha$ and the probability that any member is audited is

$$p = sx\alpha / s = x\alpha . \qquad [4]$$

A member that is revealed to be noncompliant by the enforcer incurs a known exogenous sanction of f.

2.2.2 Contributions stage

At this point in the game the coalition members have agreed to contribute to the public good and have funded the enforcer. In this stage both coalition members and non-members independently choose whether to contribute to the public good. All non-members will chose to not contribute, but coalition members make this decision by comparing the expected cost of not complying with their agreement and the benefit of noncompliance.

Assume that the coalition members are risk neutral and that they comply if they are at least indifferent between compliance and noncompliance. Then, given a coalition of *s* members, in the contributions stage an individual member will comply if its expected payoff from doing so is not less than its expected payoff from noncompliance. Given the probability of an audit *p* and the sanction *f*, a compliant coalition member's payoff is $\pi^{m}(s)-x$, while a noncompliant member's expected payoff is $\pi^{nm}(s-1)-x-pf$, where $\pi^{m}(s)$ and $\pi^{nm}(s-1)$ are defined by [2]. Since the individuals are identical and coalition members face the same enforcement parameters, all members either comply or all do not. Therefore, each coalition member complies with the terms of the agreement if and only if

$$[\pi^{m}(s)-x]-[\pi^{nm}(s-1)-x-pf]=pf-(c-b)\geq 0\,; \qquad [5]$$

that is, each coalition member complies as long as the expected penalty *pf* is not less than the gain from noncompliance $c-b$. Clearly, this is a necessary condition if a coalition of individuals who contribute to the public good is to form. Therefore, we will assume $pf\geq(c-b)$ from here on.

2.2.3 Agreement stage

In this stage the coalition members agree to contribute to the public good and to fund the enforcer provided that these decisions maximize their joint payoffs. Each member's contribution to the enforcer, *x*, is endogenous so we determine this value first. If a coalition of contributors is to form, each member would like to contribute as little as possible while providing the enforcer with sufficient resources to maintain compliance within the coalition. This requires a payment x so that $pf \geq c - b$ binds. Since $p = x\alpha$ from [4], the contribution to the enforcer that is required of each coalition member is

$$x = (c - b) / \alpha f. \qquad [6]$$

Coalition members will fund the enforcer and jointly agree to contribute to the public good only if they will be at least as well off as without the coalition. Again, contributing to the public good must be profitable for the members of the coalition. Given a coalition of s members that each earn $\pi^m(s) - x \; = A + bs - c - x$ if they contribute to the public good, and a player's payoff in the absence of a coalition, A, the minimum size profitable coalition is the smallest s such that $A + bs - c - x \geq A$. Substituting for x from [6] and rearranging terms yields $s \geq c / b + (c - b) / b\alpha f$. Thus, the minimum sized profitable coalition when members bear the cost of enforcing compliance within the coalition is

$$s^c = \min s \mid s \geq c / b + (c - b) / b\alpha f \;, \qquad [7]$$

where the superscript c indicates that enforcing compliance is costly for the members. If $s \geq s^c$ players join a coalition in the first stage of the game (the membership stage), they will agree to contribute to the public good in the second stage (the agreement stage). Furthermore, each member pays x from [6] to the enforcer in this stage and will comply with the terms of the agreement in stage three (the contributions stage). On the other hand, if $s < s^c$ from the first stage, the coalition members maximize their joint payoffs by deciding not to contribute to the public good and they do not fund the enforcer. Thus, if $s < s^c$ in the membership stage a coalition of contributors to the public good does not form and the game concludes.

2.2.4 Membership stage

As in the coalition formation game without the need for costly enforcement, the equilibrium coalition size when member-financed enforcement is required is the smallest profitable coalition, s^c defined by [7]. In contrast to the game in which compliance is assured, profitable coalitions may not exist when enforcement is required. Profitable coalitions exist when enforcement is required if and only if $n \geq s^c$, or using [7], $n \geq c/b + (c-b)/b\alpha f$. While we've assumed that $n > c/b$, there is nothing in the model that guarantees $n \geq c/b + (c-b)/b\alpha f$. Thus, a large benefit from noncompliance $c-b$, low monitoring productivity α, or a low sanction *f*, can prevent a coalition from forming. However, if $n \geq s^c$, then s^c players will join a coalition in the first stage of the game. They will agree to contribute to the public good and fund the enforcer in the second. In the third stage they all contribute to the public good, while the non-members do not. In the fourth stage the enforcer randomly audits the decisions of the coalition members but finds no violations. This is the subgame perfect equilibrium of the coalition formation game when cooperation requires member-financed enforcement and enforcement costs do not prevent coalitions from forming.

2.3 Enforcement costs and the size of stable coalitions

When a coalition that requires member-financed enforcement forms, it is likely to have more members and provide more of the public good than when compliance within a coalition is enforced without cost. To see why, recall from [3] that the equilibrium coalition size when costly enforcement is not required, s^{nc}, is the least *s* for which $s \geq c/b$. When a coalition requires costly enforcement and this requirement this does not prevent a coalition from forming, from [7] the equilibrium coalition size, s^c, is the least s for which $s \geq c/b + (c-b)/b\alpha f$. Since $(c-b)/b\alpha f > 0$, $s^c \geq s^{nc}$. The reason for this result is that funding the enforcer is an additional cost of joining a coalition to provide a public good; hence, a greater amount of the public good needs to be provided to make the coalition profitable. When each individual has one unit of the public good to contribute, this requires greater participation in the coalition. The experiments described in the next section were designed to test this hypothesis.

3. Experimental design

All of the experimental sessions were held in a computer lab at our university **<to be included>** using undergraduate and graduate students recruited from the general student population. Each session, 20 subjects were brought into the computer lab, seated and paid five dollars for arriving on time. The instructions were read aloud by the moderator. After answering a series of practice questions the subjects began the experiment.[3] At the start of each period, the 20 subjects were randomly assigned to one of two 10-person groups such that the same ten people were never together in the same group more than once. The random assignment of groups was done to mitigate potential problems of reputation that can occur when the same subjects interact in a repeated setting (Andreoni and Croson 2002). Two 13-period sessions with two groups per session were conducted for each treatment, resulting in 52 group level observations (4 groups x 13 periods) and 520 individual level observations per treatment. Earnings were reported in experimental dollars, and ten experimental dollars exchanged for one US dollar. Earnings were paid in cash at the end of each experiment. On average the subjects earned \$23, ranging from \$15 to \$33 (σ = \$4.33).

[3] The complete experiment instructions are available at the lead author's website **<to be included> <We have included the instructions with this submission as a reviewers' appendix>**

To avoid potential biases subjects may have regarding the provision of public goods, and to generalize our results to other applications of stable coalitions, we chose a neutral frame for the context and language of the experiments. Specifically, rather than having subjects decide whether to join a coalition with the others to provide a public good, they chose either to *agree to produce* one unit of an unspecified product, or *not agree to produce* the unit. An agreement was said to 'form' if enough subjects agreed to produce such that the stated participation threshold was met.

One of the unique features of our design is that while subjects were making their decisions, they were provided with real-time information about the decisions of the other nine subjects in the group.[4] Specifically, they were informed about the number of other subjects that already agreed to produce, the number of other subjects that did not agree to produce and the number of other subjects that had not yet made a decision. The real-time information feature was included for two reasons. First, the information was provided to minimize potential coordination problems that typically arise when decisions are made simultaneously.[5] Second, it best represents the timing and information of participation decisions in real cooperative coalitions (e.g., international treaties) in which agents decide when, relative to others, to join or not join. To cap the length of each period, subjects had 60 seconds to make their decisions. If a subject failed to decide before the time was up, she chose *not agree to produce* by default. Subjects were not allowed to communicate with each other in any of the treatments.

[4] Similar real-time mechanisms have been used in voluntary contribution mechanisms (Kurzban et al. 2001) and threshold public good experiments (Goren, Kurzban and Rapoport 2003; Goren, Rapoport and Kurzban 2004; McEvoy 2009).

[5] The experiments are designed with additional measures to further minimize coordination failures. Whenever a player makes a decision all players in the group see a quick flash of yellow on the screen encouraging them to pause to observe how the group's decisions have changed. Further, if two or more decisions are made in the same second, only one decision gets recorded and the remaining players receive notification that their decisions were not recorded. Finally, if a decision is made in the last five seconds and one or more players have yet to make a decision, five more seconds are added to the clock. In our experiments, 355 of 2080 decisions were recorded when this extra time feature was triggered.

3.1 Costless enforcement-low

Our first treatment is of the model from section 2.1 in which compliance within a cooperative coalition is costless to enforce. For reasons that will become obvious shortly, we chose the individual cost of producing the good to be low (i.e., low *c*) and called this treatment *costless enforcement-low*. It provides a baseline to judge the effects of adding member-financed enforcement of compliance to the coalition formation game.

In each period, the only decision a subject had to make was whether to *agree to produce* or *not agree to produce* the unit. Those who chose *agree to produce* did not have the opportunity to renege on this decision later. We chose parameter values of $n = 10$, $A = 8$, $b = 3$ and $c = 7$ for equation [1], and derived the theoretically stable coalition size of $s^{nc} = 3$ using equation [3]. Thus, the participation threshold for *costless enforcement-low* was set at 3 members. If at least three of the ten group members agreed to produce, then the agreement formed and those individuals that agreed to produce automatically produced the product and earned $\pi^{m}(s)$ using [2]. If less than three group members agreed to produce, the entire group did not produce and each subject earned eight experimental dollars, $\pi^{nm}(0) = 8$. Those subjects that chose *not agree to produce*, did not produce the product regardless of whether a coalition formed and earned $\pi^{nm}(s)$ according to [2].

Table 1 shows the matrix of payoff possibilities the subjects were given for each period of the experiment, the form of which is similar to that used by Rapoport and Eshed-Levy (1989). The boxes marked with an X indicate outcomes that are not possible because the participation threshold would not be met in these circumstances. To see why, note that the top row of the earnings table corresponds to the number of other subjects (ranging from 0 to 9) producing the good. However, production can only occur if at least three members of the group agree to produce. Therefore, under no circumstances could only one or two members of the group produce the good, hence the X's. All elements of the earnings table were clearly explained to the subjects before the experiment began.

[Insert Table 1 here]

3.2 Costly enforcement

Our second treatment was designed to incorporate the elements of the model of member-financed enforcement of compliance within a stable coalition that we presented in section 2.2. We called this treatment *costly enforcement*. Relative to the *costless enforcement-low* treatment, we added two stages to the *costly enforcement* treatment. Provided that enough subjects agreed to produce to meet the participation threshold, those who agreed to produce then had to decide whether to abide by this decision and actually produce. These compliance decisions were made simultaneously and without real-time feedback. After the coalition members made these decisions their choices were randomly audited and detected cases of noncompliance were sanctioned.

The values of n, A, b and c were set exactly as in the *costless enforcement-low* treatment. In addition, we chose an audit probability of $p = 0.8$ and a penalty for noncompliance of $f = 6$ as the enforcement parameters applied to the members of a coalition. Note that the expected penalty for noncompliance was $pf = 4.8$. The subjects were told the audit probability and sanction at the beginning of each period, but they were not told the expected penalty. Because the benefit from noncompliance was $c – b = 4.0$, the expected penalty was more than sufficient to induce compliance by risk-neutral agents. (Refer to the condition for compliance provided by equation [5]). The cost of enforcing compliance with the agreement for each member of a coalition was set at $x = 8.08$. (Using equation [6], this implies a marginal productivity of resources devoted to monitoring of $\alpha = 0.619$). We did not have members of a coalition actually pay *x*; rather it was implicit in the calculation of their earnings.

Using [7], the stable coalition size in this treatment is six members, so the subjects were told that the participation threshold for an agreement to form was six subjects. If less than six subjects agreed to produce, the entire group did not produce and each subject earned eight experimental dollars, $\pi^{nm}(0) = 8$. If six or more subjects agreed to produce, individual earnings for each possible scenario in the *costly enforcement* treatment are provided in Table 2.[6] The subjects were given this table at the start of each period of this treatment. The second row in the table shows the potential earnings for a coalition member that complies with the agreement by choosing to produce. The third and fourth rows show earnings for a noncompliant coalition member, one who agreed to produce then chose not to. The third row gives the earnings of the subject when it is audited while the earnings in the fourth row assume the subject was not audited. The difference in earnings between these two rows is simply the $f = 6$ penalty for noncompliance. The final row lists the potential earnings for a subject that does not join the coalition and, therefore, does not produce.

[Insert Table 2 here]

3.3 Costless enforcement-high

The third treatment is the same as the *costless enforcement-low* treatment except that the cost of production was increased to $c = 15.08$. This higher production cost is denoted as c_H, and we refer to this treatment as *costless enforcement-high*. This higher cost parameter was chosen so that the

[6] The values in Table 2 are calculated earnings rounded to the nearest whole number, except for negative earnings which are set at zero to make sure that subjects did not lose money in the experiments.

increase in production cost between the *costless enforcement-low* treatment and the *costless enforcement-high* treatment is equivalent to the individual cost of enforcing compliance in the *costly enforcement* treatment; that is, $x = c_H - c = 8.08.$ Because of the higher production cost, the stable coalition size for the *costless enforcement-high* treatment is 6 members, the same stable coalition size and participation threshold as for the *costly enforcement* treatment. Table 3 is the payoff table we provided each subject in this treatment. Note that it takes a similar form to the earnings table for the *costless enforcement-low* treatment, except that more outcomes are not possible (those marked by an X) because of the higher participation threshold.

[Insert Table 3 here]

Structuring the *costless enforcement-high* treatment so that the participation costs and the participation threshold are equivalent to that of the *costly enforcement* treatment allows us to isolate two effects of the compliance problem in stable coalitions. The first effect is the compliance decision itself while the second is the higher participation threshold that is associated with the additional costs of enforcing compliance within stable coalitions. Since the predicted participation levels are the same in the *costless enforcement-high* and the *costly enforcement* treatments, we can isolate the impact of the compliance decision on the performance of cooperative coalitions by comparing the results from these two treatments. Moreover, by comparing the results of the *costless enforcement-high* treatment with the *costless enforcement-low* treatment we can separate the effect of the higher participation cost and higher participation threshold from the compliance decision effect.

3.4 Costly enforcement-full

In this final treatment, we abandoned the internal and external stability conditions for determining the participation threshold and tested the performance of a coalition that requires member-financed enforcement, but also requires full participation. We call this treatment *costly enforcement-full*. For this treatment we maintained the same parameter choices as in the *costly enforcement* treatment, but we raised the participation threshold from six to ten subjects. As with the *costly enforcement* treatment, if the ten-subject threshold was satisfied, each member then had to decide whether to comply by producing the good. After these decisions, the coalition members were monitored and detected cases of noncompliance were sanctioned. The earnings table we provided the subjects in this treatment is the same as the one provided for the *costly enforcement* treatment (Table 2). A summary of our experimental design is provided in Table 4.

[Insert Table 4 here]

4. Results

4.1 Group-level analysis

Much of our analysis of the experimental data is based on the summary statistics contained in Table 5 and the regression results in Table 6. Table 5 contains the average provision of the public good, the percentage of times a coalition formed, the average number of members of coalitions, as well as the average compliance rates by members of coalitions under *costly enforcement* and *costly enforcement-full*. Drawing from our results in section 2, our predictions for each treatment are that coalitions form in every period, the number of coalition members and the provision of the public good equal the participation threshold, and that coalition members are always compliant under *costly enforcement* and *costly enforcement-full*. The results for three regressions are contained in Table 6. From left to right in the table, the dependent variables are the provision of the public good (ranging from zero to ten), whether a coalition forms (equaling one when a coalition forms and zero otherwise) and the number of members when coalitions form (ranging from three to ten). The first and last are linear regressions while the second is a logit regression.[7]

For each regression we included treatment dummies (the *costless enforcement-low* treatment dummy is suppressed for each regression), a session dummy (zero for the first session, one for the second) and two period dummies for the middle periods (5 – 9) and the later periods (10 – 13) which are interpreted relative to the beginning four periods. Recall that for each of the four treatments we generated 52 group-level observations over two sessions. The group composition was reshuffled at the beginning of each period in order to create 52 unique groups which are treated as independent observations in our regression (i.e., the same group does not make repeated decisions). We acknowledge that although each of the groups is technically different, individual subjects are making repeated decisions and repeatedly interacting with other subjects and therefore our assumption of independent observations is not trivial. That said, we purposely designed the experiment with the *strangers* feature so that subjects could play a series of one-shot games which is more consistent with the theoretical model in section 2 compared to an environment in which subjects make repeated interactions within the same group. We examine the repeated nature of the decision making process through the dummy variables for periods and we include a session dummy in order to control for any possible session effect.

Recall the main hypothesis from our theoretical model of section 2: relative to stable coalitions that do not require enforcement, the possibility of noncompliance within stable

[7] We also generated results using ordered probit models in place of the two linear models. Since our qualitative results remained unchanged between the two specifications, we report the linear results so that we can easily compare the conditional means from the linear regressions with our theoretical predictions.

coalitions in tandem with member-financed enforcement to maintain full compliance results in greater participation in coalitions and, consequently, higher provision of the public good. This hypothesis is clearly rejected by our experimental data. Although the average number of members when coalitions formed was significantly higher under *costly enforcement* than under *costless enforcement-low* (β_1^M = 2.38, $p < 0.01$), the average provision of the public good was significantly less under *costly enforcement* (β_1^{PG} = -1.63, $p < 0.01$). The drop in contributions to the public good is due to the significant decrease in the likelihood of a coalition forming under *costly enforcement* (β_1^F = -3.16, $p < 0.01$), and the significant percentage of noncompliance under this treatment (31.6% noncompliance).

The results from Tables 5 and 6 indicate that the subjects in the *costly enforcement* treatment did not come close to meeting theoretical expectations. Although when coalitions formed there were more members on average than the six predicted ($\beta_1^M + \beta_0^M = 6.67$, $p < 0.01$), there was a substantial amount of noncompliance in these coalitions.[8] Moreover, coalitions formed only 53.8% of the time. The high rates of noncompliance and the low frequency of coalition formation produced an average provision of the public good in this treatment of only 3.09 units ($\beta_1^{PG} + \beta_0^{PG}$), which is significantly below the 6 units predicted ($p < 0.01$).

Recall that we conducted the *costless enforcement-high* experiment to separate the effect of a higher participation cost and higher participation threshold for coalitions that require member-financed enforcement from the effect of giving coalition members the opportunity to violate cooperative agreements. Thus, we can explain the poor performance of the *costly enforcement* treatment by examining the relative importance of these effects.

[8] Throughout this analysis we compare the conditional mean from the regression results with the hypothesized mean using Wald chi-square tests.

When coalitions formed under *costless enforcement-high*, the average number of group members was not statistically different from the theoretical prediction of six ($\beta_2^M + \beta_0^M$ = 6.21, *p* = 0.24). However, coalitions formed less frequently under this treatment than predicted and in comparison with the *costless enforcement-low* treatment (β_2^F = -2.83, *p* < 0.01). This result is consistent with several other threshold public goods studies that found that raising the participation threshold reduced the percentage of trials in which a public good is provided (Van de Kragt et al. 1983; Dawes et al. 1986; Suleimen and Rapoport 1992; Rapoport and Suleimen 1993; Cadsby and Maynes 1999). Because coalitions formed less frequently under *costless enforcement-high*, the average provision of the public good was significantly less than the predicted 6 units ($\beta_2^{PG} + \beta_0^{PG}$ = 4.43, *p* < 0.01) and statistically indistinguishable from the average provision of the good under the *costless enforcement-low* treatment (β_2^{PG} = -0.29, *p* = 0.55). Thus the higher participation cost and participation threshold had no effect on the average provision of the public good.

Now let us compare the outcomes of *costless enforcement-high* to *costly enforcement*. Coalitions were equally likely to form under these two treatments ($Ho: \beta_1^F = \beta_2^F$, *p* = 0.42).[9] Although coalitions tended to have more members under *costly enforcement* than under *costless enforcement-high* ($Ho: \beta_1^M = \beta_2^M$, *p* = 0.03), noncompliance under *costly enforcement* more than offset this higher membership so that the average provision of the public good was significantly higher under *costless enforcement-high* ($Ho: \beta_1^{PG} = \beta_2^{PG}$, *p* < 0.01). Thus, holding the

[9] Participation rates (from Table 5) fell well within the typical 50 – 70% range found in most threshold public goods experiments (Van de Kragt et al. 1983; Dawes et al. 1986; Isaac et al. 1989; Rapoport and Eshed-Levy 1989; Erev and Rapoport 1990; Suleimen and Rapoport 1992; Rapoport and Suleimen 1993; Mysker et al. 1996; Marks and Croson 1998; Marks and Croson 1999). A handful of other studies have found results that do not fall into the 50 – 70% participation range, including Cadsby and Maynes (1999) who found that the public good is provided in only 26% of pooled trials and Bagnoli and Mckee (1991) who found that the public good was provided in 83% of all trials.

participation costs and threshold constant, giving coalition members the opportunity to be noncompliant, but randomly auditing and fining them to maintain compliance, had a significant negative effect on the cooperative provision of the public good.

We are now ready to specify the relative impacts of the higher participation cost and threshold effect and the compliance decision effect on the significant underprovision of the public good under *costly enforcement*. Average provision of the public good under this treatment is 2.91 units below the prediction of 6 units. The higher participation cost and threshold component of these 2.91 units is the difference between the predicted 6 units and average provision under *costless enforcement-high* ($6-\left(\beta_0^{PG}+\beta_2^{PG}\right)$), that is, 1.57 units (about 54% of the total effect). The compliance decision component is the remaining 1.34 units (about 46%). Thus, the poor performance of the *costly enforcement* treatment relative to its theoretical prediction is explained (nearly equally) by both the higher participation cost and threshold effect and the compliance decision effect.

However, relative to the provision of the public good under *costless enforcement-low*, nearly all of the underprovision of the good under *costly enforcement* is due to the compliance effect. Average provision of the public good under *costly enforcement* is 1.63 units below average provision under *costless enforcement-low*. The higher participation cost and threshold component of this is the difference between the average provision of the good under *costless enforcement-low* and average provision under *costless enforcement-high*, that is, only 0.29 units. We have already noted that this difference is not statistically different from zero (p = 0.55). However, the compliance decision effect is the remaining 1.34 units, which is highly significant ($Ho: \beta_1^{PG}=\beta_2^{PG}$, p = 0.01).

Groups under the *costly enforcement-full* treatment fared much better than under the *costly enforcement* treatment. Recall that *costly enforcement-full* is the same as *costly enforcement*, except that instead of setting the participation threshold at the theoretically stable coalition size, we required full participation for a coalition to form. Although the average compliance rate within coalitions under *costly enforcement-full* was similar to that under *costly enforcement* (71.3% vs. 68.4% from Table 5), coalitions were more likely to form under *costly enforcement-full* ($Ho: \beta_1^F = \beta_3^F$, $p < .01$). Consequently, the average provision of the public good was significantly higher under *costly enforcement-full* than under *costly enforcement* ($Ho: \beta_1^{PG} = \beta_3^{PG}$, $p < 0.01$).

To complete this section, we discuss how the results change over the 13 periods of the experiments. Figure 1 shows the time series of average coalition membership and average public good provision over the 13 periods in each treatment. The dark horizontal lines indicate the participation threshold for each treatment. Note that coalition membership is stable over periods for each treatment. This is supported by the insignificant coefficients (at the 0.05 level) for the middle and ending period dummy variables from the third regression in Table 6. We do, however, note a drop in the likelihood of coalitions forming and the average provision of the public good over the duration of the experiments indicated by the two significant coefficients on the period dummies in the first regression in Table 6 and the significant coefficient on the last periods in the second regression.

4.2 Individual-level analysis

Players' average earnings by treatment and decision are reported in Table 7. We report the average expected earnings of noncompliant coalition members (gross earnings minus the 4.8 expected penalty) under these treatments.[10] The low provision of the public good under the *costly enforcement* experiments is reflected in the subjects' earnings. Recall that our model from section 2 predicts that members (non-members) under *costly enforcement*, on average, will earn higher payoffs than members (non-members) under *costless enforcement-low*. In contrast to this prediction we find that, on average, those who joined a coalition (i.e., agreed to produce) under *costless enforcement-low* were better off than those who joined a coalition under *costly enforcement* regardless of whether the coalition members actually complied with the agreement (14.73 vs. 7.67, $p < 0.001$ for compliant coalition members and 14.73 vs. 7.86, $p < 0.001$ for noncompliant members).[11] Compliant coalition members and noncompliant coalition members earned about the same under the *costly enforcement* treatment (7.67 vs. 7.86, $p = 0.81$), and there is no statistical difference (at the 0.05 level) between these earnings for coalition members and the eight experimental dollars each would have earned had no coalition formed in the first place ($p = 0.54$ for compliant members and $p = 0.83$ for noncompliant members). On the other hand, when requiring full participation of the group members for a coalition to form (i.e., *costly enforcement-full*), the average payoffs for coalition members were significantly larger than under *costly enforcement*, regardless of whether members complied (15.46 vs. 7.67, $p < 0.01$ and 13.93 vs. 7.86, $p < 0.01$).

To conclude this section we analyze the individual-level decisions driving the overarching group-level results. For the first column of regression results in Table 8 the

[10] We use expected earnings rather than actual earnings because this is what subjects would likely be using as a basis for making decisions.
[11] The *p*-values reported are derived from pairwise *t*-tests of the average expected earnings between treatments.

dependent variable is the binary decision whether to join a coalition and in the second column the dependent variable is the binary decision whether to comply conditioned on joining a coalition. Both are logit regressions. We include dummy variables for the treatments (*costless enforcement-low* is dropped in the first column and *costly enforcement* is dropped in the second), session and periods and a subject-specific random-effects specification of the error term ($u_{it} = \alpha_i + \varepsilon_{it}$), where α_i captures random effects and ε_{it} is the contemporaneous error term. This specification was chosen in order to control for potentially strong individual effects that can occur when the same subject makes multiple decisions within a treatment.[12]

Consistent with our group-level findings, subjects are more likely to join a coalition when the threshold is increased ($\beta_1^J, \beta_2^J, \beta_3^J > 0$ at the 0.05 level). In support of the theory, subjects are equally likely to join a coalition between *costly enforcement* and *costless enforcement-high* in which the threshold is set at six members for both treatments ($Ho: \beta_1^J = \beta_2^J$, $p = 0.82$). We also see a decrease in the likelihood of a subject joining a coalition in the last periods which is consistent with our finding that coalitions formed less frequently in later periods. Finally, in reference to the results from the second regression in Table 8, subjects are equally likely to comply between the two treatments with member-financed enforcement ($\beta_1^C = 0.18$, $p = 0.62$) and compliance decisions do not change significantly over the periods ($\beta_3^C = -0.36$, $p = 0.13$ and $\beta_4^C = -0.50$, $p = 0.52$).

5. Concluding remarks

We have examined the compliance and enforcement problem in cooperative coalitions to provide a public good. The notion of coalitional stability that we use—that of internal and external

[12] Subject-specific random effects are significant at the 0.01 level for both regressions in Table 8.

stability—has been used in many theoretical contexts including examinations of cartels, international environmental agreements, and voluntary pollution control agreements between sources of pollution and regulators. In most of these applications, however, the rather obvious point that even cooperative arrangements must be enforced has been ignored. We have presented a theoretical model in which members of a coalition to provide a public good finance enforcement of commitments by coalition members. Our main result of this theoretical exercise is that when stable coalitions that require member-financed enforcement form they will have greater participation levels. Consequently, provision of the public good should be higher. The intuition is simple: participation in stable coalitions is higher because the added cost of enforcement must be offset by an increase in public good provision to make a cooperative coalition worthwhile.

Our laboratory test of this hypothesis is definitive—the hypothesis is flatly rejected. In experiments with member-financed enforcement when the participation threshold was set at the theoretically stable coalition size, public good provision was well below the theoretical prediction. Moreover, public good provision was below the levels obtained in a treatment that featured a participation threshold that was set at the stable coalition size, but that did not require enforcement. The lower public good provision occurred because coalitions that require enforcement formed much less frequently, and when they did form there was a significant amount of noncompliance within the coalition, even though the expected penalty was chosen to be greater than the gain from noncompliance.

Relative to stable coalitions that do not require enforcement, two things change when coalition members finance enforcement to counteract the incentive each of them has to violate their commitments. The first is the compliance decision itself and the second is the theoretical outcome that the higher participation cost leads to a higher participation threshold if coalitions with member-financed enforcement are to form. Our experimental design allows us to determine that both the compliance decision effect and the higher participation cost and threshold effect contributed to the poor performance of a theoretically stable coalition with member-financed enforcement.

That both of these components have significant negative impacts are puzzles that require further work to fully understand. Like us, other authors have found that increasing the participation threshold for a contract to provide a public good reduces the frequency of coalition formation and reduces the provision of a public good, but why this occurs is an open question. One possible explanation for this in our experiments is that increasing the participation threshold increases the free-riding payoffs of those who stay out of coalitions. The increased motivation to stay out of stable coalitions and perhaps a motivation to keep individuals from reaping the free-riding benefit may help explain why coalitions form less frequently with higher participation thresholds. This explanation is consistent with our finding that requiring full participation for coalitions to form significantly increased the provision of the public good, because requiring full participation eliminates the possibility of free riding by refusing to join a coalition.

The other puzzle is why there was so much noncompliance in coalitions that required enforcement, even though the expected penalty was chosen to be greater than the gain from noncompliance regardless of the size of the coalition. It is reasonable to expect, however, that more compliance can be induced with more stringent enforcement. Determining whether this should be done with more stringent monitoring or a higher penalty requires a more complete experimental analysis of the effects of monitoring and penalties on coalition formation and their performance. We should note that even if more stringent enforcement can improve the performance of theoretically stable coalitions with member-financed enforcement, our results suggest that it will not overcome the negative impact of the higher participation cost and threshold effect.

Despite these puzzles, our results suggest important lessons for the determination of threshold rules for coalition formation and for enforcing compliance within coalitions. Although theoretically stable coalitions with member-financed enforcement did not perform well, our results, in general, highlight the need for adequate enforcement of voluntary commitments. Further, the results illustrate the importance of jointly considering enforcement mechanisms and participation requirements when considering cooperative coalitions. Improving coalition formation and compliance within coalitions may require higher participation thresholds, perhaps even full participation, and more stringent enforcement than suggested by theory.

References

Andreoni, James and Rachel Croson, 2002. "Partners Versus Strangers: Random Rematching in Public Goods Experiments." Prepared for *Handbook of Experimental Economics Results*, edited by Charles R. Plott and Vernon L. Smith.

Bagnoli, Mark and Michael McKee, 1991. "Voluntary Contributions Games: Efficient Private Provision of Public Goods." *Economic Inquiry* April: 351-366.

Barrett, Scott, 1994. "Self-Enforcing International Environmental Agreements." *Oxford Economic Papers* 46(1): 878-94.

Cadsby, Charles Bram and Elizabeth Maynes, 1999. "Voluntary Provision of Threshold Public Goods with Continuous Contributions: Experimental Evidence." *Journal of Public Economics* 71(1): 53-73.

Carraro, Carlo and Domenico Siniscalco, 1993. "Strategies for the International Protection of the Environment." *Journal of Public Economics* 52(3): 309-328.

Cooper, David J. and Carol Kraker Stockman, 2002. "Learning to Punish: Experimental Evidence from a Sequential Step-Level Public Goods Game." *Experimental Economics* 5(1): 39-51.

D'Aspremont, Claude; Jacquemin, Alexis; Gabszewicz, Jean Jaskold and John A. Weymark, 1983. "On the Stability of Collusive Price Leadership." *The Canadian Journal of Economics* 16(1): 17-25.

Dawes, Robyn M.; Orbell, John M.; Simmons, Randy T. and Alphons J. C. Van De Kragt, 1986. "Organizing Groups for Collective Action." *The American Political Science Review* 80(4): 1171-1185.

Dawson, Na Li and Kathleen Segerson, 2008. "Voluntary Agreements with Industries: Participation Incentives with Industry-wide Targets." *Land Economics* 84(1): 97 – 114.

Diamantoudi, Effrosyni, 2005. "Stable Cartels Revisited." *Economic Theory* 26(4): 907-921.

Dorsey, Robert E., 1992. "The Voluntary Contributions Mechanism with Real Time Revisions." *Public Choice* 73(3): 261-282.

Erev, Ido and Amnon Rapoport, 1990. "Provision of Step-Level Public Goods: The Sequential Contribution Mechanism." *The Journal of Conflict Resolution* 34(3): 401-425.

Goren, Harel; Robert Kurzban and Amnon Rapoport, 2003. "Social Loafing vs. Social Enhancement: Public Goods Provisioning in Real-Time with Irrevocable Commitments." *Organizational Behavior and Human Decision Processes* 90(2):277-290.

Goren, Harel; Amnon Rapoport and Robert Kurzban, 2004. "Revocable Commitments to Public Goods Provision under the Real-Time Protocol of Play." *Journal of Behavioral Decision Making* 17(1):17-37.

Isaac, Mark R.; David Schmidtz and James M. Walker, 1989. "The Assurance Problem in a Laboratory Market." *Public Choice* 62(3): 217-236.

Kolstad, Charles, 2007. "Systematic Uncertainty in Self-Enforcing International Environmental Agreements." *Journal of Environmental Economics and Management* 53(1): 68-79.

Kurzban, Robert; McCabe, Kevin; Smith, Vernon L. and Bart J. Wilson, 2001. "Incremental Commitment and Reciprocity in a Real-Time Public Goods Game." *Personality and Social Psychology Bulletin* 27(12): 1662-1673.

Marks, Melanie and Rachel Croson, 1998. "Alternative Rebate Rules in the Provision of a Threshold Public Good: An Experimental Investigation." *Journal of Public Economics* 67(2): 195-220.

Marks, Melanie and Rachel Croson, 1999. "The Effects of Incomplete Information in a Threshold Public Good Experiment." *Public Choice*. 99(1-2): 103-118.

McEvoy, David and John K. Stranlund, 2009. "Self-Enforcing International Environmental Agreements with Costly Monitoring for Compliance." *Environmental and Resource Economics* 42(4): 491-508

McEvoy, David, 2009. "Not It: Opting out of Voluntary Coalitions that Provide a Public Good." *Public Choice*, available online http://www.springerlink.com/content/y8110w2p598x4pn2/

McGinty, Matthew, 2007. "International Environmental Agreements among Asymmetric Nations." *Oxford Economic Papers* 59(1): 45-62.

Mysker, Michael B.; Olson, Peter K. and Arlington W. Williams, 1996. "The Voluntary Provision of a Threshold Public Good: Further Experimental Results." *Research in Experimental Economics* 6(1): 149-163.

Rapoport, Amnon and D. Eshed-Levy, 1989. "Provision of Step-Level Public Goods: Effects of Greed and Fear of Being Gypped." *Organizational Behavior and Human Decision Processes* 44(3), 325-344.

Rapoport, Amnon and Ramzi Suleiman, 1993. "Incremental Contribution in Step-Level Public Goods Games with Asymmetric Players." *Organizational Behavior and Human Decision Processes* 55(2): 171-194.

Rubio, Santiago J. and Alistair Ulph, 2007. "An Infinite-Horizon Model of Dynamic Membership of International Environmental Agreements." *Journal of Environmental Economics and Management* 54(3): 296 – 310.

Rubio, Santiago J. and Alistair Ulph, 2006. "Self-Enforcing International Environmental Agreements Revisited." *Oxford Economic Papers* 58(2): 233 – 263.

Suleiman, Ramzi and Amnon Rapoport, 1992. "Provision of Step-Level Public Goods with Continuous Contribution." *Journal of Behavioral Decision Making* 5(2): 133-153.

Ulph, Alistair, 2004. "Stable International Environmental Agreements with a Stock Pollutant, Uncertainty and Learning." *Journal of Risk and Uncertainty* 29(1): 53-73.

Van de Kragt, Alphons J. C.; Orbell, John M. and Robyn M. Dawes, 1983. "The Minimal Contributing Set as a Solution to Public Goods Problems." *The American Political Science Review* 77(1): 112-122.

Vasconcelos, Helder, 2006. "Endogenous Mergers in Endogenous Sunk Cost Industries." *International Journal of Industrial Organization* 24(2): 227-250.

Table 1: Earnings table for *costless enforcement-low*

# of OTHER players that PRODUCE	0	1	2	3	4	5	6	7	8	9
YOUR earnings if you produce	X	X	$10	$13	$16	$19	$22	$25	$28	$31
YOUR earnings if you don't produce	$8	X	X	$17	$20	$23	$26	$29	$32	$35

Table 2: Earnings table for *costly enforcement*

	# of OTHER people that PRODUCE	0	1	2	3	4	5	6	7	8	9
YOUR EARNINGS if YOU:	Agree to Produce and Produce	$0	$0	$2	$5	$8	$11	$14	$17	$20	$23
	Agree to Produce and Don't Produce – Audited	$0	$0	$0	$3	$6	$9	$12	$15	$18	$21
	Agree to Produce and Don't Produce – Not Audited	$0	$3	$6	$9	$12	$15	$18	$21	$24	$27
	Don't Agree to Produce	$0	$11	$14	$17	$20	$23	$26	$29	$32	$35

Table 3: Earnings table for *costless enforcement-high*

# of OTHER players that PRODUCE	0	1	2	3	4	5	6	7	8	9
YOUR earnings if you produce	X	X	X	X	X	$11	$14	$17	$20	$23
YOUR earnings if you don't produce	$8	X	X	X	X	X	$26	$29	$32	$35

Table 4: Experimental design summary

Treatment	Stable Coalition Size (Participation Threshold)	Number of Subjects (group size n = 10)	Number of Group Observations (13 periods)	Number of Individual Observations
Costless Enforcement-Low	3	40	52	520
Costly Enforcement	6	40	52	520
Costless Enforcement-High	6	40	52	520
Costly Enforcement-Full	10	40	52	520
Totals		**160**	**208**	**2,080**

Table 5: Coalition formation, compliance, and public good provision

Treatment	Average provision of the public good	Percent of trials in which a coalition formed	Average number of members when coalition formed	Percent compliance
Costless Enforcement-Low (Threshold = 3)	4.10 (0.197) [52]	96.2 (2.69) [52]	4.26 (.160) [50]	---
Costly Enforcement (Threshold = 6)	2.46 (0.342) [52]	53.8 (6.98) [52]	6.68 (.179) [28]	68.4 (3.4) [187]
Costless Enforcement-High (Threshold = 6)	3.81 (0.425) [52]	61.5 (6.81) [52]	6.19 (.095) [32]	---
Costly Enforcement-Full (Threshold = 10)	6.31 (0.382) [52]	88.5 (4.47) [52]	10 --- [46]	71.3 (2.1) [460]

Standard errors in parentheses, number of observations in brackets.

Table 6: Group-level regressions on public good provision, coalition formation and coalition membership

	dependent variables		
	public good provision	whether a coalition forms	number of members when coalitions form
constant	$\beta_0^{PG} = 4.72$ ($p < 0.01$)	$\beta_0^{F} = 3.60$ ($p < 0.01$)	$\beta_0^{M} = 4.29$ ($p < 0.01$)
costly enforcement	$\beta_1^{PG} = -1.63$ ($p < 0.01$)	$\beta_1^{F} = -3.16$ ($p < 0.01$)	$\beta_1^{M} = 2.38$ ($p < 0.01$)
costless enforcement-high	$\beta_2^{PG} = -0.29$ ($p = 0.55$)	$\beta_2^{F} = -2.83$ ($p < 0.01$)	$\beta_2^{M} = 1.92$ ($p < 0.01$)
costly enforcement-full	$\beta_3^{PG} = 2.21$ ($p < 0.01$)	$\beta_3^{F} = -1.20$ ($p = 0.16$)	$\beta_3^{M} = 5.73$ ($p < 0.01$)
session	$\beta_4^{PG} = 0.22$ ($p = 0.52$)	$\beta_4^{F} = 0.51$ ($p = 0.16$)	$\beta_4^{M} = 0.29$ ($p = 0.02$)
periods 5 - 9	$\beta_5^{PG} = -0.84$ ($p = 0.04$)	$\beta_5^{F} = -0.56$ ($p = 0.22$)	$\beta_5^{M} = -0.29$ ($p = 0.06$)
periods 10 - 13	$\beta_6^{PG} = -1.34$ ($p < 0.01$)	$\beta_6^{F} = -1.04$ ($p = 0.03$)	$\beta_6^{M} = -0.24$ ($p = 0.14$)
n	208	208	156
joint hyp test	$F = 12.60$ ($p < 0.01$)	$\chi^2 = 45.83$ ($p < 0.01$)	$F = 212.92$ ($p < 0.01$)

Table 7: Average expected earnings when coalitions formed

Treatment / Player Decision	Frequency	Average Period Earnings	Predicted Earnings
Costless Enforcement-Low			
Agree to produce (Coalition members)	213	14.73 (0.35)	10.00
Do not agree to produce (Non-members)	287	20.07 (0.30)	17.00
Costly Enforcement			
Agree to produce – produce (Compliant coalition members)	128	7.67 (0.45)	11.00
Agree to produce – not produce (Noncompliant coalition members)	59	7.86 (0.66)	---
Do not agree to produce (Non-members)	93	21.06 (0.52)	26.00
Costless Enforcement-High			
Agree to produce (Coalition members)	198	11.70 (0.36)	11.00
Do not agree to produce (Non-members)	122	26.34 (0.46)	26.00
Costly Enforcement-Full			
Agree to produce – produce (Compliant coalition members)	328	15.46 (0.28)	23.00
Agree to produce – not produce (Noncompliant coalition members)	132	13.93 (0.44)	---

Earnings reported in experimental dollars, standard errors in parentheses. In all treatments, all subjects earned $8 if a coalition did not form.

Table 8: Subject-level regressions on joining and complying with coalitions

	dependent variables	
	whether a subject joins a coalition	whether a member complies
constant	β_0^J = -0.38 (p = 0.12)	β_0^C = 1.68 (p < 0.01)
costly enforcement	β_1^J = 0.69 (p = 0.01)	---
costless enforcement-high	β_2^J = 0.63 (p = 0.03)	---
costly enforcement-full	β_3^J = 5.40 (p < 0.01)	β_1^C = 0.18 (p = 0.62)
session	β_4^J = 0.27 (p = 0.23)	β_2^C = -0.69 (p = 0.06)
periods 5 – 9	β_5^J = -0.22 (p = 0.11)	β_3^C = -0.36 (p = 0.13)
periods 10 -13	β_6^J = -0.31 (p = 0.04)	β_4^C = -0.50 (p = 0.52)
n	1977	647
joint hyp test	$\chi^2 = 112.23$ (p < 0.01)	$\chi^2 = 7.78$ (p = 0.10)
subject random effects	$\chi^2 = 136.81$ (p < 0.01)	$\chi^2 = 62.12$ (p < 0.01)