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Domestic politics and the formation of international environmental agreements

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Abstract

This paper investigates the effect of domestic politics on international environmental policy by incorporating into a classic model of coalition formation the phenomenon of lobbying by national special-interest groups. In doing so, it contributes to the theory of international environmental agreements, which has overwhelmingly assumed that governments make choices based on benefits and costs that are simple national aggregates, and on a single set of public-interest motivations. Our analysis establishes general conditions for the effect of lobbying, showing how domestic special interests might influence both the extent of environmental protection and the channels through which it is achieved. Using specific functional forms, we obtain a range of further results. Interestingly, we find that domestic lobbying may increase the incentives for parallel unilateral action, a result consistent with some recent empirical observations.

Keywords: game theory, international environmental agreements, lobbying, special-interest groups, strategic cooperation

JEL codes: C7, H41, K33, Q2, Q54

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1 Introduction

The game theory of international environmental agreements (IEAs) has provided us with many fundamental insights. In the standard model of a transnational public good such as greenhouse gas emissions abatement, each country's benefits depend on the supply of the good by all countries, but each country's costs depend only on its own supply of the good. The resulting strong incentive to free-ride on the efforts of other countries, coupled with the primacy of national sovereignty, makes it difficult to secure cooperation that is at the same time broad and deep.

Over more than two decades, the approaches set out in the pioneering papers of Barrett (1994), Carraro and Siniscalco (1993), Chander and Tulkens (1992), Hoel (1992) and Maeler (1989), and the many ways in which they have been extended since, have enabled the theory to incorporate an impressive array of issues.[1]

In the adjacent literature on experimental public goods games, there has also been a recent flurry of papers testing the predictions of IEA theory empirically. Since the basic theory does not perform especially well in experimental conditions, such papers have been notable for introducing behavioural factors like perceptions of fairness (Dannenberg, 2012; Kosfeld et al., 2009; Tavoni et al., 2011), thus broadening the set of motivations assumed to act on the 'players'.

Yet one assumption shared by virtually all of this work is that the nation-state is, in effect, a monolithic entity. In most theoretical models, each nation-state aims to maximise its utility, which depends on national-aggregate benefits and costs. While the experimental literature includes wider determinants of a player's utility, such as fairness, its unit of analysis is also singular: the human being. Insofar as one seeks to draw an analogy between experiments and the behaviour of countries in IEAs, the nation-state must therefore similarly be a unitary actor.

This may not, however, be an innocuous assumption. In particular, the contemporary literature on political economy, building on public and rational choice traditions, throws into the mix the fear that public officials are motivated at least in part by their own private interests, as opposed to the public interest (e.g Besley, 2006; Persson and Tabellini, 2000). Moreover, given self-interested behaviour on the part of public officials, we must consider the role that special-interest groups play in policy formation and implementation (Grossman and Helpman, 2001). This is the primary focus of the present paper.

We will use the terms 'special-interest' group and 'lobby' group interchangeably. Both comprise "any minority group of citizens that shares identifiable characteristics and similar concerns on some set of issues" (Grossman and Helpman, 2001, p75), and both "seek to influence legislators on a particular issue" (the definition of a lobby in the Oxford English Dictionary). Generally, then, the lobby groups that feature in our model are special-interest groups with the ability to self-organise. Not all special-interest groups enjoy this ability, however, as Olson's (1965) seminal theory explained. Lobby groups include *inter alia* trade, business and commercial organisations, labour unions, and environmental advocacy groups. These groups can lobby the government in various ways. One set of activities revolves around education and information, of elected officials, a lobby group's own members, or wider citizens.[2] The second set of activities, which we focus on here, is the giving of resources, particularly finance, to elected officials (for example, political action committees or PACs in the United States' political system). The question is, what can lobby groups actually buy with these contributions? One theory has it that money buys access to policy officials, for whom time is a scarce resource to be allocated to the highest bidder. Another suggests that campaign contributions buy credibility, in the sense that money is a signal of the strength of a lobby group's preferences in a situation where it is hard for politicians to become informed about group preferences. The third theory, however, is that money buys influence. This is not to be equated with corruption. The suggestion is that contributions are usually made to boost the electoral prospects of politicians whose proposed policies best reflect the preferences of the lobby group. As we explain below, our reduced-form model is consistent with this

[1]These include, to name but a few, competing rationality assumptions ascribed to countries, repeated games, asymmetric countries with the related possibility of making side payments, and linkage of cooperation on IEAs with other issues such as R&D and trade (see Barrett, 2005, and Finus, 2008, for recent summaries of the literature).

[2]Indeed some (e.g. Grossman and Helpman, 2001) define such informational/educational activities as 'lobbying', whereas our definition is broader, as stated.

third interpretation.

The importance of lobby groups in making environmental policies has been examined both by economists (see Oates and Portney, 2003, for an excellent review of earlier literature, and Habla and Winkler, 2012, for a recent analysis of the influence of lobbying on emissions trading) and by scholars in environmental policy and politics (see e.g. Bryner, 2008, and Kamieniecki, 2006, on the US; Markussen and Svendsen, 2005, and Michaelowa, 1998, in a European context). The approaches are unified in their identification of policy-making as, at least in part, a 'battle' between business lobby groups on the one hand and environmental lobby groups on the other, whereby, intuitively, business lobby groups generally seek to limit the scope of costly environmental measures, while environmental lobby groups do the opposite. Importantly, this work has shown that neither the business lobby nor environmental groups can be said to have won the battle in general. Indeed, much environmental legislation has been passed despite business opposition (Kraft and Kamieniecki, 2007), which in fact chimes with the observation that more environmental protection is often undertaken than theory predicts (Kolstad, 2012).

In this paper, we seek to enrich the theory of IEA formation with an account from political-economic theory of the role played by lobby groups in policy-making. Specifically, we develop a theoretical framework to analyse how domestic pressure by special-interest groups might influence governments' decisions to contribute to global environmental protection. We take as our starting point a classic IEA stage-game in the tradition of Barrett and others (1994; 1997), Carraro and Siniscalco (1993), Hoel (1992), where symmetric countries choose whether to be signatories to a stylised IEA for the provision of a transboundary public good (couched in terms of pollution abatement), and then signatories and non-signatories choose their levels of abatement.

We extend this model to introduce lobbying, fashioned after the approach of Grossman and Helpman (2001). The latter is intended to represent circumstances in which an incumbent policy-maker is concerned about the public interest (thus placing a certain emphasis on maximising social welfare), but is also in need of campaign resources for re-election, which may be offered by competing lobby groups. As such it captures the notion of 'common agency'; the policy-maker acts as the common agent for the various lobby groups and for other interests. As indicated above, campaign contributions are not imagined to be explicit offers of resources in exchange for policy decisions: the contribution schedule is a fictitious construct. Rather, lobby groups may develop a reputation for supporting political allies, such that there is a tacit understanding of the dependence of a policy-maker's future electoral fortunes on contributions from various groups. By also taking social welfare into account, note that this approach is consistent with a mixed public/private view of the motives of public officials (e.g. Besley, 2006).

Our model of coalition formation under domestic lobby pressure is structured as follows: first, governments choose whether to sign an agreement for the reduction of emissions which originate from the production of a homogeneous good and cause global environmental damage; second, domestic lobby groups present their own governments with prospective contributions, which depend on the abatement policy chosen; faced with these contribution schedules, governments (both signatories and non-signatories) simultaneously choose their abatement policies; in the final stage, firms decide how much to produce taking the abatement policy set by the government as given. The game is solved using backward induction.

Our analysis establishes some general conditions for the effect of lobbying, and shows how domestic pressure might influence both the extent of environmental protection (i.e. the level of emission abatement) and the channels through which it is achieved. Using specific functions and numerical simulations, we obtain a range of further results. Among others, we find that the combined presence of national interests and lobbying pressure may create more scope for parallel unilateral action than an a-political approach to IEAs would predict.

The paper is structured as follows. We begin in Section 2 by solving for the non-cooperative equilibrium, in which all countries act unilaterally (in Appendix 1 we set out the corresponding analysis when all countries cooperate). The analysis leads to a comparison of optimal policy settings with and without lobbying, showing formally how lobbying by business on the one hand (and/or environmental advocates on the other) draws the government's attention away from the maximisation of social welfare, and reduces (increases) the abatement standard it sets. In Section 3, we consider the formation of an IEA. We obtain a general result linking the size of the equilibrium coalition to the relative magnitude of lobby groups' contributions in signatory and non-signatory countries, and to governments' taste for money. Since these results depend, however, on functional specification, we complete the analysis in Section 4 with an application. We round up in Section 5.

2 The political equilibrium in unilateral policies

2.1 Firm stage

Consider N symmetric countries, with a single firm (industry) residing in each country. Firm j in country j produces a homogeneous good x_j for its domestic market and generates transboundary pollution, the cost of which is fully externalised. Let $r(x_j)$ and $A(x_j, q_j)$ denote firm j's revenues and costs respectively from production, where $q_j \in [0, 1]$ is the abatement standard faced by the firm. Firm j chooses the level of output x_j that maximises its profit while taking the abatement standard q_j as given. Formally:

$$\max_{x_j} \Pi_j = r(x_j) - A(x_j, q_j) \tag{1}$$

The first-order condition (FOC) for an interior solution requires

$$\frac{\partial r(x_j)}{\partial x_j} - \frac{\partial A(x_j, q_j)}{\partial x_j} = 0 \tag{2}$$

2.2 Unilateral abatement policy stage

In setting abatement policy, the relationship between a government and groups lobbying it can be interpreted as a common-agency problem. Specifically, the lobby groups are principals, having preferences over alternative policies but lacking the authority to set the policy themselves and thus needing the government to act on their behalf. The government is an agent, because its abatement-policy decision affects the principals' well-being (as well as its own). Each lobby group can design a contribution schedule in order to influence the policy choice. Yet, in doing so, it must take into consideration the incentives that other lobby groups may offer, while bearing in mind that the government itself has preferences over alternative abatement policies and cannot be made to accept an offer leaving it with lower utility than it could otherwise achieve.

We begin by describing the maximisation problem faced by the government. In a similar vein to Grossman and Helpman (2001), we define government j's utility (or political welfare) as

$$G_j = \gamma W_j(q_j, q_{-j}) + (1-\gamma) \sum_{l=1}^{L} C_j^l(q_j) \tag{3}$$

where W_j is country j's aggregate social welfare, L is the number of lobby groups in j, and C_j^l is the campaign contribution of lobby group l. The parameter $\gamma \in [0,1]$ represents the government's weighting of a dollar of social welfare compared to a dollar of campaign contributions. Therefore political utility is strictly increasing in both social welfare and campaign contributions.[3] Aggregate social welfare is given by

$$W_j(q_j, q_{-j}) = \Pi_j(q_j) + S_j(q_j) - D(q_j, q_{-j}) \tag{4}$$

where Π_j is firm j's profits, S_j is the consumer surplus realised by the citizens of country j, and D is the environmental damage suffered equally by all countries: pollution is assumed to be a pure public bad, so D is a function of abatement in all countries. Accordingly, we assume that the derivatives of the three elements of (4) with respect to q_j are negative: $\nabla\Pi_j(\cdot) < 0$; $\nabla S_j(\cdot) < 0$; $\nabla D(\cdot) < 0$. For simplicity, we further assume that countries' individual levels of abatement enter the damage function in a separable manner.

In the context of unilateral policies (i.e. if governments do not cooperate at all), each government will take the abatement standards of other countries as given and choose q_j to solve the following optimisation problem:

$$\max_{q_j} G_j = \gamma W_j(q_j, \overline{q_{-j}}) + (1-\gamma)\sum_{l=1}^{L} C_j^l(q_j)$$

subject to (2). The FOC is

$$\gamma \nabla W_j(q_j, \overline{q_{-j}}) + (1-\gamma)\sum_{l=1}^{L} \nabla C_j^l(q_j) = 0 \tag{5}$$

It is also useful to identify the optimal unilateral policy in the absence of political influence, since this provides a reference point. The game with no lobbying consists of two stages. The second stage is exactly the same as the firm stage set out above. In the first stage, government j takes the abatement standards of other countries as given and unilaterally chooses q_j to solve the following maximisation problem

$$\max_{q_j} G_j = W_j(q_j, \overline{q_{-j}})$$

subject to (2). The FOC is

$$\nabla W_j(q_j, \overline{q_{-j}}) = 0$$

and can be expressed, using (4), as

$$\nabla\Pi_j(q_j) + \nabla S_j(q_j) - \nabla D(q_j, \overline{q_{-j}}) = 0 \tag{6}$$

2.3 Lobbying stage

We can now turn to the problem faced by the lobby groups. The utility of lobby group l in country j is

$$U_j^l = W_j^l(q_j, \overline{q_{-j}}) - C_j^l(q_j) \tag{7}$$

where $W_j^l(q_j, \overline{q_{-j}})$ is the gross-of-contribution utility of lobby group l and represents its preferences over alternative abatement policies. This function may or may not depend on the abatement standard

[3] And, evidently from the summation operator, the government has no preference over the source of its gifts.

chosen in other countries (i.e., as set out below, it will in the case of an environmental lobby group). The contribution function $C_j^l(q_j)$ captures the idea that different actions by the government lead to different levels of campaign support.

We assume that both $W_j^l(.)$ and $C_j^l(.)$ are continuous and differentiable local to the equilibrium, and that contributions are non-negative. Hence, the group's utility U_j^l is strictly decreasing in $C_j^l(q_j)$, reflecting the costliness of the contribution for the group.

The objective of the lobby group is to maximise its own utility as described in (7). It anticipates that the government will take the action that maximises its own political welfare G_j. In addition, it takes the contribution schedules of all the other lobby groups as given. Thus the purpose of offering gifts is to shift the government's abatement standard towards what the lobby group favours, and this is patently subject to the constraint that the government's utility must be at least as large as it would be in the absence of any contribution by the lobby group in question. Let $\overline{G_j} = G_j(q_j^{-l}, \mathbf{C}_j^{-l}(q_j^{-l}))$ be the political welfare that the government can achieve without group l, where q_j^{-l} is the policy-maker's best response to $\mathbf{C}_j^{-l}(q_j)$. Then lobby l's maximisation problem can be formally defined as

$$\begin{aligned} \max_{q_j} U_j^l &= W_j^l(q_j, \overline{q_{-j}}) - C_j^l(q_j) \\ s.t.\ G_j &\geq \overline{G_j} \end{aligned}$$

and given (5). This is equivalent to solving the following maximisation problem

$$\max_{q_j} (1-\gamma) W_j^l + \gamma W_j + (1-\gamma) \sum_{\theta \neq l} C_j^\theta$$

subject to (5). The resulting first-order conditions imply

$$\nabla W_j^l(q_j, \overline{q_{-j}}) = \nabla C_j^l(q_j) \qquad \forall l = 1, .., L \tag{8}$$

Equation (8) establishes that each lobby group sets its contribution schedule so that the marginal change in the contribution for a small change in the abatement policy matches the effect of the policy change on the lobby's gross welfare. In other words, the contribution schedules reveal the lobbies' true preferences in the neighbourhood of the equilibrium. This notion of truthful reporting, first discussed by Bernheim and Whinston (1986), lends itself to Grossman and Helpman's interpretation of a truthful (or compensating) contribution schedule. This is a contribution schedule that everywhere reflects the true preferences of the lobby. Specifically, for any (abatement) policy q_j, it pays to the government the excess, if any, of group l's gross welfare at q_j relative to some baseline welfare level. Following this approach, we define the contribution function of lobby group l as

$$C_j^l(q_j) = \max\left[0, W_j^l(q_j, \overline{q_{-j}}) - \overline{W_j^l}(q_j^{-l}, \overline{q_{-j}})\right] \tag{9}$$

where $\overline{W_j^l}$ is group l's utility in the absence of any political contribution of its own. Equation (9) satisfies our initial assumption that the contribution schedule is non-negative, continuous and differentiable (except possibly where the contribution becomes nil).[4]

[4] It is a common assumption of the political-economy literature on lobbying – including Grossman and Helpman's (2001) widely used approach – that special-interest groups are not constrained by a limited contributions budget. We also make this assumption, so that lobby groups are able to contribute up to a constant representing their reservation

Before we proceed, it is useful to specify which lobbying scenarios we will focus on for the rest of the paper. It follows from Equation (4) that we could consider three lobby groups, business, consumers and environmentalists. Indeed our model is in principle able to incorporate lobbying by any subset of these three constituencies. But we narrow our focus to business and environmental lobby groups, who operate simultaneously or in isolation. That is, we do not consider lobbying over abatement policies by consumers. This choice is principally motivated by the fact that business and environmental groups have been identified in the environmental policy and politics literature as the most relevant special-interest groups to the formation of environmental policy (see Section 1). Hence, the following four cases will be explored: (i) no lobbying (i.e. baseline scenario); (ii) business lobbying alone; (iii) environmental lobbying alone; and (iv) business and environmental lobbying.

2.4 The effect of lobbying

At this stage, let us examine the effects of domestic lobbying by different groups on unilateral abatement policy.

Lemma 1. *Given aggregate social welfare (4), lobbying by a strict subset of groups results in the government down-weighting by $\gamma \in [0, 1]$ the effect of a marginal change in the abatement standard on the utility of the unorganised group(s).*

To appreciate Lemma 1, consider the example of lobbying undertaken by business and environmentalists. The business lobby's utility function is

$$U_j^{\pi} = \Pi_j(q_j) - C_j^{\pi}(q_j) \tag{10}$$

In the case where pollution is a pure transboundary public bad, we can similarly write the utility function of the environmental lobby as

$$U_j^D = -D(q_j, \overline{q_{-j}}) - C_j^D(q_j, \overline{q_{-j}})$$

Using (8), the FOCs describing the contributions of the two lobby groups are:

$$\nabla \Pi_j(q_j) = \nabla C_j^{\pi}(q_j)$$

$$-\nabla D(q_j, \overline{q_{-j}}) = \nabla C_j^D(q_j, \overline{q_{-j}})$$

These can be substituted into (5) in order to obtain the FOC describing the abatement policy in the political equilibrium:

utility. If a budget constraint binds for one or more lobby groups, then the ability of these lobbies to steer environmental policy in their preferred direction will be reduced. Our results on the direction of the effect will remain valid, but could thus be seen as an upper bound on its size. In this context it is worth mentioning another feature of our model in common with other contributions in the literature (e.g. Grossman and Helpman, 1994) – a direct implication of defining the contribution schedule as in Equation (9) is that any welfare surplus that may arise will be fully extracted by the government. This modelling feature mitigates to some extent the absence of an explicit budget constraint on lobby contributions, because it reduces the bargaining power of the lobby groups by another means. A more explicit account of contribution budgets would add further value to the political-economy approach to lobbying. Of course, any exogenous budget constraint would be arbitrary, and for it to be endogenous one would need to write down a much more complex model of production and consumption that seemed beyond the scope of our already multi-layered model.

$$\nabla G_j^{\pi,D} = \nabla \Pi_j(q_j) + \gamma \nabla S_j(q_j) - \nabla D(q_j, \overline{q_{-j}}) = 0 \tag{11}$$

Equation (11) can be directly compared with the no-lobbying case in (6). It can readily be seen that rival lobbying by business and environmental advocacy groups reduces the sensitivity of the equilibrium abatement standard to changes it brings about in consumer surplus. The result is intuitive, since there is no group lobbying on the basis of consumer surplus in this case. Conversely marginal changes in firm profits and environmental damage with respect to the abatement standard receive a weight of one, due to the influence of the respective lobby groups. This example is consistent with some of the initial outcomes of the EU Emissions Trading Scheme, for instance. Here, rival lobbying by business and environmental advocacy groups pushed the EU towards a policy design, where the overall cap on emissions allowances was expected to ensure scarcity, in line with environmentalists' preferences, yet the initial allocation was free (or almost entirely so), as a concession to business. The result was some emissions abatement, but due to the free allocation of permits firms enjoyed windfall profits by passing compliance costs on to consumers, who were the losers (Sijm et al., 2006; Ellerman et al., 2010).

If either the business or environmental lobby is further assumed away, then it is easy to show that the weight γ is also applied to the element of social welfare it represented, so that only the element of social welfare represented by the remaining lobby group receives a weight of one.[5] Nonetheless, it is important to realise that the preferences of the groups that do not self-organise still have a bearing on the relative success of the organised groups. In this sense policy is made not only by those who 'show up', but also by those who do not.

Let us continue to pursue the case in which lobbying is undertaken by business and environmental advocacy groups, and let us compare this case with lobbying by each group alone and with no lobbying at all. We represent by q_u the solution to (6) , $q_u^{\pi,D}$ the solution to (11), and q_u^D and q_u^π the corresponding solutions in the sole presence of either an environmental lobby or a business lobby. In order to more explicitly identify the effect of lobbying on the government's abatement standard, and given that $q_u = q_u^{\pi,D} = q_u^D = q_u^\pi$ when $\gamma = 1$, we can proceed by deriving $\frac{dq_j}{d\gamma}$ from (11), and studying its sign. The results are summarised in the following two propositions:

Proposition 1. *In the presence of rival business and environmental lobbying, or in the presence of environmental lobbying alone, equilibrium unilateral abatement is weakly larger than in the absence of lobbying.*

Proof: By differentiating (11) and collecting terms, we can obtain, in the case of rival lobbying by business and environmentalists,

$$\frac{dq_j}{d\gamma} = \frac{-\nabla S_j(q_j)}{\nabla^2 \Pi_j(q_j) + \gamma \nabla^2 S_j(q_j) - \nabla^2 D(q_j, \overline{q_{-j}})} = \frac{-\nabla S_j(q_j)}{\nabla^2 G_j^{\pi,D}}$$

The sign of $\frac{dq_j}{d\gamma}$ depends exclusively on the sign of the denominator, because the numerator is always positive; $\nabla^2 G_j^{\pi,D} \le 0$ is necessary for a solution to the FOC to be a maximum, so $\frac{-\nabla S_j(q_j)}{\nabla^2 G_j^{\pi,D}} < 0$

[5] That is, in the case where there is only a business lobby

$$\nabla G_j^\pi = \nabla \Pi_j(q_j) + \gamma \nabla S_j(q_j) - \gamma \nabla D(q_j, \overline{q_{-j}}) = 0,$$

and in the case where there is only an environmental lobby

$$\nabla G_j^D = \gamma \nabla \Pi_j(q_j) + \gamma \nabla S_j(q_j) - \nabla D(q_j, \overline{q_{-j}}) = 0.$$

(if $\nabla^2 G_j^{\pi,D} = 0$ then q is not differentiable with respect to γ). Hence, $q_u^{\pi,D} \geq q_u$. In the case of environmental lobbying alone, $\frac{dq_j}{d\gamma} = \frac{-\nabla \Pi_j(q_j) - \nabla S_j(q_j)}{\gamma \nabla^2 \Pi_j(q_j) + \gamma \nabla^2 S_j(q_j) - \nabla^2 D(q_j, \overline{q_{-j}})} = \frac{-\nabla \Pi_j(q_j) - \nabla S_j(q_j)}{\nabla^2 G_j^D} < 0 \Rightarrow q_u^D \geq q_u$. ■

Proposition 2. *In the presence of lobbying by business alone, equilibrium unilateral abatement is weakly smaller than in the absence of lobbying.*

Proof: $\frac{dq_j}{d\gamma} = \frac{-\nabla S_j(q_j) + \nabla D(q_j, \overline{q_{-j}})}{\nabla^2 \Pi_j(q_j) + \gamma \nabla^2 S_j(q_j) - \gamma \nabla^2 D(q_j, \overline{q_{-j}})} = \frac{-\nabla S_j(q_j) + \nabla D(q_j, \overline{q_{-j}})}{\nabla^2 G_j^{\pi}}$. The sign of $\frac{dq_j}{d\gamma}$ under business lobbying is undetermined. While it is also true in this case that $\nabla^2 G_j^{\pi} \leq 0$ is necessary for a solution to the FOC to be a maximum, the numerator may be positive or negative, depending on the magnitude of its two elements, since $\nabla S_j(q_j) < 0$ and $-\nabla D(q_j, \overline{q_{-j}}) > 0$. However, in the case where the numerator is positive, we would have $q_u^{\pi} > q_u$, which contradicts the assumption that any lobby's gross-of-contribution utility has to be strictly larger than it would otherwise be in order for a positive contribution to be offered. It follows that $C_j^{\pi}(q_j) = 0$ and $q_u^{\pi} = q_u$ whenever $-\nabla S_j(q_j) + \nabla D(q_j, \overline{q_{-j}}) > 0$. Hence $q_u^{\pi} \leq q_u$. ■

To summarise, the equilibrium abatement standard selected by a government acting unilaterally is at least as high when it is lobbied solely by environmental advocacy groups as it is in the absence of lobbying, while it is at least as low when it is lobbied solely by business. These results are obvious enough. More interesting is that, with rival lobbying from business *and* environmental advocacy groups, equilibrium abatement is at least as great as it is without lobbying. This comes from the fact that the effect of a policy change on the welfare of the unorganised consumer group is downweighted and this is a negative function of abatement. Insofar as this is the lobbying configuration that best describes reality, it suggests more environmental protection than the game-theoretic literature would otherwise predict, and chimes with Kraft and Kamieniecki's (2007) observation that much environmental legislation has been passed despite business opposition. Analogous results obtain if governments cooperate fully with each other at the abatement policy stage. The full-cooperative equilibrium is formally derived in Appendix 1 and will be referred to in Section 4 when discussing the potential gains to cooperation. However, the question remains whether (and through which channels) similar effects may emerge under partial cooperation?

3 Forming a self-enforcing IEA

We now consider the case in which countries can form an IEA to cooperate on pollution abatement. Non-cooperative coalition theory typically models the formation of an IEA as a two-stage game where countries decide on their participation in the first stage and choose their abatement levels in the second. The standard assumption in the second stage is that coalition members choose their abatement levels so as to maximise the aggregate payoff to their coalition, while behaving non-cooperatively towards outsiders. In the first stage, the decision about participation is modelled as a membership stage in which players simultaneously announce their decision to join the coalition (i.e. partake in the international agreement) or to remain in the fringe. The equilibrium coalition is then determined by applying the concepts of internal and external stability, which will be shortly defined.

Introducing the possibility of forming an agreement therefore requires that we modify the structure of the game so as to explicitly incorporate decisions about participation and joint welfare maximisation by coalition members. The modified game consists of the following stages: (i) a membership stage, where governments decide whether to sign an IEA; (ii) a lobbying stage, in which domestic lobby groups in both signatory and non-signatory countries present contribution schedules to their governments, linking gifts to the level of the national abatement standard; (iii) an abatement policy stage, in which signatories set their level of abatement according to joint welfare maximisation, and non-signatories act unilaterally, taking the abatement of other countries as given; and (iv) a firm stage, which is identical to the one introduced in Section 2.1. The game is solved using backward induction.

Before presenting the model (skipping the firm stage to avoid redundancy), it is opportune to briefly comment on the ordering of stages. As previously mentioned, in the standard coalition-theoretic model of IEA formation, the first stage is the membership stage. We follow this convention, which implies that lobbying happens after governments have made their decisions on participation. Yet, since it is assumed governments can look forwards and reason backwards, they will take into consideration the gifts they might receive from lobby groups in making their membership decisions. These gifts are, in turn, linked directly to abatement standards. Hence, the proposed structure allows us to capture the influence of domestic lobby groups on IEA formation through their effect on domestic abatement policies, without making any *a priori* assumptions about the preferences they might have over coalition formation *per se*. Within this set-up, the abatement standard can therefore be interpreted as a political variable, whose value is anticipated by governments when deciding whether to sign the treaty.

3.1 Abatement policy stage

Let k be the number of countries that decide to sign the IEA, while the remaining $(N-k)$ countries choose to be outsiders. In the abatement policy stage, each non-signatory government behaves non-cooperatively, taking the abatement standards of other countries as given and choosing $q_j \in [0,1]$ so as to maximise political utility, given the condition on the optimal production level of the domestic firm (2). Call q_n the non-signatory's abatement standard and write the government's optimisation problem in terms of the given behaviour of signatories and other non-signatories:

$$\max_{q_n} G_n = \gamma W_n(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) + (1-\gamma)\sum_{l=1}^{L} C_n^l(q_n)$$

subject to (2), where q_s is the abatement standard chosen by each of the signatories. The FOC is given by

$$\gamma \nabla W_n(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) + (1-\gamma)\sum_{l=1}^{L} \nabla C_n^l(q_n) = 0. \tag{12}$$

The remaining k countries choose q_s to maximise their joint payoff:

$$\max_{q_s} kG_s = k\left[\gamma W_s(q_s, (k-1)q_s, \overline{(N-k)q_n}) + (1-\gamma)\sum_{l=1}^{L} C_s^l(q_s)\right]$$

subject to (2). The FOC for signatories is hence

$$\gamma \nabla W_s(q_s, (k-1)q_s, \overline{(N-k)q_n}) + (1-\gamma)\sum_{l=1}^{L} \nabla C_s^l(q_s) = 0 \tag{13}$$

Note that when $\gamma = 1$, Equations (12) and (13) allow us to uniquely determine the optimal abatement of signatories and non-signatories in a standard model with no lobbying. We will subsequently refer to signatories' and non-signatories' optimal abatement in the absence of lobbying as q_s^0 and q_n^0.

3.2 Lobbying stage

The lobbying stage is similar in nature to that described in Section 2.3. As before, each lobby group designs its contribution schedule so as to maximise its utility, subject to the constraint that the government must be as well off as it would have been in the absence of any contribution from that group. The principal difference is that, in specifying the maximisation problem faced by lobby group l in country j, we now need to distinguish between two alternative cases, depending on whether j is a signatory or non-signatory. Formally, we have

$$\begin{aligned} \max_{q_n} U_n^l &= W_n^l(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) - C_n^l(q_n) \\ \text{s.t. } G_n &\geq \overline{G_n} \end{aligned} \tag{14}$$

and given (12), if j is a non-signatory, and

$$\begin{aligned} \max_{q_s} U_s^l &= W_s^l(q_s, (k-1)q_s, \overline{(N-k)q_n}) - C_s^l(q_s) \\ \text{s.t. } G_s &\geq \overline{G_s} \end{aligned} \tag{15}$$

and given (13), if j is a signatory. $\overline{G_j} = G_j(q_j^{-l}, \mathbf{C}_j^{-l}(q_j^{-l}))$ represents the political welfare that government j can achieve without group l.

The maximisation problems in (14) and (15) lead to the following FOCs:

$$\nabla W_n^l(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) = \nabla C_n^l(q_n) \tag{16}$$

$$\nabla W_s^l(q_s, (k-1)q_s, \overline{(N-k)q_n}) = \nabla C_s^l(q_s) \tag{17}$$

In line with the notion of truthfulness discussed above, these FOCs establish that each lobby group sets its contribution schedule so that the marginal change in the contribution for a small change in the abatement policy matches the effect of the policy change on the lobby's gross welfare. Combining conditions (16) and (17) with (12) and (13) respectively, we have

$$\gamma \nabla W_n(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) + (1-\gamma)\sum_{l=1}^{L} \nabla W_n^l(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) = 0 \tag{18}$$

$$\gamma \nabla W_s(q_s, (k-1)q_s, \overline{(N-k)q_n}) + (1-\gamma)\sum_{l=1}^{L} \nabla W_s^l(q_s, (k-1)q_s, \overline{(N-k)q_n}) = 0 \tag{19}$$

Hence, for a given k, the abatement standards that solve the common-agency problem between a government (either signatory or non-signatory) and its lobby groups must satisfy conditions on a weighted sum of the corresponding welfare of the interest groups and the general public. The solutions to (18) and (19) will be denoted $q_n^{\mathbf{L}}$ and $q_s^{\mathbf{L}}$ respectively. The superscript $\mathbf{L}$ refers to different lobbying scenarios. Specifically: (i) no lobbying ($\mathbf{L} = 0$); (ii) business lobbying alone ($\mathbf{L} = \pi$); (iii) environmental lobbying alone ($\mathbf{L} = D$); (iv) business *and* environmental lobbying ($\mathbf{L} = \pi, D$). In our setting $q_n^{\mathbf{L}}$ corresponds to the unilateral abatement standard derived in Section 2.3, while $q_s^{\mathbf{L}}$ is the optimal abatement standard of a signatory country as a function of k. Applying the same logic used in the proofs of Propositions 1 and 2, it can be shown that, for a given k, the order of signatories' abatement standards is as follows: $q_s^{\mathbf{D}}(k)\big|\, k \geq q_s^{\pi,\mathbf{D}}(k)\big|\, k \geq q_s^{\mathbf{0}}(k)\big|\, k \geq q_s^{\pi}(k)\big|\, k$. That is, similar patterns obtain for signatories and non-signatories' abatement standards, given k.

Of course, k is endogenous in a game of partial cooperation and needs to be determined in order to compute the equilibrium abatement standards. By substituting $q_n^{\mathbf{L}}$ and $q_s^{\mathbf{L}}$ into $G_n(\cdot)$ and $G_s(\cdot)$, we can express the payoffs of signatories and non-signatories in terms of k (and γ) only. These payoff functions will be denoted by G_n^* and G_s^*, and used in the following section to solve the membership stage.

3.3 IEA membership stage

The equilibrium coalition size is determined by applying the concepts of internal and external stability, which respectively guarantee that no signatory is better off leaving the coalition, and that there is no incentive for a non-signatory to join the coalition (d'Aspremont et al., 1983; Hoel, 1992; Carraro and Siniscalco, 1993; Barrett, 1994).

A useful tool to identify the size of the stable coalition is the *stability function*. In a standard setting, this is defined as $\mathcal{L}(k) = H_s^*(k) - H_n^*(k-1)$, where $H_j^*(\cdot)$ denotes the optimal payoff of country j. It has been shown that, if a stable coalition exists, it coincides with the largest integer k^* smaller than or equal to the value of k that satisfies $\mathcal{L}(k) = 0$, and $\frac{\partial \mathcal{L}(k)}{\partial k} < 0$ (Carraro and Siniscalco, 1993).

In our setting with lobbying, the optimal payoffs to signatories and non-signatories are given by G_n^* and G_s^*, which depend on both k and γ. Consequently, the stability function is $\mathcal{L}(k,\gamma) = G_s^*(k,\gamma) - G_n^*(k-1,\gamma)$, which can be written more explicitly as

$$\begin{aligned}\mathcal{L}(k,\gamma) \qquad &= \gamma W_s(k,\gamma) + (1-\gamma)\sum_{l=1}^{L} C_s^l(k,\gamma) + \\ &-\gamma W_n(k-1,\gamma) - (1-\gamma)\sum_{l=1}^{L} C_n^l(k-1,\gamma)\end{aligned}$$

Hence, the relevant conditions for a stable coalition become:

$$\begin{gathered}\mathcal{L}(k,\gamma) = 0 \Rightarrow \\ \gamma(W_s(k,\gamma) - W_n(k-1,\gamma)) + (1-\gamma)\sum_{l=1}^{L}\left(C_s^l(k,\gamma) - C_n^l(k-1,\gamma)\right) = 0\end{gathered} \tag{20}$$

$$\begin{gathered}\nabla_k \mathcal{L}(k,\gamma) < 0 \Rightarrow \gamma(\nabla_k W_s(k,\gamma) - \nabla_k W_n(k-1,\gamma)) + \\ +(1-\gamma)\sum_{l=1}^{L}\left(\nabla_k C_s^l(k,\gamma) - \nabla_k C_n^l(k-1,\gamma)\right) < 0\end{gathered} \tag{21}$$

Let $k^{\mathbf{L}}$ denote the equilibrium coalition size derived from the above conditions. Notice that when $\gamma = 1$ equations (20) and (21) coincide with the conditions for a stable coalition in the absence of lobbying (i.e. $k^{\mathbf{L}} = k^0$). In order to investigate how the presence of lobbying affects the equilibrium coalition size compared to the a-political case, we proceed by deriving $\frac{dk}{d\gamma}$ from (20) and studying its sign. This leads to the following result:

Proposition 3. *Let* $\Theta = \sum_{l=1}^{L} \left(C_n^l(k^{\mathbf{L}} - 1, \gamma) - C_s^l(k^{\mathbf{L}}, \gamma) \right)$*. In the presence of lobbying by L special-interest groups, the equilibrium coalition size* $k^{\mathbf{L}}$ *of an IEA is weakly larger (smaller) than the equilibrium coalition size* k^0 *in the absence of lobbying, provided that* Θ *is weakly smaller (larger) than zero.*

Proof: By differentiating 20 and collecting terms we can obtain $\frac{dk}{d\gamma} =$

$$\frac{\left[(W_n - W_s) - \sum_{l=1}^{L} \left(C_n^l - C_s^l \right) \right] + \left[\gamma \nabla_\gamma (W_n - W_s) + (1-\gamma) \sum_{l=1}^{L} \nabla_\gamma \left(C_n^l - C_s^l \right) \right]}{\gamma \nabla_k (W_s - W_n) + (1-\gamma) \sum_{l=1}^{L} \nabla_k \left(C_s^l - C_n^l \right)}$$

The denominator of $\frac{dk}{d\gamma}$ coincides with $\nabla_k \mathcal{L}(k, \gamma)$. Thus it must be smaller than zero for (21) to hold. From (20), we have $\gamma(W_n - W_s) = (1-\gamma) \sum_{l=1}^{L} \left(C_s^l - C_n^l \right)$. Using this equality, we can re-write the numerator of $\frac{dk}{d\gamma}$ as simply $-\frac{1}{\gamma} \sum_{l=1}^{L} \left(C_n^l - C_s^l \right)$. If $\sum_{l=1}^{L} \left(C_n^l - C_s^l \right) \geq 0$, then the numerator is negative and $\frac{dk}{d\gamma} \geq 0$, which implies $k^{\mathbf{L}} \leq k^0$. ■

The magnitude Θ in Proposition 3 is a measure of the loss (or gain) of campaign contributions that a government incurs by leaving the coalition. To appreciate Proposition 3, consider the example of lobbying undertaken by environmentalists alone. The reason for focusing on this example is that the sign of Θ can be unambiguously determined.

Setting $\mathbf{L} = D$, then

$$\Theta = C_n^D(k^D - 1, \gamma) - C_s^D(k^D, \gamma)$$

Using (9) and the fact that environmental damage (D) is a function of total abatement, we can write

$$C_n^D(k^D, \gamma) = C_s^D(k^D, \gamma) = \max\{0, -D(Q(k^D, \gamma)) + D(\overline{Q(k^0)})\}$$

Hence

$$C_n^D(k^D - 1, \gamma) = \max\{0, -D(Q(k^D - 1, \gamma)) + D(\overline{Q(k^0)})\}$$

which implies that $C_n^D(k^D - 1, \gamma)$ is weakly smaller than $C_s^D(k^D, \gamma)$ and, from Proposition 3, $k^D \geq k^0$. Therefore the presence of environmental lobbying alone has a positive effect on accession (and on total abatement).[6] This unambigous result can be obtained using the fact that the welfare of environmentalists depends on environmental damage, which is, in turn, a function of *total* abatement. In the case of business lobbying alone and of rival business and environmental lobbies, we are unable to unequivocally determine the sign of Θ in a general setting (i.e. without introducing any functional specification). In the next section we hence pursue an application, where we choose particular forms for firm profits, consumer surplus and environmental damage.

[6]Recall that for a given k, the order of signatories' abatement standards is as follows: $q_s^{\mathbf{D}}(k)\big| k \geq q_s^{\pi,\mathbf{D}}(k)\Big| k \geq q_s^{\mathbf{0}}(k)\big| k \geq q_s^{\pi}(k)\big| k$

4 An application of the model

4.1 Functional specification

In order to remain close to the existing literature, our special case is similar in nature to Barrett (1997), who also explicitly modelled firm behaviour (albeit for different purposes), and whose model makes assumptions about functional specifications that are a natural starting point.

Specifically, we assume that inverse demand in country j is $p(x_j) = 1 - x_j$, and that firm j faces production costs $A(x_j, q_j) = \sigma q_j x_j$, where $\sigma < 1$ is the unit cost of abatement. Hence firm j's profit is $\Pi_j = (1 - x_j - \sigma q_j)x_j$. Given how we specify inverse demand, we can represent consumer surplus as $S_j = (x_j)^2/2$. Pollution is assumed to be a pure public bad, and marginal environmental damage for each country is a constant ω. Thus $D = \omega \left[x_j(1 - q_j) + \sum_{i \neq j}^{N} x_i(1 - q_i)\right]$ and we have a special case of the aggregate social welfare function in (4):

$$W_j = (1 - x_j - \sigma q_j)x_j + (x_j)^2/2 - \omega \left[x_j(1 - q_j) + \sum_{i \neq j}^{N} x_i(1 - q_i)\right] \tag{22}$$

We can derive analytical expressions for equilibrium abatement using these functions, expressions which depend on the parameters σ, ω and on the government's taste for money γ (when some form of lobbying is present). The analysis required to obtain them is long and involved, so we relegate most of it to Appendix 2, and here we instead use Tables 1 and 2 as a convenient way to summarise. Table 1 presents the equilibrium in unilateral policies, which one can see is consistent with the general results set out in Propositions 1 and 2. That is, provided $\gamma < 1$, the ordering of unilateral abatement standards is: environmental lobbying alone $\geq$ rival lobbying $\geq$ no lobbying $\geq$ business lobbying alone. In Appendix 2, we further compute the equilibrium abatement standards under full cooperation, the results of which are summarised in Table 2. The same ordering of abatement standards is found, while comparing Tables 1 and 2 also shows that abatement under full cooperation, which is found by internalising the environmental externality across all countries, is weakly larger than under unilateral policies, as one would expect.

[TABLES 1 AND 2 HERE]

We could also derive analytical expressions for equilibrium abatement under partial cooperation, for given k. However k is of course endogenously determined. Closed-form solutions cannot be determined when k is endogenous. Therefore we turn to numerical simulations, based on the functional forms introduced above, to better understand the effect of lobbying on coalition size and equilibrium abatement under partial cooperation. The simulation results are discussed in the next section.

4.2 Simulation results

In order to appreciate how lobbying affects cooperation under a self-enforcing IEA, it is useful to start by briefly discussing the potential gains to cooperation, as well as equilibrium abatement and coalition size, in the standard a-political case. We will do so graphically, before entering into the details of the simulation results under alternative lobbying scenarios.

[FIGURE 1 HERE]

The potential gains to cooperation are measured by the difference between the global net benefits under full cooperation and unilateral policies; i.e. $\sum_j W_j(q_c) - \sum_j W_j(q_u)$. Figure 1 plots this and shows that gains are large when marginal benefits (ω) and costs (σ) of abatement are relatively high. That is to say, cooperation would matter most in the case of hazardous pollutants, which are relatively costly to control. The equilibrium outcomes in the absence of lobbying are shown in Figure 2. Larger coalitions are more likely to form (panel a) and abatement is greatest (panel b) when the gains to cooperation are small. By contrast, it is harder to achieve effective cooperation when ω and σ are relatively high (that is, when cooperation is most needed). The predictions for the no-lobby case are, therefore, consistent with the classic result from IEA theory that, with high benefits to cooperation, the incentive for countries to free-ride is correspondingly high (e.g. Barrett, 1994).

[FIGURE 2 HERE]

How do these predictions change when domestic lobbying is taken into account? Table 3 summarises the simulation results under different lobbying scenarios for $\omega = 0.67$, $\sigma = 0.9$ and when the total number of countries $N = 100$. This describes a situation in which the gains to cooperation are very high and the efficient outcome in terms of total emission reduction is maximum abatement ($Q = 100$). We use this case as an illustrative example and refer to Appendix 3 for a more comprehensive map of the parameter space. Column 1 shows that, in the reference scenario with no lobbies, a coalition forms in which each signatory reduces emissions substantially (q_s^* is approximately equal to one), but the coalition is so small ($k^* = 2$) that total abatement is rather small.

The equilibrium solutions in the presence of lobbying depend on the government's taste for money γ. The empirical literature is inconclusive on reasonable values of γ,[7] so in Table 3 we report the results for low, intermediate and high values. We start with $\gamma = 0.25$, which implies a relatively high preference for lobby contributions. Our simulations predict that rival lobbying by environmental and business groups (column 4) translates into *substantially higher total abatement than in the absence of lobbying.* This higher abatement is not, however, achieved through the formation of an IEA. Instead, the main driver is the positive effect that lobbying has on the abatement level of non-signatories, which is markedly higher than in the no-lobby case. Analogous results are found for higher values of γ, although the magnitude of the effect is lower.

[TABLE 3 HERE]

In the case of environmental lobbying alone (column 3), we find that the grand coalition $k^* = 100$ may form. Yet looking at the table more closely, one can see that this is a coalition that merely codifies maximum unilateral action, as $q_n = q_s = 1$ in equilibrium. The sole presence of a business lobby, on the other hand, will generally lead to lower total abatement, as one would expect. Interestingly, however, we find instances in which this may not be the case (see, for example, the results reported in Table 3 for $\gamma = 0.25, 0.5$). How can we explain this result? Business pressure tends to water down the terms of the agreement by negatively affecting q_s; this, in turn, may make it 'easier' for countries to cooperate

[7] For discussions on the link between special interests and government protection, see Gawande and Hoekman (2006) and the literature referenced therein. The latter tends to produce high estimates of γ, implying a much higher weight on aggregate welfare compared to lobbying contributions, both in the US and abroad. Gawande and Hoekman point out, however, that such estimates are inconsistent with the large deadweight losses resulting from trade restrictions (and correspondingly large predicted lobby contributions). To address this puzzle, they propose to amend the Grossman-Helpman model by introducing a multiplicative parameter representing the probability that the policy is implemented, effectively scaling down γ (and contributions) due to uncertainty about the effectiveness of policy-making.

and lead to the formation of a larger and shallower coalition. If the number of signatories is large enough, total abatement will increase even if less is done individually by coalition members.

5 Discussion

Our aim has been to enrich the theory of providing international environmental goods by considering the role played by special-interest groups in shaping policy. We set out by relaxing the near-ubiquitous assumption that national governments make choices based on benefits and costs that are simple national aggregates, and on a single set of public-interest motivations. Instead we allow national policy-makers to be motivated not only to increase social welfare, but also to advance their own private interests, i.e. to boost their prospects of re-election. In doing so we integrated two fundamental strands of literature, which have largely developed in parallel, (i) the game-theoretic literature on IEA formation and (ii) the economic literature on political lobbying. The resulting model is a multiple-stage, non-cooperative game of coalition formation, which incorporates the possibility that governments are lobbied by special interests.

We first showed in a general setting that the influence of lobby groups on policy stringency depends on which groups are organised, but the preferences of the interest groups that do not self-organise have a bearing on the relative success of the organised groups. When all governments act symmetrically (either unilaterally or cooperatively), rival lobbying by environmentalists and business, as well as by environmentalists alone, translates into higher abatement than in the absence of lobbying. Conversely, governments set a lower abatement standard when lobbied solely by business groups.

Under partial cooperation we found general conditions for the size of the equilibrium coalition that depend on the relative magnitude of lobby groups' contributions in signatory and non-signatory countries, and on governments' taste for money. With the help of numerical simulations based on specific functions for the components of social welfare, we could further show that lobbying affects both the extent of environmental protection and the channels through which it is achieved. Namely, lobbying by business and environmental groups (or by environmentalists alone) translates into higher abatement than in the absence of lobbying. Yet, since this result mostly derives from increased unilateral action rather than from additional abatement by the coalition, it is in fact consistent with the observation that, in reality, countries have often taken more unilateral action to provide international environmental goods than the standard theory would predict (Kolstad, 2012). For example, a number of countries, including member states of the European Union and emerging markets such as Mexico (Townshend et al., 2013; Burck et al., 2012; Institute, 2012), have been forging ahead with unilateral abatement of greenhouse gas emissions, despite the ongoing absence of a comprehensive international agreement specifying emissions reductions.

In the case of business lobbying alone, the model generally predicts a lower level of abatement; however, there are instances where business pressure may lead to higher environmental protection relative to the no-lobby case. More specifically this is the case when governments' taste for money is relatively high, and the business lobby is able to bring down signatory abatement enough to stabilise a larger coalition. In these circumstances the gains from the agreement are small, but so are countries' incentives to free-ride, which is a new form of a familiar finding in the literature, as it sheds light on the underlying political-economic drivers.

There are several avenues along which to extend the present work. Here we focused on domestic lobby groups who are regarded as particularly influential, given the higher concentration of interests within national borders. Yet it may also be interesting to explore the role of international lobby groups within a context of multi-level governance. Another extension could be to include trade, which might illuminate phenomena like the ‘California effect’: will the threat of trade sanctions to a firm exporting a polluting good to a regulated market trigger lobbying for a stringent domestic policy? Given the richness of the model as it stands, and the goal of isolating the effect of lobbying, we decided to leave trade out of this work. Lastly, it would be interesting to test the model empirically, estimating the effect of lobbying on environmental policy using, for example, data from U.S. campaign contributions.

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Appendix 1 The political equilibrium under full cooperation

In this Appendix we repeat the analysis of Section 2 for the case of N cooperating countries. The firm stage and equations (3)-(4) still apply, so we begin here with the governments' maximisation problem.

The full-cooperative abatement policy stage

Under universal cooperation, government j will choose q_j to solve the following optimisation problem:

$$\max_{q_j} G_{FC} = \sum_{i=1}^{N}[\gamma W_i(q_i) + (1-\gamma)\sum_{l=1}^{L} C_i^l(q_i)]$$

subject to (2). The first order condition is

$$\nabla G_{FC} = N[\gamma \nabla W_c(q) + (1-\gamma)\sum_{l=1}^{L} \nabla C_c^l(q)] = 0 \tag{23}$$

where the subscript c indicates a representative cooperating country and FC refers to the entire cooperating bloc.

By comparison, in the game with no lobbying government j solves

$$\max_{q_j} G_{FC} = \sum_{i=1}^{N} G_i(q_i) = \sum_{i=1}^{N} W_i(q_i)$$

subject to (2). The FOC is

$$\nabla G_{FC} = N \nabla W_c(q) = 0$$

and it can be expressed in terms of the components of (4):

$$\nabla \Pi_c(q) + \nabla S(q) - \nabla D(Nq) = 0. \tag{24}$$

Lobbying stage

Recall the definition of joint efficiency in (7), such that the equilibrium and the optimal contribution schedules are derived by solving

$$\max_{q_j} W_j^l(q_j, \overline{q_{-j}}) - C_j^l(q_j) + \sum_{i=1}^{N}[\gamma W_i(q_i) + (1-\gamma)\sum_{l=1}^{L} C_i^l(q_i)]$$

The FOC is

$$\nabla W_c^l(q) - \nabla C_c^l(q) + N[\gamma \nabla W_c(q) + (1-\gamma)\sum_{l=1}^{L} \nabla C_c^l(q)] \ = 0 \tag{25}$$

for every $l = 1, ..., L$.

Combining conditions (23) and (25), we have that in a cooperating country c, lobby l must satisfy:

$$\nabla W_c^l(q) = \nabla C_c^l(q) \qquad \forall l = 1, .., L \tag{26}$$

The effect of lobbying on the full-cooperation outcome

Lemma A1. *Under full cooperation, lobbying by a strict subset of groups results in the government down-weighting by the factor $\gamma \in [0,1]$ the effect of a marginal change in the abatement standard on the utility of the unorganised group(s).*

To appreciate Lemma A1, consider (as in Section 2) the example of lobbying undertaken by business and environmentalists, but not by consumers. Using (26), the conditions describing the contributions of the two lobby groups in equilibrium are:

$$\nabla \Pi_c(q) = \nabla C_c^{\pi}(q)$$
$$-\nabla D(Nq) = \nabla C_c^{D}(Nq)$$

These can be substituted into (5) in order to obtain the conditions describing the abatement standard set under global cooperation:

$$\nabla G_{FC}^{\pi,D} = \nabla \Pi_c(q) + \gamma \nabla S_c(q) - \nabla D(Nq) = 0 \tag{27}$$

Equation (27) can be directly compared with the no-lobbying case in (6).

Let q_c denote the solution to (24), $q_c^{\pi,D}$ the solution to (27), and q_c^D and q_c^{π} the corresponding solutions in the presence of an environmental lobby alone and a business lobby alone, respectively.

Proposition A1. *In the presence of rival business and environmental lobbying, or in the presence of environmental lobbying alone, full-cooperative abatement in equilibrium is weakly larger than in the absence of lobbying.*

Proof: Proceed in the same way as the proof of Proposition 1. ■

Proposition A2. *In the presence of lobbying by business organisations only, full-cooperative abatement in equilibrium is weakly smaller than in the absence of lobbying.*

Proof: Proceed in the same way as the proof of Proposition 2. ■

Appendix 2 Equilibrium abatement with specific functions

No-lobbying case

Firm stage

With the functional specifications introduced in Section 4, the optimisation problem for firm j is

$$\max_{x_j} \Pi_j = (1 - x_j - \sigma q_j) x_j$$

The FOCs for an interior solution require

$$1 - 2x_j - \sigma q_j = 0 \qquad \forall j \tag{28}$$

which gives

$$x_j = \frac{1 - \sigma q_j}{2} \tag{29}$$

Equilibrium under unilateral policy with no lobbying

If governments act unilaterally, then in the first stage of the game government j takes the abatement standards of other countries as given and chooses q_j so as to maximise (22), i.e.:

$$\max_{q_j} W_j = (1 - x_j - \sigma q_j) x_j + (x_j)^2/2 - \omega \left[x_j (1 - q_j) + \sum_{i \neq j}^{N} x_i (1 - q_i) \right]$$

subject to (28) and $q_j \in [0, 1]$. The Kuhn-Tucker conditions require

$$\begin{gathered} \tfrac{\partial W_j}{\partial q_j} - \lambda_j \leq 0, \quad \left(\tfrac{\partial W_j}{\partial q_j} - \lambda_j \right) q_j = 0, \quad q_j \geq 0, \\ q_j \leq 1, \quad \lambda_j (1 - q_j) = 0, \quad \lambda_j \geq 0 \end{gathered} \tag{30}$$

where λ_j is a Lagrangian multiplier and

$$\frac{\partial W_j}{\partial q_j} = (\omega - \sigma) x_j - \frac{\sigma}{2} x_j + \omega \frac{\sigma}{2} (1 - q_j) \tag{31}$$

By substituting (29) into (31) and collecting terms we have

$$\frac{\partial W_j}{\partial q_j} = \frac{2\omega - 3\sigma + 2\sigma\omega}{4} - q_j \frac{\sigma (4\omega - 3\sigma)}{4} \tag{32}$$

The Kuhn-Tucker conditions in (30) are necessary and sufficient when $\omega > \frac{3\sigma}{4}$. Provided the latter condition is satisfied, the interior solution is found by setting (32) equal to zero; the corner solution for $q_j = 0$ is found by setting $q_j = 0$ in (32) and solving for $\frac{\partial W_j}{\partial q_j} \leq 0$; and the corner solution for $q_j = 1$ is found by setting $q_j = 1$ in (32) and solving for $\frac{\partial W_j}{\partial q_j} \geq 0$.

If $\omega \leq \frac{3\sigma}{4}$, then $\frac{\partial W_j}{\partial q_j}$ is non-decreasing in q_j. Therefore, if we were to find that $\frac{\partial W_j}{\partial q_j} < 0$ at $q_j = 1$, we could conclude that $\frac{\partial W_j}{\partial q_j} < 0 \; \forall q_j \in [0, 1]$. By setting $q_j = 1$ in (32) we have: $\left. \frac{\partial W_j}{\partial q_j} \right|_{q_j = 1} = \frac{(2\omega - 3\sigma)(1 - \sigma)}{4}$.

By assumption $\sigma < 1$ to ensure output is positive. Moreover, $2\omega - 3\sigma < 0$ when $\omega \leq \frac{3\sigma}{4}$. As a result, $\frac{\partial W_j}{\partial q_j} < 0$. From (30), this implies that $q_j = 0$ is optimal when the second-order conditions fail to hold.

As the problem is symmetric, in equilibrium all countries will choose the same level of abatement. Therefore we can remove the subscript j and express the optimal unilateral abatement standard as q_u^0, where the superscript zero indicates that we are in the no-lobby case. The solution is summarised below:

$$q_u^0 = \begin{cases} 0 & \text{if } \omega \leq \frac{3\sigma}{2(1+\sigma)} \\ \frac{2\omega-3\sigma+2\sigma\omega}{\sigma(4\omega-3\sigma)} & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)}, \frac{3\sigma}{2}\right) \\ 1 & \text{if } \omega \geq \frac{3\sigma}{2} \end{cases} \tag{33}$$

for $\omega > \frac{3\sigma}{4}$, and $q_u^0 = 0$ otherwise.

Equilibrium under full cooperation with no lobbying

If countries cooperate fully, then in the first stage of the game government j will choose $q_j \in [0,1]$ so as to maximise $W_c = \sum_{i=1}^{N} W_i$, subject to (28). The Kuhn-Tucker conditions will be analogous to (30) and so need not be written down. By differentiating W_c, we obtain

$$\frac{\partial W_c}{\partial q_j} = N\left[(N\omega - \sigma)x - \frac{\sigma}{2}x + \frac{N\omega\sigma(1-q)}{2}\right] \tag{34}$$

where x and q are each firm's output and each government's abatement level respectively.

Applying to (34) the same reasoning used in the derivation of the equilibrium in unilateral policies (see above), we find that the optimal level of abatement under full cooperation is

$$q_c^0 = \begin{cases} 0 & \text{if } \omega \leq \frac{3\sigma}{2(1+\sigma)N} \\ \frac{2N\omega-3\sigma+2N\omega\sigma}{\sigma(4\omega N-3\sigma)} & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)N}, \frac{3\sigma}{2N}\right) \\ 1 & \text{if } \omega \geq \frac{3\sigma}{2N} \end{cases} \tag{35}$$

for $\omega > \frac{3\sigma}{4N}$, and $q_c^0 = 0$ otherwise.

Self-enforcing IEA with no lobbying

The game is now as follows: in the first stage, countries decide independently and simultaneously whether to join a coalition. In the second stage, signatories choose the level of abatement that maximises the aggregate payoff of the coalition, while non-signatories pursue their individually optimal abatement policies. In the third stage – which was solved above – firms choose their outputs.

From (28), the optimal output levels of firms located in signatory and non-signatory countries are

$$\begin{aligned} x_s &= \frac{1-\sigma q_s}{2} \\ x_n &= \frac{1-\sigma q_n}{2} \end{aligned}$$

where q_s and q_n are the abatement levels chosen by signatories and non-signatories respectively.

Non-signatories behave non-cooperatively and each solves the problem set established above for the equilibrium in unilateral policies. Thus their optimal abatement level, denoted here by q_n^0, is as per (33).

The optimisation problem for a representative signatory is

$$\max_{q_s} kW_s = k\left\{(1-x_s-\sigma q_s)x_s+(x_s)^2/2-\omega\left[kx_s(1-q_s)+(N-k)x_n(1-q_n)\right]\right\}$$

where k denotes the number of signatories. Differentiation yields:

$$k\frac{\partial W_s}{\partial q_s} = k\left\{(k\omega-\sigma)x_s - \frac{\sigma}{2}x_s + \frac{\omega k\sigma(1-q_s)}{2}\right\} \tag{36}$$

Applying to (36) the same logic used to derive the equilibrium in unilateral policies, we find that optimal abatement for a signatory country is

$$q_s^0 = \begin{cases} 0 & \text{if } \omega \leq \frac{3\sigma}{2(1+\sigma)k} \\ \frac{2k\omega-3\sigma+2k\omega\sigma}{\sigma(4k\omega-3\sigma)} & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)k}, \frac{3\sigma}{2k}\right) \\ 1 & \text{if } \omega \geq \frac{3\sigma}{2k} \end{cases}$$

for $\omega > \frac{3\sigma}{4k}$, and $q_s^0 = 0$ otherwise.

Combining the above solution with Eq. (33), the following cases can be identified:

$$\text{for } k \geq 1+\sigma \Rightarrow \begin{cases} (a) & q_s^0 = q_n^0 = 0 & \text{if } \omega \leq \frac{3\sigma}{2(1+\sigma)k} \\ (b) & q_s^0 = \frac{2k\omega-3\sigma+2k\omega\sigma}{\sigma(4k\omega-3\sigma)}, q_n^0 = 0 & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)k}, \frac{3\sigma}{2k}\right] \\ (c) & q_s^0 = 1, q_n^0 = 0 & \text{if } \omega \in \left(\frac{3\sigma}{2k}, \frac{3\sigma}{2(1+\sigma)}\right) \\ (d) & q_s^0 = 1, q_n^0 = \frac{2\omega-3\sigma+2\sigma\omega}{\sigma(4\omega-3\sigma)} & \text{if } \omega \in \left[\frac{3\sigma}{2(1+\sigma)}, \frac{3\sigma}{2}\right) \\ (e) & q_s^0 = q_n^0 = 1 & \text{if } \omega \geq \frac{3\sigma}{2} \end{cases}$$

$$\text{for } k \in [1, 1+\sigma) \Rightarrow \begin{cases} (a') & q_s^0 = q_n^0 = 0 & \text{if } \omega \leq \frac{3\sigma}{2(1+\sigma)k} \\ (b') & q_s^0 = \frac{2k\omega-3\sigma+2k\omega\sigma}{\sigma(4k\omega-3\sigma)}, q_n^0 = 0 & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)k}, \frac{3\sigma}{2(1+\sigma)}\right] \\ (c') & q_s^0 = \frac{2k\omega-3\sigma+2k\omega\sigma}{\sigma(4k\omega-3\sigma)}, q_n^0 = \frac{2\omega-3\sigma+2\sigma\omega}{\sigma(4\omega-3\sigma)} & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)}, \frac{3\sigma}{2k}\right) \\ (d') & q_s^0 = 1, q_n^0 = \frac{2\omega-3\sigma+2\sigma\omega}{\sigma(4\omega-3\sigma)} & \text{if } \omega \in \left[\frac{3\sigma}{2k}, \frac{3\sigma}{2}\right) \\ (e') & q_s^0 = q_n^0 = 1 & \text{if } \omega \geq \frac{3\sigma}{2} \end{cases}$$

Notice that for $k = 1+\sigma$, case (c) collapses into (b); while for $k = 1$ cases (b') and (d') collapse into (a') and (e') respectively.[8]

As mentioned in Section 3.3, by substituting the optimal levels of abatement q_s^0 and q_n^0 into the payoff functions of signatories and non-signatories, one can derive the stability function $\mathcal{L}(k) = W_s^*(k) - W_n^*(k-1)$. When positive, $\mathcal{L}(k)$ shows that an outsider has an incentive to join the coalition k. When negative, it signals an incentive to free-ride on the coalition's actions. The stable coalition coincides with the largest integer below the value of k for which $\mathcal{L}(k) = 0$ and $\mathcal{L}'(k) \leq 0$. In Section 4 we use numerical simulations to derive the equilibrium coalition size in the absence of lobbying, as well as under alternative lobbying scenarios.

[8] A non-trivial coalition is defined as a non-empty set of players, which implies $k > 1$.

Equilibrium abatement in the presence of lobbying

The equilibrium abatement policy in the presence of lobbying must be jointly efficient for the government and the interest groups. That is, it must maximise $W_j^l - C_j^l$, $\forall l = 1, ..., L$, subject to $G_j \geq \overline{G_j}$ for some constant $\overline{G_j}$ (and given firm j's optimal output decision, which is as in Eq. 29). The constraint $G_j \geq \overline{G_j}$ can be written as $\gamma W_j + (1-\gamma)\sum_{l=1}^{L} C_j^l \geq \overline{G_j}$, which implies $C_j^l \geq \left[\overline{G_j} - \gamma W_j - (1-\gamma)C_j^{-l}\right]/(1-\gamma)$, where $C_j^{-l} = \sum_{i=1, i\neq l}^{L} C_j^i$. Therefore $W_j^l - C_j^l$ is maximised when $C_j^l = \left[\overline{G_j} - \gamma W_j - (1-\gamma)C_j^{-l}\right]/(1-\gamma)$. This is equivalent to the maximization of $(1-\gamma)W_j^l - \overline{G_j} + \gamma W_j + (1-\gamma)C_j^{-l}$, which is achieved when q_j solves the following problem:

$$\max_{q_j} M_j^l = (1-\gamma)W_j^l + \gamma W_j + (1-\gamma)C_j^{-l}$$

subject to (28) and $q_j \in [0,1]$. The Kuhn-Tucker conditions require

$$\begin{gathered} \left(\frac{\partial M_j^l}{\partial q_j} - \lambda_j\right) \leq 0, \quad \left(\frac{\partial M_j^l}{\partial q_j} - \lambda_j\right) q_j = 0, \quad q_j \geq 0, \\ q_j \leq 1, \quad \lambda_j(1-q_j) = 0, \quad \lambda_j \geq 0 \end{gathered} \tag{37}$$

where λ_j is a Lagrangian multiplier. At this point, it becomes necessary to specify the lobbying scenario. We will focus here on the case of two lobbies (i.e. business and environmentalists), since this is the most complex of the three scenarios considered in the application. In this case, M_j^l becomes:

$$M_j^\pi(q_j^{\pi,D}, \bullet) = (1-\gamma)\Pi_j(q_j^{\pi,D}) + \gamma W_j(q_j^{\pi,D}, \bullet) + (1-\gamma)C^D(q_j^{\pi,D}, \bullet) + \lambda_j(1-q_j^{\pi,D})$$

$$M_j^D(q_j^{\pi,D}, \bullet) = -(1-\gamma)D(q_j^{\pi,D}, \bullet) + \gamma W_j(q_j^{\pi,D}, \bullet) + (1-\gamma)C_j^\pi(q_j^{\pi,D}) + \lambda_j(1-q_j^{\pi,D}),$$

for business and environmentalists respectively, where $C^D(q_j^{\pi,D}, \bullet) = \max\left[0, -D(q_j^{\pi,D}, \bullet) + \overline{D}(\overline{q_j}^\pi, \bullet)\right]$, and $C_j^\pi(q_j^{\pi,D}) = \max\left[0, \Pi_j(q_j^{\pi,D}) - \overline{\Pi}_j(\overline{q_j}^D)\right]$.[9] Using the definition of social welfare in $M_j^\pi(q_j^{\pi,D}, \bullet)$ and $M_j^D(q_j^{\pi,D}, \bullet)$, and upon differentiation, we obtain

$$\frac{\partial M_j^\pi(q_j^{\pi,D}, \bullet)}{\partial q_j^{\pi,D}} = \frac{\partial M_j^D(q_j^{\pi,D}, \bullet)}{\partial q_j^{\pi,D}} = \frac{\partial \Pi_j(q_j^{\pi,D})}{\partial q_j^{\pi,D}} + \gamma \frac{\partial S_j(q_j^{\pi,D})}{\partial q_j^{\pi,D}} - \frac{\partial D(q_j^{\pi,D}, \bullet)}{\partial q_j^{\pi,D}} \tag{38}$$

Hence, the Kuhn-Tucker conditions are identical for the business and environmental lobbies. With this in mind, and using the functional specifications introduced in Section 4, we can now proceed to derive the equilibrium abatement policies under unilateral action, full cooperation and partial cooperation.

[9] The expressions for C_j^D and C_j^π are obtained by simply applying the definition of a contribution schedule in (9).

Equilibrium under unilateral policy with business and environmental lobbies

When acting unilaterally, government j disregards the externality associated with emissions reductions. Formally, this can be captured by writing the optimal environmental damage function as $D = \omega \left[x_j(q_j^{\pi,D})(1 - q_j^{\pi,D}) + \sum_{i \neq j} x_j(\overline{q}_i^{\pi,D})(1 - \overline{q}_i^{\pi,D}) \right]$, where $x_j(q_j^{\pi,D})$ is firm j's optimal output (Eq. 29). Consequently (38) becomes

$$
\begin{aligned}
\frac{\partial M_j}{\partial q_j^{\pi,D}} &= -\sigma \left(\frac{1 - \sigma q_j^{\pi,D}}{2} \right) - \gamma \frac{\sigma}{2} \left(\frac{1 - \sigma q_j^{\pi,D}}{2} \right) + \omega \left[\frac{\sigma(1 - q_j^{\pi,D})}{2} + \frac{1 - \sigma q_j^{\pi,D}}{2} \right] \\
&= \frac{2\omega(1+\sigma) - (2+\gamma)\sigma}{4} - q_j^{\pi,D} \, \frac{\sigma(4\omega - (2+\gamma)\sigma)}{4} \qquad (39)
\end{aligned}
$$

The Kuhn-Tucker conditions in (37) are necessary and sufficient when $\omega > \frac{(2+\gamma)\sigma}{4}$. Provided the latter condition is satisfied, the interior solution is found by setting (39) equal to zero; the solution for $q_j = 0$ is found by setting $q_j = 0$ in (39) and solving for $\frac{\partial M_j}{\partial q_j^{\pi,D}} \leq 0$; and the solution for $q_j = 1$ is found by setting $q_j = 1$ in (39) and solving for $\frac{\partial M_j}{\partial q_j^{\pi,D}} \geq 0$.

If $\omega \leq \frac{(2+\gamma)\sigma}{4}$, then $\frac{\partial M_j}{\partial q_j^{\pi,D}}$ is non-decreasing in $q_j^{\pi,D}$. By setting $q_j^{\pi,D} = 1$ in (39) we obtain $\left. \frac{\partial M_j}{\partial q_j^{\pi,D}} \right|_{q_j^{\pi,D}=1} = \frac{(2\omega - (2+\gamma)\sigma)(1-\sigma)}{4}$, which is negative for $\omega \leq \frac{(2+\gamma)\sigma}{4}$. So we have $\frac{\partial M_j}{\partial q_j^{\pi,D}} < 0$ in equilibrium. From (37), this implies $q_j^{\pi,D} = 0$ is optimal when the second-order conditions fail to hold.

Removing the subscript j and expressing the optimal level of abatement in unilateral policy with two rival lobbies as $q_u^{\pi,D}$, the full solution is summarised below:

$$
q_u^{\pi,D} = \begin{cases} 0 & \text{if } \omega \leq \frac{(2+\gamma)\sigma}{2(1+\sigma)} \\ \frac{2\omega(1+\sigma) - (2+\gamma)\sigma}{\sigma(4\omega - (2+\gamma)\sigma)} & \text{if } \omega \in \left(\frac{(2+\gamma)\sigma}{2(1+\sigma)}, \frac{(2+\gamma)\sigma}{2} \right) \\ 1 & \text{if } \omega \geq \frac{(2+\gamma)\sigma}{2} \end{cases} \qquad (40)
$$

for $\omega > \frac{(2+\gamma)\sigma}{4}$, and $q_u^{\pi,D} = 0$ otherwise.

Equilibrium under full cooperation with business and environmental lobbies

Under full cooperation, each government fully internalises the pollution externality when choosing its optimal abatement policy. Formally, this implies that the optimal damage function must be differentiated with respect to every country's level of abatement. With symmetric countries, this leads to $\frac{\partial D}{\partial q_c^{\pi,D}} = \omega N \left[\frac{\sigma(1 - q_c^{\pi,D})}{2} + \frac{1 - \sigma q_c^{\pi,D}}{2} \right]$, where $q_c^{\pi,D}$ denotes the abatement standard imposed by each country under full cooperation. As a result, (38) becomes

$$
\frac{\partial M_c}{\partial q_c^{\pi,D}} = \frac{2\omega N(1+\sigma) - (2+\gamma)\sigma}{4} - q_c^{\pi,D} \, \frac{\sigma(4\omega N - (2+\gamma)\sigma)}{4} \qquad (41)
$$

Applying to (41) the same reasoning used in the derivation of the equilibrium in unilateral policies (see above), we obtain the following solution:

$$q_c^{\pi,D} = \begin{cases} 0 & \text{if } \omega \leq \frac{(2+\gamma)\sigma}{2(1+\sigma)N} \\ \frac{2\omega N(1+\sigma)-(2+\gamma)\sigma}{\sigma(4\omega N-(2+\gamma)\sigma)} & \text{if } \omega \in \left(\frac{(2+\gamma)\sigma}{2(1+\sigma)N}, \frac{(2+\gamma)\sigma}{2N}\right) \\ 1 & \text{if } \omega \geq \frac{(2+\gamma)\sigma}{2N} \end{cases}$$

for $\omega > \frac{(2+\gamma)\sigma}{4N}$, and $q_c^{\pi,D} = 0$ otherwise.

Self-enforcing IEA with business and environmental lobbies

Under partial cooperation, non-signatories pursue their individually optimal policies, thus setting their abatement level as in (40). Signatories maximise the aggregate payoff of the coalition, taking as given the abatement policies of those outside. This can be captured by writing the damage function as $D = \omega\left[kx_s(q_s^{\pi,D})(1-q_s^{\pi,D}) + (N-k)\overline{x}_n(\overline{q}_n^{\pi,D})(1-\overline{q}_n^{\pi,D})\right]$, where $q_s^{\pi,D}$ and $q_n^{\pi,D}$ denote signatories' and non-signatories' abatement levels respectively. Differentiation yields $\frac{\partial D}{\partial q_c^{\pi,D}} = \omega k\left[\frac{\sigma(1-q_s^{\pi,D})}{2} + \frac{1-\sigma q_s^{\pi,D}}{2}\right]$. Using this in (38), we obtain

$$\frac{\partial M_s}{\partial q_s^{\pi,D}} = \frac{2\omega k(1+\sigma)-(2+\gamma)\sigma}{4} - q_s^{\pi,D}\frac{\sigma(4\omega k-(2+\gamma)\sigma)}{4}$$

Applying again the same reasoning used to derive the equilibrium in unilateral policies, we find that the optimal level of abatement of a signatory is

$$q_s^{\pi,D} = \begin{cases} 0 & \text{if } \omega \leq \frac{(2+\gamma)\sigma}{2(1+\sigma)k} \\ \frac{2\omega k(1+\sigma)-(2+\gamma)\sigma}{\sigma(4\omega k-(2+\gamma)\sigma)} & \text{if } \omega \in \left(\frac{(2+\gamma)\sigma}{2(1+\sigma)k}, \frac{(2+\gamma)\sigma}{2k}\right) \\ 1 & \text{if } \omega \geq \frac{(2+\gamma)\sigma}{2k} \end{cases}$$

for $\omega > \frac{(2+\gamma)\sigma}{4k}$, and $q_s^{\pi,D} = 0$ otherwise.

Combining the above solution with Eq. (40), the following cases can be identified:

$$\text{for } k \geq 1+\sigma \Rightarrow \begin{cases} (a) & q_s^{\pi,D} = q_n^{\pi,D} = 0 & \text{if } \omega \leq \frac{(2+\gamma)\sigma}{2(1+\sigma)k} \\ (b) & q_s^{\pi,D} = \frac{2\omega k(1+\sigma)-(2+\gamma)\sigma}{\sigma(4\omega k-(2+\gamma)\sigma)}, q_n^{\pi,D} = 0 & \text{if } \omega \in \left(\frac{(2+\gamma)\sigma}{2(1+\sigma)k}, \frac{(2+\gamma)\sigma}{2k}\right] \\ (c) & q_s^{\pi,D} = 1, q_n^{\pi,D} = 0 & \text{if } \omega \in \left(\frac{(2+\gamma)\sigma}{2k}, \frac{(2+\gamma)\sigma}{2(1+\sigma)}\right) \\ (d) & q_s^{\pi,D} = 1, q_n^{\pi,D} = \frac{2\omega(1+\sigma)-(2+\gamma)\sigma}{\sigma(4\omega-(2+\gamma)\sigma)} & \text{if } \omega \in \left[\frac{(2+\gamma)\sigma}{2(1+\sigma)}, \frac{(2+\gamma)\sigma}{2}\right) \\ (e) & q_s^{\pi,D} = q_n^{\pi,D} = 1 & \text{if } \omega \geq \frac{(2+\gamma)\sigma}{2} \end{cases}$$

$$\text{for } k \in [1, 1+\sigma) \Rightarrow \begin{cases} (a') & q_s^{\pi,D} = q_n^{\pi,D} = 0 & \text{if } \omega \leq \frac{3\sigma}{2(1+\sigma)k} \\ (b') & q_s^{\pi,D} = \frac{2\omega k(1+\sigma)-(2+\gamma)\sigma}{\sigma(4\omega k-(2+\gamma)\sigma)}, q_n^{\pi,D} = 0 & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)k}, \frac{3\sigma}{2(1+\sigma)}\right] \\ (c') & q_s^{\pi,D} = \frac{2\omega k(1+\sigma)-(2+\gamma)\sigma}{\sigma(4\omega k-(2+\gamma)\sigma)}, q_n^{\pi,D} = \frac{2\omega(1+\sigma)-(2+\gamma)\sigma}{\sigma(4\omega-(2+\gamma)\sigma)} & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)}, \frac{3\sigma}{2k}\right) \\ (d') & q_s^{\pi,D} = 1, q_n^{\pi,D} = \frac{2\omega(1+\sigma)-(2+\gamma)\sigma}{\sigma(4\omega-(2+\gamma)\sigma)} & \text{if } \omega \in \left[\frac{3\sigma}{2k}, \frac{3\sigma}{2}\right) \\ (e') & q_s^{\pi,D} = q_n^{\pi,D} = 1 & \text{if } \omega \geq \frac{3\sigma}{2} \end{cases}$$

Notice that for $k = 1+\sigma$, case (c) collapses into (b); while for $k = 1$ cases (b') and (d') collapse into (a') and (e') respectively.

Appendix 3 Comprehensive map of the parameter space for marginal costs and benefits of abatement

Figure 3 presents equilibrium abatement under a self-enforcing IEA, for the full range of values of the parameters σ and ω, when $\gamma = 0.25$.

[FIGURE 3 HERE]

Figure 1: Benefits to cooperation.

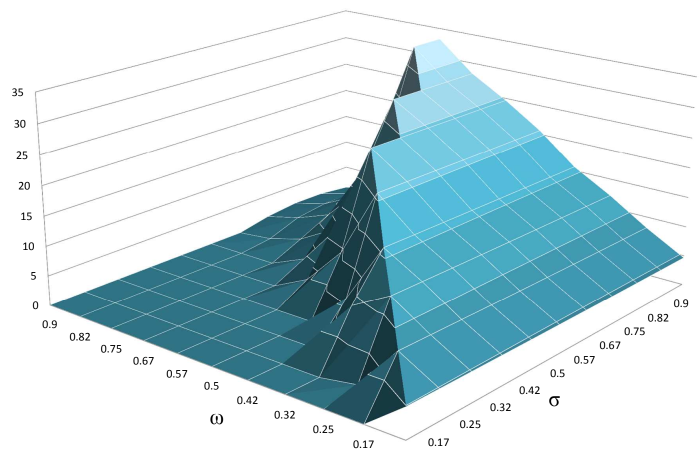
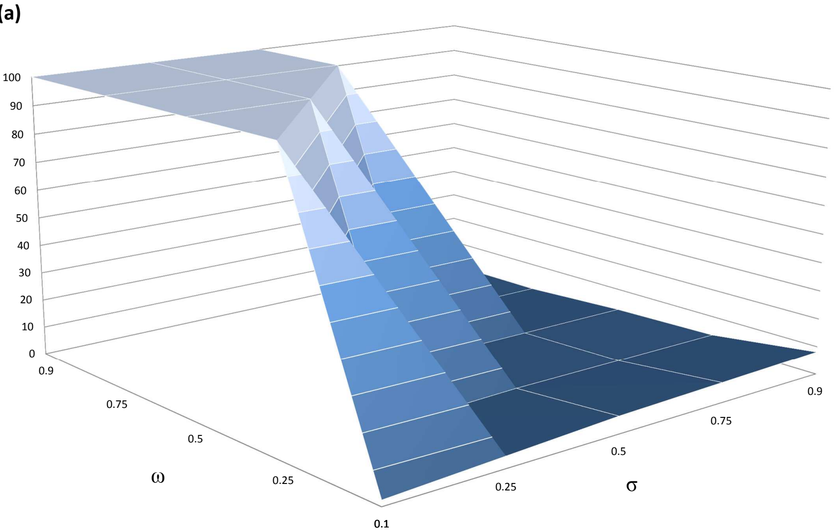


Figure 2: Equilibrium coalition size (a) and abatement (b) when countries may form a self-enforcing IEA, without lobbying.

(a)



(b)

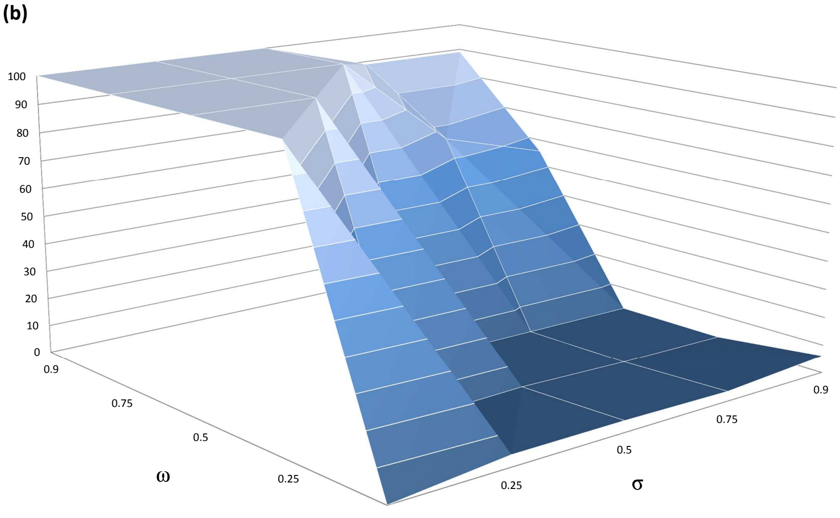


Figure 3: Equilibrium abatement under (a) business lobbying, (b) environmental lobbying and (c) business and environmental lobbying as a function of σ and ω; $\gamma = 0.25$.

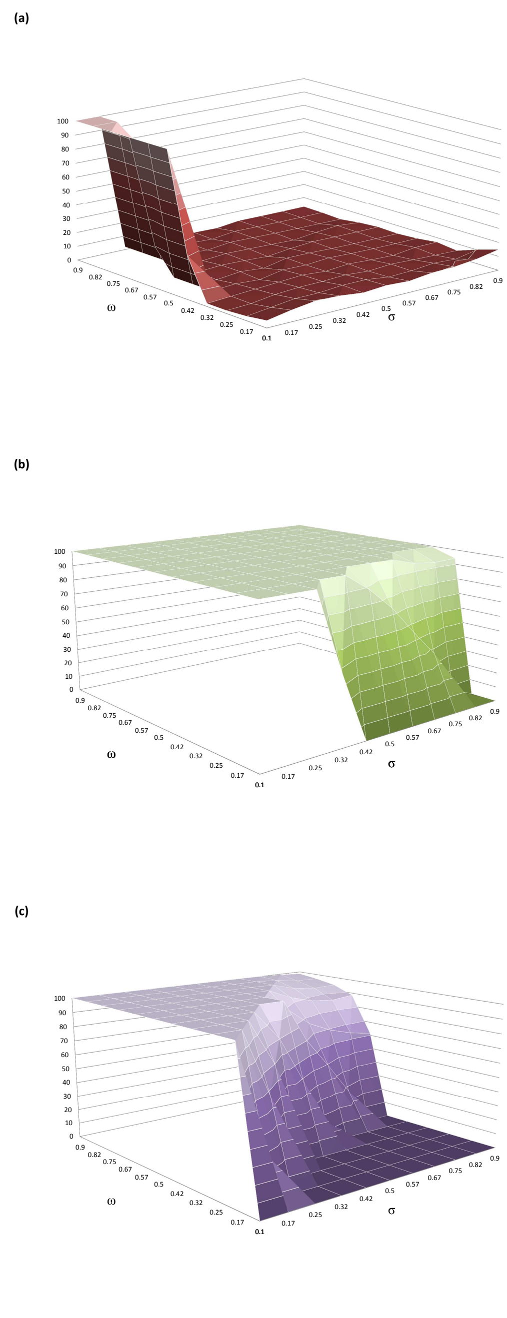


Table 1: Comparison of unilateral abatement levels with different types of lobbying.

Unilateral abatement level	No lobbies	Business lobby	Environmental lobby	Both lobbies
0	$\omega \leq \frac{3\sigma}{2(1+\sigma)}$	$\omega \leq \frac{\sigma(2+\gamma)}{2\gamma(1+\sigma)}$	$\omega \leq \frac{3\gamma\sigma}{2(1+\sigma)}$	$\omega \leq \frac{\sigma(2+\gamma)}{2(1+\sigma)}$
$0 < q_u < 1$	$\frac{2\omega-3\sigma+2\sigma\omega}{\sigma(4\omega-3\sigma)}$ if $\omega \in \left(\frac{3\sigma}{2(1+\sigma)}, \frac{3\sigma}{2}\right)$	$\frac{2\omega\gamma(1+\sigma)-\sigma(2+\gamma)}{\sigma(4\omega\gamma-\sigma(2+\gamma))}$ if $\omega \in \left(\frac{\sigma(2+\gamma)}{2\gamma(1+\sigma)}, \frac{\sigma(2+\gamma)}{2\gamma}\right)$	$\frac{2\omega(1+\sigma)-3\gamma\sigma}{\sigma(4\omega-3\gamma\sigma)}$ if $\omega \in \left(\frac{3\gamma\sigma}{2(1+\sigma)}, \frac{3\gamma\sigma}{2}\right)$	$\frac{2\omega(1+\sigma)-\sigma(2+\gamma)}{\sigma(4\omega-(2+\gamma)\sigma)}$ if $\omega \in \left(\frac{\sigma(2+\gamma)}{2(1+\sigma)}, \frac{\sigma(2+\gamma)}{2}\right)$
1	$\omega \geq \frac{3\sigma}{2}$	$\omega \geq \frac{\sigma(2+\gamma)}{2\gamma}$	$\omega \geq \frac{3\gamma\sigma}{2}$	$\omega \geq \frac{\sigma(2+\gamma)}{2}$

Table 2: Comparison of abatement levels under full cooperation, with different types of lobbying.

Full cooperative abatement level	No lobbies	Business lobby	Environmental lobby	Both lobbies
0	$\omega \leq \frac{3\sigma}{2(1+\sigma)N}$	$\omega \leq \frac{\sigma(2+\gamma)}{2\gamma(1+\sigma)N}$	$\omega \leq \frac{3\gamma\sigma}{2(1+\sigma)N}$	$\omega \leq \frac{\sigma(2+\gamma)}{2(1+\sigma)N}$
$0 < q_c < 1$	$\frac{2N\omega-3\sigma+2N\omega\sigma}{\sigma(4\omega N-3\sigma)}$ if $\omega \in \left(\frac{3\sigma}{2(1+\sigma)N}, \frac{3\sigma}{2N}\right)$	$\frac{2N\omega\gamma(1+\sigma)-\sigma(2+\gamma)}{\sigma(4N\omega\gamma-\sigma(2+\gamma))}$ if $\omega \in \left(\frac{\sigma(2+\gamma)}{2\gamma(1+\sigma)N}, \frac{\sigma(2+\gamma)}{2\gamma N}\right)$	$\frac{2N\omega(1+\sigma)-3\gamma\sigma}{\sigma(4N\omega-3\gamma\sigma)}$ if $\omega \in \left(\frac{3\gamma\sigma}{2(1+\sigma)N}, \frac{3\gamma\sigma}{2N}\right)$	$\frac{2N\omega(1+\sigma)-\sigma(2+\gamma)}{\sigma(4N\omega-(2+\gamma)\sigma)}$ if $\omega \in \left(\frac{\sigma(2+\gamma)}{2(1+\sigma)N}, \frac{\sigma(2+\gamma)}{2N}\right)$
1	$\omega \geq \frac{3\sigma}{2N}$	$\omega \geq \frac{\sigma(2+\gamma)}{2\gamma N}$	$\omega \geq \frac{3\gamma\sigma}{2N}$	$\omega \geq \frac{\sigma(2+\gamma)}{2N}$

Table 3: Simulation of equilibrium coalition size and abatement under a self-enforcing IEA, with different types of lobbying.

			No lobbies	Business lobby	Environ-mental lobby	Both lobbies
γ	0.25	$k*$	2	4	100	0
		$Q(k*)$	1.998	3.535	100	88.38
		q_n	0	0	1	0.884
		q_s	0.999	0.884	1	1
	0.5	$k*$	2	3	0	0
		$Q(k*)$	1.998	2.955	99.92	76.49
		q_n	0	0	0.999	0.765
		q_s	0.999	0.985	1	1
	0.75	$k*$	2	2	0	0
		$Q(k*)$	1.998	1.933	88.38	38.48
		q_n	0	0	0.884	0.385
		q_s	0.999	0.967	1	1

$\sigma = 0.9$; $\omega = 0.67$; $N = 100$