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Simon Dietz

*Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science,  
Department of Geography and Environment, London School of Economics and Political Science*

Carmen Marchiori

*Department of Geography and Environment, London School of Economics and Political Science, c.marchiori@lse.ac.uk*

Alessandro Tavoni

*Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science*

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# Domestic politics and the formation of international environmental agreements

Simon Dietz<sup>\*†</sup>, Carmen Marchiori<sup>†</sup> and Alessandro Tavoni<sup>\*</sup>

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## Abstract

The theory of international environmental agreements overwhelmingly assumes that governments engage as unitary agents. Each government makes choices based on benefits and costs that are simple national aggregates, and similarly on a single set of national-level motivations, together drawing a strong analogy with the behaviour of an individual or firm in other strategic contexts. In reality, however, various domestic special interests shape environmental policy, including how national governments cooperate on cross-border issues. Therefore in this paper we introduce to a classic model of international environmental cooperation the phenomenon of domestic political competition, whereby lobby groups seek to influence policy by offering to fund political campaigning. We use the model to establish some general conditions for the effects of lobbying on the stringency of policy and the size of coalitions cooperating to provide an environmental good. Using specific functional forms, we obtain a range of further results, including circumstances in which the omission of lobbying results in environmental protection being underestimated.

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

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

<sup>\*</sup>Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science.

<sup>†</sup>Department of Geography and Environment, London School of Economics and Political Science.

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Email for correspondence: c.marchiori@lse.ac.uk

Telephone: +44 207 852 3767.

## 1 Introduction

The game theory of international environmental agreements (IEAs) has already 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.<sup>1</sup>

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 (Dannenbergh, 2012; Kosfeld et al., 2009; Tavoni et al., 2011), thus broadening the set of motivations assumed to act on the 'players'.<sup>2</sup>

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 its private (i.e. 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). The primary aim of the present work is to enrich the theory of IEA formation with an account from political-economic theory of the role played by special-interest groups in environmental policy-making.

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.<sup>3</sup> 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

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<sup>1</sup>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).

<sup>2</sup>For IEA theory including preferences for fairness, see for example Lange and Vogt (2003).

<sup>3</sup>Indeed some (e.g. Grossman and Helpman, 2001) define such informational/educational activities as 'lobbying', whereas our definition is broader, as stated.

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 most consistent with this 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) and by scholars in environmental policy and politics, although it is predominantly in the latter field that domestic policy towards transboundary public goods provision has been considered<sup>4</sup> (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 made about providing international environmental goods that more unilateral action is observed in reality than would be predicted by the standard theory (Kolstad, 2012).

In this paper, we take as our starting point a classic IEA stage-game in the tradition of Barrett (1994; 1997), Carraro and Siniscalco (1993), Hoel (1992) and others. The game surrounds the provision of a transboundary public good, couched in terms of pollution abatement (and linked with production of a homogeneous good), while the stages are defined as follows: (i) countries decide in a non-cooperative mode whether to sign the treaty; (ii) signatories and non-signatories set their levels of abatement; and (iii) firms choose their own output by taking governments’ abatement decisions as given.

We combine this model with a model of lobbying fashioned after the approach of Grossman and Helpman (2001). The principal addition is therefore a set of lobby groups in each country, each of which establishes a contribution schedule linking its ‘gifts’ to the various possible abatement levels chosen by the government. The Grossman and Helpman model of lobbying 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 the model is consistent with a mixed public/private view of the motives of public officials (e.g. Besley, 2006).

The combination of the two models is achieved by constructing the following stage game: first, governments, whose objective functions include as elements *both* lobby-group contributions *and* aggregate social welfare, choose whether to be signatories to an IEA; second, domestic lobby groups present their own governments with prospective contributions, which depend on the abatement policy chosen; third, governments (both signatories to the IEA and non-signatories) choose their abatement policies; and fourth, firms decide how much to produce taking as given the abatement policy set by the

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<sup>4</sup>But see Johal and Ulph (2002).

government. As usual, we solve the model by backward induction. The structure of the game 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*. In this way the abatement standard can be interpreted as a ‘political variable’, whose value is anticipated by governments when deciding whether to sign the treaty.

The paper is structured as follows. We begin in Section 2 with the case in which national policies are made unilaterally. 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 affects the abatement standard it sets (in Appendix 1 we set out the corresponding analysis when all countries cooperate, which is very similar to the unilateral case). In Section 3, we go on to consider the formation of an IEA, using the model described just now. 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 the relative magnitude of lobby groups’ contributions depends, however, on functional specification, we complete the analysis in Section 4 by applying specific functional forms and using numerical simulation. We obtain a range of findings, considering three different configurations of lobbying: business lobbying; environmental lobbying; and business and environmental lobbying. 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 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. Inverse demand in country  $j$  is denoted by  $p(x_j)$ . Firm  $j$ ’s costs are  $A(x_j, q_j) = a(q_j)x_j$ , where  $q_j \in [0, 1]$  is the abatement standard faced by firm  $j$  and  $a(q_j)$  is the abatement cost per unit of output. Firm  $j$  emits pollution  $x_j(1 - q_j)$ , so for given  $q_j$  its optimisation problem is

$$\max_{x_j} \Pi_j = (p(x_j) - a(q_j))x_j \quad (1)$$

and the first-order conditions for an interior solution require

$$\frac{\partial p(x_j)}{\partial x_j} x_j + p(x_j) - a(q_j) = 0. \quad (2)$$

### 2.2 Unilateral abatement policy stage

In a similar vein to Grossman and Helpman (2001), government  $j$ ’s net benefits are – i.e. its political utility function is –

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

where  $W_j$  is country  $j$ ’s aggregate social welfare,  $L$  is the set 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.<sup>5</sup> Aggregate social welfare is further given by

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

where  $\Pi_j$  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 emissions in all countries. Accordingly, we assume that the derivatives of the three elements of (4) with respect to  $q_j$  are negative:  $\nabla \Pi_j(q_j) < 0$ ;  $\nabla S_j(q_j) < 0$ ;  $\nabla D(q_j, \bar{q}_{-j}) < 0$ .

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:

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

subject to (2). The FOC is

$$\gamma \nabla W_j(q_j, \bar{q}_{-j}) + (1 - \gamma) \sum_{l=1}^L \nabla C_j^l(q_j) = 0. \quad (5)$$

It is also useful to briefly identify the optimal unilateral policy in the absence of political influence, since it will provide 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

$$\max_{q_j} G_j = W_j(q_j, \bar{q}_{-j})$$

subject to (2). The FOC is

$$\nabla W_j(q_j, \bar{q}_{-j}) = 0$$

and it will shortly prove useful to express it in terms of the components of (4):

$$\nabla \Pi_j(q_j) + \nabla S_j(q_j) - \nabla D(q_j, \bar{q}_{-j}) = 0. \quad (6)$$

### 2.3 Lobbying stage

Lobby groups have preferences over abatement standards and attempt to influence the government by – implicitly, remember – promising to contribute to the campaign funds of politicians serving the incumbent government, conditional on the abatement standard they choose. The objective function of lobby group  $l$  in country  $j$  is

$$U_j^l = W_j^l(q_j, \bar{q}_{-j}) - C_j^l(q_j) \quad (7)$$

where  $W_j^l(q_j, \bar{q}_{-j})$  is the gross-of-contribution utility of lobby group  $l$ , which may or may not depend on abatement standards 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. The group's utility is strictly decreasing in  $C_j^l(q_j)$ , reflecting

<sup>5</sup>And, evidently from the summation operator, the government has no preference over the source of its gifts.

the costliness of the contribution for the group. We assume that both  $W_j^l(\cdot)$  and  $C_j^l(\cdot)$  are continuous and differentiable local to the equilibrium, that gross-of-contribution utility has to be strictly larger than it would otherwise be in order for a positive contribution to be offered, and that contributions cannot be negative. Therefore, following Grossman and Helpman (2001), a general expression for the contribution function of lobby group  $l$  is

$$C_j^l(q_j) = \max \left[ 0, W_j^l(q_j, \bar{q}_{-j}) - \overline{W}_j^l(\bar{q}_j^{-l}, \bar{q}_{-j}^{-l}) \right] \quad (8)$$

where  $\overline{W}_j^l$  denotes its utility in the absence of any political contribution of its own, being instead a function of social welfare and the given contributions of other lobbies  $-l$ .

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 utility  $G_j$ . In addition, it takes the contribution schedules of all the other lobby groups as given. The purpose of offering gifts is clearly 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 great as it would be in the absence of any contribution by the lobby group in question.

The equilibrium abatement policy is attained when there is no other abatement standard  $q_j$  and no other level of campaign gift that could be offered, such that a lobby group is better off, and the government is no worse off, for all lobby groups. We can say that such an abatement standard is jointly efficient for all lobby groups and for the government. Formally, the equilibrium can be derived, together with the optimal contribution schedules, by solving the following:

$$\max_{q_j} W_j^l(q_j, \bar{q}_{-j}) - C_j^l(q_j) + \gamma W_j(q_j, \bar{q}_{-j}) + (1 - \gamma) \sum_{l=1}^L C_j^l(q_j).$$

The FOC is

$$\nabla W_j^l(q_j, \bar{q}_{-j}) - \nabla C_j^l(q_j) + \gamma \nabla W_j(q_j, \bar{q}_{-j}) + (1 - \gamma) \sum_{l=1}^L \nabla C_j^l(q_j) = 0 \quad (9)$$

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

Combining conditions (5) and (9), we have

$$\nabla W_j^l(q_j, \bar{q}_{-j}) = \nabla C_j^l(q_j) \quad \forall l = 1, \dots, L. \quad (10)$$

## 2.4 The effect of lobbying

At this stage, let us explore the effects of domestic lobbying, in various forms, on unilateral abatement policy. Given our specification of social welfare (4), there is the potential for lobbying from three sources: business, which seeks to maximise its profits, consumers, who seek to maximise consumer surplus, and 'environmentalists', who seek to minimise domestic environmental damage.

**Lemma 1.** *Given aggregate social welfare (4), 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 1, consider the leading example of lobbying undertaken by business and environmentalists, but not by consumers. It is consistent with the literature on domestic political competition over environmental policy, discussed in Section 1, and it is arguably consistent with the logic of collective action, which points towards the extra difficulty faced by consumers in self-organising into a lobby, since the impact on them of changes in the abatement standard is especially diffuse.

The business lobby's utility function is

$$U_j^\pi = \Pi_j(q_j) - C_j^\pi(q_j). \quad (11)$$

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

$$U_j^D = -D(q_j, \bar{q}_{-j}) - C_j^D(q_j, \bar{q}_{-j}).$$

Using (10), the FOCs describing the contributions of the two lobby groups in equilibrium are:

$$\begin{aligned} \nabla \Pi_j(q_j) &= \nabla C_j^\pi(q_j) \\ -\nabla D(q_j, \bar{q}_{-j}) &= \nabla C_j^D(q_j, \bar{q}_{-j}) \end{aligned}$$

These can be substituted into (5) in order to obtain the FOC describing the government's abatement standard:

$$\nabla G_j^{\pi,D} = \nabla \Pi_j(q_j) + \gamma \nabla S_j(q_j) - \nabla D(q_j, \bar{q}_{-j}) = 0. \quad (12)$$

An alternative way to derive (12) is to make use of the constraint on the contribution of either lobby group that the government's utility must be at least as great as it would be in the absence of the contribution,  $G_j^{\pi,D} \geq \bar{G}_j$ .<sup>6</sup>

Equation (12) can be directly compared with the no-lobbying case in (6), and it can readily be seen that the difference is that the new equilibrium abatement standard is, broadly speaking, less sensitive to consumer surplus. Thus we have an example of Lemma 1. 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 domestic environmental damage with respect to the abatement standard receive a weight of one, due to the influence of the respective lobby groups. It is easy to further show that, if either the business or environmental lobby is assumed away, then the weight  $\gamma$  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.<sup>7</sup> Finally, equation (12) also enables us to re-express the two lobby groups' marginal campaign contributions in equilibrium:

$$\nabla C_j^\pi(q_j) = \nabla D(q_j, \bar{q}_{-j}) - \gamma \nabla S_j(q_j)$$

<sup>6</sup>Taking for example the business lobby's standpoint,

$$G_j^{\pi,D} \geq \bar{G}_j \iff \gamma W_j(q_j, \bar{q}_{-j}) + (1 - \gamma) [C_j^\pi(q_j) + C_j^D(q_j)] \geq \bar{G}_j$$

which can be re-expressed in terms of  $C_j^\pi(q_j)$ :

$$C_j^\pi(q_j) \geq \frac{\bar{G}_j - \gamma W_j(q_j, \bar{q}_{-j}) - (1 - \gamma) C_j^D(q_j)}{1 - \gamma}$$

The business lobby seeks to maximise its own utility (11), which after substitution of the right-hand side of the above expression and rearrangement, gives (12).

<sup>7</sup>That is, in the case where there is only a business lobby



$$\nabla C^D(q_j, \bar{q}_{-j}) = -\nabla \Pi_j(q_j) - \gamma \nabla S_j(q_j)$$

Let  $q_u$  denote the solution to (6),  $q_u^{\pi, D}$  the solution to (12), and  $q_u^D$  and  $q_u^\pi$  the corresponding solutions in the presence of an environmental lobby alone and a business lobby alone, respectively. 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 (12), and studying its sign.

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

*Proof:* By differentiating (12) and collecting terms, we can obtain, in the case of rival lobbying by business and environmentalists,

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

The sign of  $\frac{dq_j}{d\gamma}$  depends exclusively on the sign of the denominator, because the numerator is always positive;  $\nabla^2 G_j^{\pi, D} \leq 0$  is necessary for a solution to the FOC to be a maximum, so  $\frac{-\nabla S_j(q_j)}{\nabla^2 G_j^{\pi, D}} < 0$  (if  $\nabla^2 G_j^{\pi, D} = 0$  then  $q$  is not differentiable with respect to  $\gamma$ ). Hence,  $q_u^{\pi, D} \geq q_u$ . In the case of environmental lobbying alone,  $\frac{dq_j}{d\gamma} = \frac{-\nabla \Pi_j(q_j) - \nabla S_j(q_j)}{\gamma \nabla^2 \Pi_j(q_j) + \gamma \nabla^2 S_j(q_j) - \nabla^2 D(q_j, \bar{q}_{-j})} = \frac{-\nabla \Pi_j(q_j) - \nabla S_j(q_j)}{\nabla^2 G_j^D} < 0 \Rightarrow q_u^D \geq q_u$ . ■

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

*Proof:*  $\frac{dq_j}{d\gamma} = \frac{-\nabla S_j(q_j) + \nabla D(q_j, \bar{q}_{-j})}{\nabla^2 \Pi_j(q_j) + \gamma \nabla^2 S_j(q_j) - \gamma \nabla^2 D(q_j, \bar{q}_{-j})} = \frac{-\nabla S_j(q_j) + \nabla D(q_j, \bar{q}_{-j})}{\nabla^2 G_j^\pi}$ . 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  $-\nabla D(q_j, \bar{q}_{-j}) > 0$ . 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  $-\nabla S_j(q_j) + \nabla D(q_j, \bar{q}_{-j}) > 0$ . 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 would be in the absence of lobbying, while it is at least as low when it is lobbied solely by business. These results should come as no surprise. Perhaps more surprising is that, with rival lobbying from business and

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

and in the case where there is only an environmental lobby

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

environmental advocacy groups, the equilibrium abatement standard is at least as high as it would be without lobbying. Note by inspecting the numerators of  $\frac{dq_i}{d\gamma}$  in the proofs of Propositions 1 and 2 that the preferences of the interest group(s) which do not self-organise have a bearing on the relative success of the organised groups.

Analogous results to the ones identified in this Section hold if governments cooperate fully in the abatement policy stage. See Appendix 1 for the derivations.

### 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 the coalition (i.e. joint welfare maximisation), 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. IEA) or to remain an outsider. Equilibrium coalition structures are then determined by applying the concepts of internal and external stability, which will shortly be formally defined.

Introducing the possibility of forming an IEA therefore requires that we modify the structure of the game so as to explicitly incorporate decisions about participation and joint welfare maximization by coalition members. The modified game consists of the following stages: (i) a membership stage; (ii) a lobbying stage, in which domestic lobby groups in both signatories and non-signatories 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.

Before presenting the model (skipping the firm stage for obvious reasons), it is opportune to comment briefly on the implications of our ordering of stages. As mentioned above, in the standard coalition-theoretic model of IEA formation, the first stage is indeed the membership stage. We follow this convention, which implies that lobbying happens after governments have made their decisions on IEA membership. Yet, since it is assumed governments can look forwards and reason backwards, they will of course take into consideration the gifts they might receive from lobby groups in making their membership decisions. Furthermore, by making lobbying the second stage, gifts are linked directly to abatement standards, which is what, in our set-up, lobbies are interested in first and foremost (i.e. rather than coalition membership *per se*).

#### 3.1 Abatement policy stage

Let  $k$  be the endogenously determined subset of countries that decide to take part in 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 the non-signatory's abatement standard  $q_n$  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, and

$$\gamma \nabla W_n(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) + (1-\gamma) \sum_{l=1}^L \nabla C_n^l(q_n) = 0. \quad (13)$$

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 is now

$$\gamma \nabla W_s(q_s, (k-1)q_s, \overline{(N-k)q_n}) + (1-\gamma) \sum_{l=1}^L \nabla C_s^l(q_s) = 0. \quad (14)$$

Note that for  $\gamma = 1$  equations (13) and (14) 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

In the lobbying stage, the joint-efficiency problem for lobby groups in non-signatory and signatory countries respectively is

$$\begin{aligned} & \max_{q_n} W_n^l(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) - C_n^l(q_n) + \\ & + \gamma W_n(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) + (1-\gamma) \sum_{l=1}^L C_n^l(q_n) \\ & \max_{q_s} W_s^l(q_s, (k-1)q_s, \overline{(N-k)q_n}) - C_s^l(q_s) + \\ & + \gamma W_s(q_s, (k-1)q_s, \overline{(N-k)q_n}) + (1-\gamma) \sum_{l=1}^L C_s^l(q_s). \end{aligned}$$

The FOCs for the above problems are

$$\begin{aligned} & \nabla W_n^l(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) - \nabla C_n^l(q_n) + \\ & + \gamma \nabla W_n(q_n, \overline{(N-k-1)q_n}, \overline{kq_s}) + (1-\gamma) \sum_{l=1}^L \nabla C_n^l(q_n) = 0 \end{aligned} \quad (15)$$

$$\begin{aligned} & \nabla W_s^l(q_s, (k-1)q_s, \overline{(N-k)q_n}) - \nabla C_s^l(q_s) + \\ & + \gamma \nabla W_s(q_s, (k-1)q_s, \overline{(N-k)q_n}) + (1-\gamma) \sum_{l=1}^L \nabla C_s^l(q_s) = 0. \end{aligned} \quad (16)$$

The solutions to (15) and (16) will be denoted by  $q_n^{\mathbf{L}}$  and  $q_s^{\mathbf{L}}$  respectively, where the superscript  $\mathbf{L}$  refers to different lobbying scenarios (e.g. environmental lobby alone, business lobby alone, environmental and business lobbies). Note that  $q_n^{\mathbf{L}}$  – i.e. the level of abatement that is jointly efficient for all lobby groups and for the government in a non-signatory country – coincides with the unilateral abatement policy derived in 2.3, and is independent of  $k$ . Therefore the effect of different lobby configurations on  $q_n^{\mathbf{L}}$  is as summarised in Propositions 1 and 2. Applying the same logic used in Section 2.4 to equation (16), it can be shown that similar patterns obtain for  $q_s^{\mathbf{L}}$ , thus leading to the following proposition:

**Proposition 3.** *Consider the following configurations: (i) no lobby ( $\mathbf{L} = 0$ ); (ii) business lobby alone ( $\mathbf{L} = \pi$ ); (iii) environmental lobby alone ( $\mathbf{L} = D$ ); and (iv) business and environmental lobbies ( $\mathbf{L} = \pi, D$ ). For a given  $k$ , the order of signatories' level of abatement under partial cooperation is as follows:  $q_s^D(k)|k \geq q_s^{\pi, D}(k)|k \geq q_s^0(k)|k \geq q_s^\pi(k)|k$ .*

Of course, in a game of partial cooperation  $k$  is endogenously determined. Therefore the results stated in Propositions 1, 2 and 3 will have implications for equilibrium coalition size and total abatement under the various lobbying scenarios, as we will see in the following sections.

By substituting the optimal levels of abatement  $q_n^{\mathbf{L}}$  and  $q_s^{\mathbf{L}}$  into  $G_n(\cdot)$  and  $G_s(\cdot)$ , one can express the payoffs of signatories and non-signatories as a function of  $k$  (and  $\gamma$ ). These optimal payoff functions will be denoted by  $G_n^*$  and  $G_s^*$  and used to solve the membership stage below.

### 3.3 IEA membership stage

In non-cooperative coalition models, the equilibrium coalition size is typically 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  $j$  with  $j \in \{s, n\}$ . 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; Carraro and Marchiori, 2003).

In our setting with lobbying, the optimal payoffs to signatories and non-signatories are given by  $G_s^*$  and  $G_n^*$  respectively, which depend on both  $k$  and  $\gamma$ . 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

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

The relevant conditions for a stable coalition become:

$$\begin{aligned} \mathcal{L}(k, \gamma) = 0 &\Rightarrow \\ \gamma(W_s(k, \gamma) - W_n(k - 1, \gamma)) + (1 - \gamma) \sum_{l=1}^L (C_s^l(k, \gamma) - C_n^l(k - 1, \gamma)) &= 0 \end{aligned} \tag{17}$$

$$\begin{aligned} \nabla_k \mathcal{L}(k, \gamma) < 0 \Rightarrow \gamma(\nabla_k W_s(k, \gamma) - \nabla_k W_n(k - 1, \gamma)) + \\ + (1 - \gamma) \sum_{l=1}^L (\nabla_k C_s^l(k, \gamma) - \nabla_k C_n^l(k - 1, \gamma)) < 0. \end{aligned} \quad (18)$$

From the value of  $k$  satisfying the above conditions, we can identify the equilibrium coalition size under lobbying, which will be denoted by  $k^L$ . Notice that for  $\gamma = 1$  equations (17) and (18) can be used to determine the stable coalition in the absence of lobbying. This will be denoted by  $k^0$ . In order to investigate how the presence of lobbying affects the equilibrium coalition size, and given that  $k^0 = k^L$  when  $\gamma = 1$ , one can proceed by deriving  $\frac{dk}{d\gamma}$  from (17) and studying its sign. This leads to the following result:

**Proposition 4.** *In the presence of lobbying by  $L$  special-interest groups, the equilibrium size  $k^L$  of an IEA is weakly larger (smaller) than the equilibrium coalition size  $k^0$  in the absence of lobbying, provided  $\sum_{l=1}^L (C_n^l(k^L - 1, \gamma) - C_s^l(k^L, \gamma))$  is weakly larger (smaller) than zero.*

*Proof:* By differentiating (17) and collecting terms we can obtain  $\frac{dk}{d\gamma} =$

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

The denominator of  $\frac{dk}{d\gamma}$  coincides with  $\nabla_k \mathcal{L}(k, \gamma)$ . Thus it must be smaller than zero for (18) to hold. From (17), we have  $\gamma(W_n - W_s) = (1 - \gamma) \sum_{l=1}^L (C_n^l - C_s^l)$ . Using this equality, we can re-write the numerator of  $\frac{dk}{d\gamma}$  as simply  $\frac{2(1-\gamma)}{\gamma} \sum_{l=1}^L (C_n^l - C_s^l)$ . If  $\sum_{l=1}^L (C_n^l - C_s^l) \geq 0$ , then the numerator is non-negative and  $\frac{dk}{d\gamma} \leq 0$ , which implies  $k^L \geq k^0$ . ■

## 4 An application of the model

So far we have established conditions in a general setting for the effect of lobbying on abatement. However, since many of those effects are ambiguous, depending as they do on functional specification, it is worth pursuing an application here where we choose particular functional forms for firm profits (1), consumer surplus and environmental damage. In order to remain close to the existing literature, our functional specification is very similar to Barrett (1997), who also explicitly modelled firm behaviour (albeit his interest was in trade), and whose model has the additional advantage of making assumptions that are a natural starting point.

Inverse demand in country  $j$  is  $p(x_j) = 1 - x_j$ . Firm  $j$  faces the production-cost function  $A(x_j, q_j) = \sigma q_j x_j$ , where the unit cost of abatement  $\sigma < 1$ . Hence the optimisation problem for firm  $j$  is now

$$\max_{x_j} \Pi_j = (1 - x_j - \sigma q_j) x_j. \quad (19)$$

Given how we specify inverse demand, we can represent consumer surplus  $S_j = (x_j)^2/2$ . Pollution is assumed to be a pure public bad, and marginal environmental damage for each country is a constant  $\omega$ . Thus  $D = \omega \left[ \sum_{j=1}^N x_j(1 - q_j) \right]$  and we have a special case of the aggregate social welfare function in Eq. (4):

$$W_j = (1 - x_j - \sigma q_j)x_j + (x_j)^2/2 - \omega \left[ \sum_{j=1}^N x_j(1 - q_j) \right]. \quad (20)$$

With these specific functional forms, we can derive analytical expressions for equilibrium abatement by country  $j$ , which depends on the parameters  $\sigma$ ,  $\omega$ , the government's taste for money  $\gamma$ , and (where partial or full cooperation is concerned) the number of signatories/total number of countries. The analysis required to derive these expressions is long and involved, so we relegate most of it to Appendix 2 and here we instead use Tables 1-3 as a convenient way to summarise the cases of unilateral abatement policy, full cooperation and a self-enforcing IEA respectively.

[TABLES 1-3 ABOUT HERE]

Looking at the equilibrium in unilateral policies set out in Table 1 and at full cooperation in Table 2, it is evident that, providing  $\gamma < 1$ , abatement in the sole presence of a business lobby is no larger than in the absence of lobbying, while in the sole presence of an environmental lobby, or when both lobbies are present, it is at least as large. Overall, we can see that the order of abatement under unilateral policy or full cooperation is as follows: environmental lobbying alone  $\geq$  business and environmental lobbying  $\geq$  no lobbying  $\geq$  business lobbying alone.

Table 3 presents the corresponding results for the self-enforcing IEA.<sup>8</sup> For a given  $k$  the same pattern obtains, however  $k$  is of course endogenously determined. To proceed we could solve the model analytically, but closed-form solutions for the equilibrium coalition size can only be obtained in a subset of cases and in any event the resulting expressions are so large as to be of very limited expositional value. Therefore we will use simulation to understand how abatement under a self-enforcing IEA depends on lobbying. Appendix 3 contains results for a comprehensive map of the parameter space, but across most of that space the disparity between marginal abatement costs and marginal environmental damages is so large as to ensure that equilibrium abatement is either zero or one, regardless of lobbying. Consequently we focus on the more interesting case in which marginal costs and benefits are in a fine balance and lobbying matters.<sup>9</sup>

Table 4 compares abatement under different kinds of lobbying in the case where countries may form a self-enforcing IEA. Results are also presented for the non-cooperative and full-cooperative models, as a point of reference. Notice in this regard that, for any of the three values of  $\gamma$  chosen, the order of the level of abatement under the non-cooperative and full-cooperative equilibria is consistent with Tables 1 and 2 above. Abatement is greatest in the presence of environmental lobbying alone, followed by the case of two lobbies, followed by no lobbying, with the least abatement taking place when lobbying is done only by business.

Turning now to a self-enforcing IEA, notice that abatement is also highest in the presence of an environmental lobby alone. Indeed, for the chosen values of  $\sigma$  and  $\omega$ , environmental lobbying alone can lead to a grand coalition in which all countries undertake maximum abatement,  $q_s = 1$ . In the

<sup>8</sup>Note that the conditions in Table 3 only hold for  $k > 1 + \sigma$ . If  $k = 1 + \sigma$  then case (c) disappears. If  $k < 1 + \sigma$  then cases (b)-(d) are slightly modified.

<sup>9</sup>In particular, we choose  $\sigma = \omega = 0.501$ . Similar results obtain for other joint values of the two parameters.

case of two rival lobbies, however, abatement is partial. In particular, there is no stable and non-trivial coalition, but the parameterisation puts us in case (d) in Table 4, such that it is in the interests of all countries, acting unilaterally, to undertake  $0 < q_n < 1$ . Notice that case (d) also obtains in the absence of lobbying, but that abatement is lower than in the case of two rival lobbies, as it is with no cooperation and with full cooperation.

[TABLE 4 ABOUT HERE]

A particularly interesting feature is that, when countries may form a self-enforcing IEA, equilibrium abatement in the presence of a business lobby alone can actually be *larger* than in the absence of lobbying. For  $\gamma \in [0.25, 0.5]$ , there is a small stable coalition of four and two countries respectively, each member of which undertakes significant abatement. To see why this result can obtain, the top panel of Figure 1 plots equilibrium abatement as a function of  $\gamma$  when countries may form a self-enforcing IEA, for  $\gamma \in [0, 1]$ . Observe that when  $\gamma$  is low equilibrium abatement under business lobbying alone is positive and indeed for very low (but positive)  $\gamma$  it can be quite significant. The reason for this is evident when we consider the bottom panel of Figure 1, which plots as a function of  $\gamma$  the benefits to cooperation under business lobbying, defined as the difference in political utility  $G_j$  under full cooperation compared with unilateral action. These benefits stem from a reduction in environmental damage, but the value that the government places on reducing environmental damage falls as  $\gamma$  falls, when the government is only being lobbied by business. Hence when  $\gamma$  is small, the benefits to cooperation are small. But it is a classic result from IEA theory that, with small benefits to cooperation, the incentive for countries to free-ride is correspondingly small (e.g. Barrett, 1994), and as a consequence stable coalitions are actually *more* likely to form, *ceteris paribus*. That is the effect we observe here and it also explains why abatement is a decreasing function of  $\gamma$  for any of the three configurations of lobbying (with some exceptions under business lobbying alone, including when  $\gamma \in [0, 0.5]$ ), despite business groups and environmental advocacy groups being quite differently motivated.

[FIGURE 1 ABOUT HERE]

Lastly, Figure 2 is concerned with comparing the effect on abatement of a changing balance of marginal costs and benefits on the one hand, with changing  $\gamma$  on the other hand, in the case of the two rival lobbies. It can be seen that equilibrium abatement is increasing in marginal environmental damage, for fixed marginal abatement costs, and that it is also increasing in the weight placed on lobby-group contributions. As the contour lines indicate, the same aggregate emissions abatement can be delivered in a situation where either the marginal benefits of abatement are relatively low (in relation to marginal costs) yet the government is much influenced by lobbying, or the marginal benefits of abatement are relatively high (again in relation to marginal costs) at the same time as the government is little influenced by lobbying. Similar qualitative patterns obtain if we repeat this analysis for the business or environmental lobbies alone.

[FIGURE 2 ABOUT HERE]

## 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 engage as unitary agents, where each maximises a simple, national-aggregate objective function. 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. To do this we combined 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 business and/or environmental advocacy groups.

We first showed in a general setting that the influence of lobby groups on policy stringency depends on which groups are organised. When all governments act symmetrically (i.e. 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 under business lobbying than in the absence of lobbying.

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 increases abatement when it is done by business and environmentalists (or by environmentalists alone), not only under unilateral action and full cooperation, but also when a coalition may form. Since this result derives from increased unilateral action, rather than action within a self-enforcing IEA, 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).

Finally, we showed that, perhaps surprisingly, in the case of business lobbying alone, total abatement may increase relative to the no-lobby case when governments can form an IEA. More specifically this is the case when governments' taste for money is relatively high. In these circumstances the benefits to cooperation are small, but so are the incentives on countries 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. Our focus has been on domestic lobby groups, given the high concentration of interests within national borders and the possibilities to exert influence. However, one may want to look at the same problem from the perspective of international lobby groups. 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 using data from, for example, 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

$$\nabla G_{FC} = N[\gamma \nabla W_c(q) + (1 - \gamma) \sum_{l=1}^L \nabla C_c^l(q)] = 0 \quad (21)$$

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):

$$\nabla \Pi_c(q) + \nabla S(q) - \nabla D(Nq) = 0. \quad (22)$$

### Lobbying stage

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

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

The FOC is

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

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

Combining conditions (21) and (23), we have that in a cooperating country  $c$ , lobby  $l$  must satisfy:

$$\nabla W_c^l(q) = \nabla C_c^l(q) \quad \forall l = 1, \dots, L \quad (24)$$

## 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 (24), the conditions describing the contributions of the two lobby groups in equilibrium are:

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

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

$$\nabla G_{FC}^{\pi,D} = \nabla\Pi_c(q) + \gamma\nabla S_c(q) - \nabla D(Nq) = 0 \quad (25)$$

Equation (25) can be directly compared with the no-lobbying case in (6).

Let  $q_c$  denote the solution to (22),  $q_c^{\pi,D}$  the solution to (25), and  $q_c^D$  and  $q_c^\pi$  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 (19), repeated here for convenience:

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

The FOCs for an interior solution require

$$1 - 2x_j - \sigma q_j = 0 \quad \forall j \quad (26)$$

which gives

$$x_j = \frac{1 - \sigma q_j}{2}. \quad (27)$$

#### 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 (20), i.e.:

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

subject to (26) and  $q_j \in [0, 1]$ . The Kuhn-Tucker conditions require

$$\begin{aligned} \frac{\partial W_j}{\partial q_j} - \lambda_j &\leq 0, & \left( \frac{\partial W_j}{\partial q_j} - \lambda_j \right) q_j &= 0, & q_j &\geq 0, \\ q_j &\leq 1, & \lambda_j(1 - q_j) &= 0, & \lambda_j &\geq 0, \end{aligned} \quad (28)$$

where  $\lambda_j$  is a Lagrangian multiplier and

$$\frac{\partial W_j}{\partial q_j} = (\omega - \sigma)x_j - \frac{\sigma}{2}x_j + \omega \frac{\sigma}{2}(1 - q_j). \quad (29)$$

By substituting (27) into (29) and collecting terms we have

$$\frac{\partial W_j}{\partial q_j} = \frac{2\omega - 3\sigma + 2\sigma\omega}{4} - q_j \frac{\sigma(4\omega - 3\sigma)}{4}. \quad (30)$$

The Kuhn-Tucker conditions in (28) are necessary and sufficient when  $\omega > \frac{3\sigma}{4}$ . Provided the latter condition is satisfied, the interior solution is found by setting (30) equal to zero; the corner solution for  $q_j = 0$  is found by setting  $q_j = 0$  in (30) 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 (30) 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 (30) we have:  $\frac{\partial W_j}{\partial q_j} \Big|_{q_j=1} = \frac{(2\omega - 3\sigma)(1 - \sigma)}{4}$ .

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 (28), 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:

$$q_u^0 = \begin{cases} 0 & \text{if } \omega \leq \frac{3\sigma}{2(1+\sigma)} \\ \frac{2\omega - 3\sigma + 2\sigma\omega}{\sigma(4\omega - 3\sigma)} & \text{if } \omega \in \left(\frac{3\sigma}{2(1+\sigma)}, \frac{3\sigma}{2}\right) \\ 1 & \text{if } \omega \geq \frac{3\sigma}{2} \end{cases} \quad (31)$$

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 (26). The Kuhn-Tucker conditions will be analogous to (28) and so need not be written down. By differentiating  $W_c$ , we obtain

$$\frac{\partial W_c}{\partial q_j} = N \left[ (N\omega - \sigma)x - \frac{\sigma}{2}x + \frac{N\omega\sigma(1 - q)}{2} \right] \quad (32)$$

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

Applying to (32) 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

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

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 (26), 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 (31).

The optimisation problem for a representative signatory is

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

where  $k$  denotes the number of signatories. Differentiation yields:

$$k \frac{\partial W_s}{\partial q_s} = k \left\{ (k\omega - \sigma) x_s - \frac{\sigma}{2} x_s + \frac{\omega k \sigma (1 - q_s)}{2} \right\}. \quad (34)$$

Applying to (34) 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. (31), 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.<sup>10</sup>

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.

<sup>10</sup>A non-trivial coalition is defined as a non-empty set of players, which implies  $k \geq 1$ .

### 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  $W_j^l - C_j^l, \forall l = 1, \dots, L$ , subject to  $G_j \geq \bar{G}_j$  for some constant  $\bar{G}_j$  (and given firm  $j$ 's optimal output decision, which is as in Eq. 27). The constraint  $G_j \geq \bar{G}_j$  can be written as  $\gamma W_j + (1 - \gamma) \sum_{l=1}^L C_j^l \geq \bar{G}_j$ , which implies  $C_j^l \geq [\bar{G}_j - \gamma W_j - (1 - \gamma) C_j^{-l}] / (1 - \gamma)$ , where  $C_j^{-l} = \sum_{i=1, i \neq l}^L C_j^i$ . Therefore  $W_j^l - C_j^l$  is maximised when  $C_j^l = [\bar{G}_j - \gamma W_j - (1 - \gamma) C_j^{-l}] / (1 - \gamma)$ . This is equivalent to the maximization of  $(1 - \gamma) W_j^l - \bar{G}_j + \gamma W_j + (1 - \gamma) C_j^{-l}$ , 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 (26) and  $q_j \in [0, 1]$ . The Kuhn-Tucker conditions require

$$\begin{aligned} \left( \frac{\partial M_j^l}{\partial q_j} - \lambda_j \right) \leq 0, \quad \left( \frac{\partial M_j^l}{\partial q_j} - \lambda_j \right) q_j = 0, \quad q_j \geq 0, \\ q_j \leq 1, \quad \lambda_j (1 - q_j) = 0, \quad \lambda_j \geq 0, \end{aligned} \tag{35}$$

where  $\lambda_j$  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  $C^D(q_j^{\pi,D}, \bullet) = \max [0, -D(q_j^{\pi,D}, \bullet) + \bar{D}(\bar{q}_j^\pi, \bullet)]$ , and  $C_j^\pi(q_j^{\pi,D}) = \max [0, \Pi_j(q_j^{\pi,D}) - \bar{\Pi}_j(\bar{q}_j^D)]$ .<sup>11</sup> 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

$$\frac{\partial M_j^\pi(q_j^{\pi,D}, \bullet)}{\partial q_j^{\pi,D}} = \frac{\partial M_j^D(q_j^{\pi,D}, \bullet)}{\partial q_j^{\pi,D}} = \frac{\partial \Pi_j(q_j^{\pi,D})}{\partial q_j^{\pi,D}} + \gamma \frac{\partial S_j(q_j^{\pi,D})}{\partial q_j^{\pi,D}} - \frac{\partial D(q_j^{\pi,D}, \bullet)}{\partial q_j^{\pi,D}}. \tag{36}$$

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.

<sup>11</sup>The expressions for  $C_j^D$  and  $C_j^\pi$  are obtained by simply applying the definition of a contribution schedule in (8).



**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  $D = \omega \left[ x_j(q_j^{\pi,D})(1 - q_j^{\pi,D}) + \sum_{i \neq j} x_j(\bar{q}_i^{\pi,D})(1 - \bar{q}_i^{\pi,D}) \right]$ , where  $x_j(q_j^{\pi,D})$  is firm  $j$ 's optimal output (Eq. 27). Consequently (36) becomes

$$\begin{aligned} \frac{\partial M_j}{\partial q_j^{\pi,D}} &= -\sigma \left( \frac{1 - \sigma q_j^{\pi,D}}{2} \right) - \gamma \frac{\sigma}{2} \left( \frac{1 - \sigma q_j^{\pi,D}}{2} \right) + \omega \left[ \frac{\sigma(1 - q_j^{\pi,D})}{2} + \frac{1 - \sigma q_j^{\pi,D}}{2} \right] \\ &= \frac{2\omega(1 + \sigma) - (2 + \gamma)\sigma}{4} - q_j^{\pi,D} \frac{\sigma(4\omega - (2 + \gamma)\sigma)}{4}. \end{aligned} \tag{37}$$

The Kuhn-Tucker conditions in (35) are necessary and sufficient when  $\omega > \frac{(2+\gamma)\sigma}{4}$ . Provided the latter condition is satisfied, the interior solution is found by setting (37) equal to zero; the solution for  $q_j = 0$  is found by setting  $q_j = 0$  in (37) 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 (37) 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 (37) 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 (35), 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:

$$q_u^{\pi,D} = \begin{cases} 0 & \text{if } \omega \leq \frac{(2+\gamma)\sigma}{2(1+\sigma)} \\ \frac{2\omega(1+\sigma) - (2+\gamma)\sigma}{\sigma(4\omega - (2+\gamma)\sigma)} & \text{if } \omega \in \left( \frac{(2+\gamma)\sigma}{2(1+\sigma)}, \frac{(2+\gamma)\sigma}{2} \right) \\ 1 & \text{if } \omega \geq \frac{(2+\gamma)\sigma}{2} \end{cases} \tag{38}$$

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, (36) becomes

$$\frac{\partial M_c}{\partial q_c^{\pi,D}} = \frac{2\omega N(1 + \sigma) - (2 + \gamma)\sigma}{4} - q_c^{\pi,D} \frac{\sigma(4\omega N - (2 + \gamma)\sigma)}{4}. \tag{39}$$

Applying to (39) 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 (38). 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  $D = \omega [kx_s(q_s^{\pi,D})(1 - q_s^{\pi,D}) + (N - k)\bar{x}_n(\bar{q}_n^{\pi,D})(1 - \bar{q}_n^{\pi,D})]$ , where  $q_s^{\pi,D}$  and  $\bar{q}_n^{\pi,D}$  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 (36), 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. (38), 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**

Tables 5-7 present equilibrium abatement under a self-enforcing IEA, non-cooperative behaviour and full cooperation for the full range of values of the parameters  $\sigma$ ,  $\omega$  and  $\gamma$ .

[TABLES 5-7 HERE]

Figure 1: The effect of changing governments' taste for money on equilibrium abatement when countries may form a self-enforcing IEA (top) and on the benefits to cooperation under business lobbying (bottom);  $\sigma = 0.501$ ;  $N = 100$ .

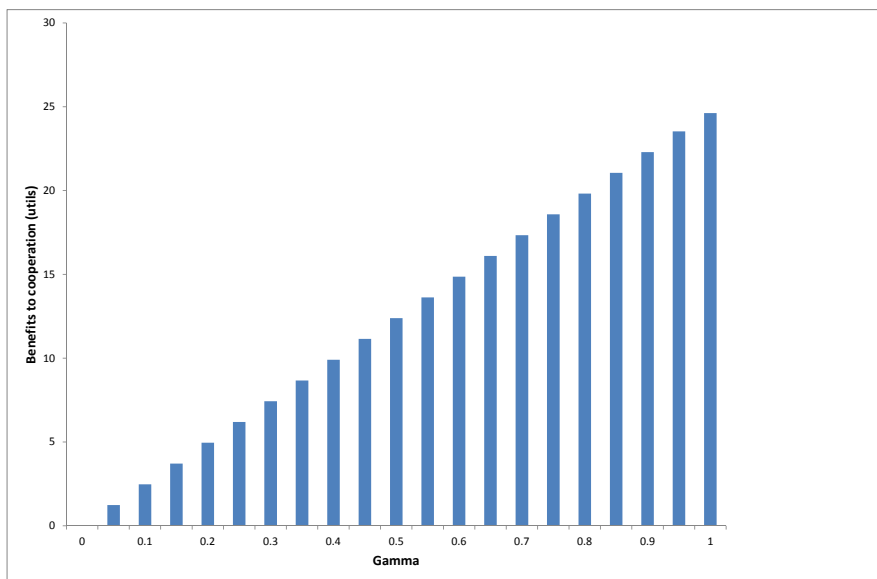
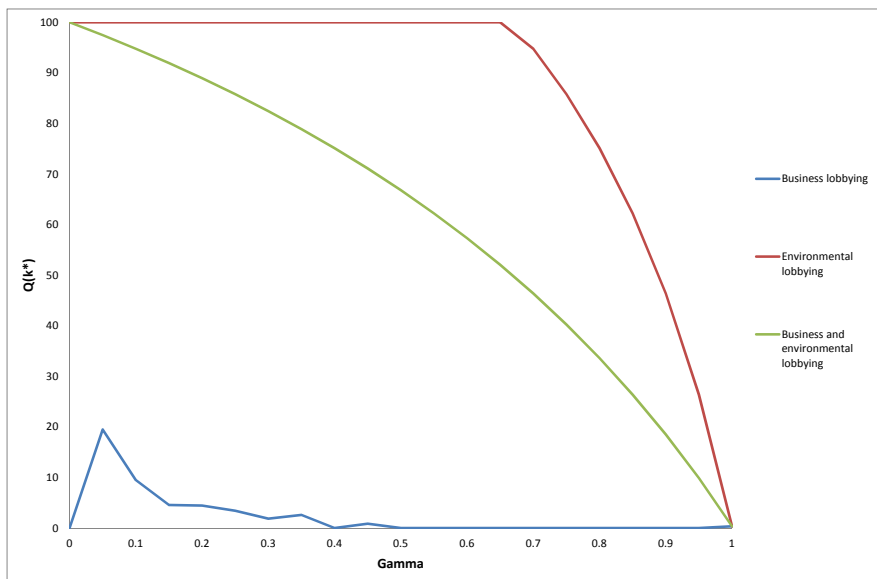


Figure 2: A comparison of the effect of marginal environmental damage and governments' taste for money on equilibrium abatement when countries may form a self-enforcing IEA and there is lobbying from both business and environmentalists;  $\sigma = 0.501$ ;  $N = 100$ .

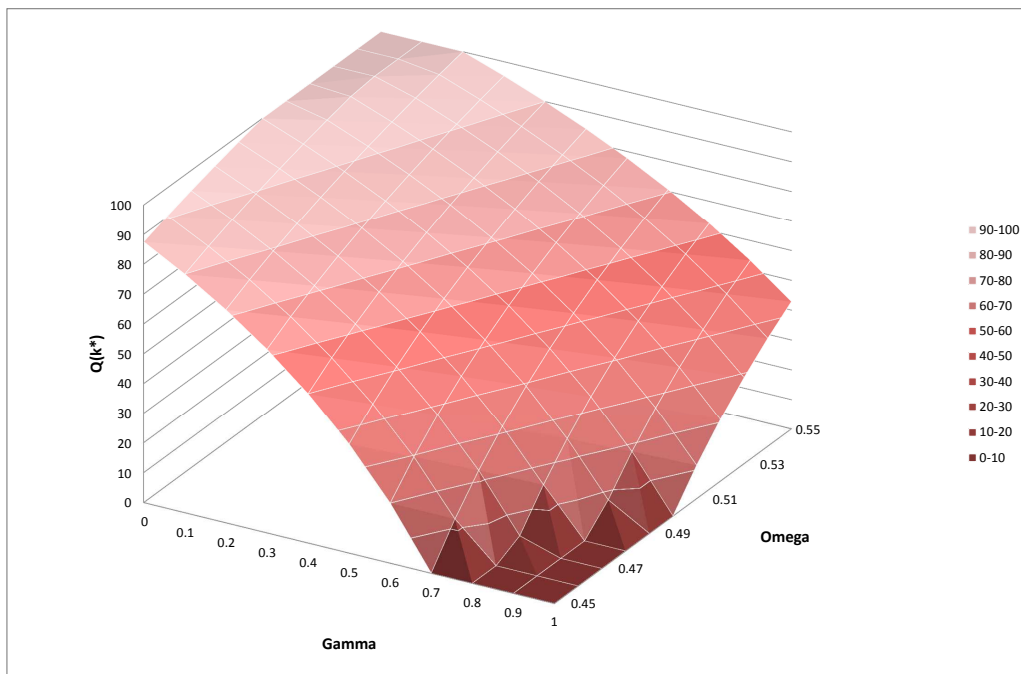


Table 1: Comparison of unilateral abatement levels with different types of lobbying.

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 $\omega \in \left(\frac{3\gamma\sigma}{2(1+\sigma)}, \frac{3\gamma\sigma}{2}\right)$	$\frac{\sigma(4\omega - (2+\gamma)\sigma)}{2\omega(1+\sigma) - \sigma(2+\gamma)}$ 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: Comparison of abatement levels under self-enforcing IEA, with different types of lobbying.

Abatement level under self-enforcing IEA	No lobbies	Business lobby	Environmental lobby	Both lobbies
(a) $q_s = q_n = 0$	$\omega \leq \frac{3\sigma}{2(1+\sigma)k}$	$\omega \leq \frac{\sigma(2+\gamma)}{2\gamma(1+\sigma)k}$	$\omega \leq \frac{3\gamma\sigma}{2(1+\sigma)k}$	$\omega \leq \frac{\sigma(2+\gamma)}{2(1+\sigma)k}$
(b) $0 < q_s < 1$ , $q_n = 0$	$q_s = \frac{2k\omega - 3\sigma + 2k\omega\sigma}{\sigma(4k\omega - 3\sigma)}$ if $\omega \in \left( \frac{3\sigma}{2(1+\sigma)k}, \frac{3\sigma}{2k} \right)$	$q_s = \frac{2k\omega\gamma(1+\sigma) - \sigma(2+\gamma)}{\sigma(4k\omega\gamma - \sigma(2+\gamma))}$ if $\omega \in \left( \frac{\sigma(2+\gamma)}{2\gamma(1+\sigma)k}, \frac{\sigma(2+\gamma)}{2\gamma k} \right)$	$q_s = \frac{2k\omega(1+\sigma) - 3\gamma\sigma}{\sigma(4k\omega - 3\gamma\sigma)}$ if $\omega \in \left( \frac{3\gamma\sigma}{2(1+\sigma)k}, \frac{3\gamma\sigma}{2k} \right)$	$q_s = \frac{2k\omega(1+\sigma) - \sigma(2+\gamma)}{\sigma(4k\omega - (2+\gamma)\sigma)}$ if $\omega \in \left( \frac{\sigma(2+\gamma)}{2(1+\sigma)k}, \frac{\sigma(2+\gamma)}{2k} \right)$
(c) $q_s = 1$ , $q_n = 0$	$\omega \in \left( \frac{3\sigma}{2k}, \frac{3\sigma}{2(1+\sigma)} \right)$	$\omega \in \left( \frac{\sigma(2+\gamma)}{2\gamma k}, \frac{\sigma(2+\gamma)}{2\gamma(1+\sigma)} \right)$	$\omega \in \left( \frac{3\gamma\sigma}{2k}, \frac{3\gamma\sigma}{2(1+\sigma)} \right)$	$\omega \in \left( \frac{\sigma(2+\gamma)}{2k}, \frac{\sigma(2+\gamma)}{2(1+\sigma)} \right)$
(d) $q_s = 1$ , $0 < q_n < 1$	$q_n = \frac{2\omega - 3\sigma + 2\sigma\omega}{\sigma(4\omega - 3\sigma)}$ if $\omega \in \left( \frac{3\sigma}{2(1+\sigma)}, \frac{3\sigma}{2} \right)$	$q_n = \frac{2\omega\gamma(1+\sigma) - \sigma(2+\gamma)}{\sigma(4\omega\gamma - \sigma(2+\gamma))}$ if $\omega \in \left( \frac{\sigma(2+\gamma)}{2\gamma(1+\sigma)}, \frac{\sigma(2+\gamma)}{2\gamma} \right)$	$q_n = \frac{2\omega(1+\sigma) - 3\gamma\sigma}{\sigma(4\omega - 3\gamma\sigma)}$ if $\omega \in \left( \frac{3\gamma\sigma}{2(1+\sigma)}, \frac{3\gamma\sigma}{2} \right)$	$q_n = \frac{2\omega(1+\sigma) - \sigma(2+\gamma)}{\sigma(4\omega - (2+\gamma)\sigma)}$ if $\omega \in \left( \frac{\sigma(2+\gamma)}{2(1+\sigma)}, \frac{\sigma(2+\gamma)}{2} \right)$
(e) $q_s = q_n = 1$	$\omega \geq \frac{3\sigma}{2}$	$\omega \geq \frac{\sigma(2+\gamma)}{2\gamma}$	$\omega \geq \frac{3\gamma\sigma}{2}$	$\omega \geq \frac{\sigma(2+\gamma)}{2}$



Table 4: Simulation of non-cooperative abatement, full-cooperative abatement and abatement under a self-enforcing IEA, with different types of lobbying.

		No lobbies	Business lobby	Environmental lobby	Both lobbies	
$\gamma$	0.25	$k^*$	0	4	100	0
		$Q(k^*)$	0.3	3.4	100	85.8
		$Q_u$	0.3	0	100	85.8
		$Q_c$	100	100	100	100
	0.5	$k^*$	0	2	100	0
		$Q(k^*)$	0.3	1.3	100	66.8
		$Q_u$	0.3	0	100	66.8
		$Q_c$	100	100	100	100
	0.75	$k^*$	0	0	0	0
		$Q(k^*)$	0.3	0	85.8	40.2
		$Q_u$	0.3	0	85.8	40.2
		$Q_c$	100	100	100	100

$\sigma = \omega = 0.501$ ;  $N = 100$ .

Table 5: Non-cooperative abatement, full-cooperative abatement and abatement under a self-enforcing IEA, with different types of lobbying, over a full sweep of the parameter space;  $\gamma = 0$ .

$\sigma$	$\omega$												
	0.001			0.01			0.1			0.99			
	None	B.	E.	B&E	None	B.	E.	B&E	None	B.	E.	B&E	
0.001	$Q(k^*)$	0	0	100	100	0	0	100	100	0	0	100	100
	$Q_u$	0	0	100	100	100	0	100	100	100	0	100	100
	$Q_c$	100	0	100	100	100	0	100	100	100	0	100	100
0.01	$Q(k^*)$	0	0	100	0	0	0	100	100	0	0	100	100
	$Q_u$	0	0	100	0	0	0	100	100	100	0	100	100
	$Q_c$	100	0	100	100	100	0	100	100	100	0	100	100
0.1	$Q(k^*)$	0	0	100	0	0	0	100	0	0	0	100	100
	$Q_u$	0	0	100	0	0	0	100	0	0	0	100	100
	$Q_c$	0	0	100	100	100	0	100	100	100	0	100	100
0.99	$Q(k^*)$	0	0	100	0	0	0	100	0	0	0	100	0
	$Q_u$	0	0	100	0	0	0	100	0	0	0	100	0
	$Q_c$	0	0	100	0	99.0	0	100	100	100	0	100	100

Table 6: Non-cooperative abatement, full-cooperative abatement and abatement under a self-enforcing IEA, with different types of lobbying, over a full sweep of the parameter space;  $\gamma = 0.5$ .

$\sigma$	$\omega$											
	0.001			0.01			0.1			0.99		
	None	B.	E.	B&E	None	B.	E.	B&E	None	B.	E.	B&E
0.001	$Q(k^*)$	0	0	100	0	100	100	100	100	100	100	100
	$Q_u$	0	0	100	0	100	100	100	100	100	100	100
	$Q_c$	100	100	100	100	100	100	100	100	100	100	100
0.01	$Q(k^*)$	0	0	0	0	0	100	0	100	100	100	100
	$Q_u$	0	0	0	0	0	100	0	100	100	100	100
	$Q_c$	100	100	100	100	100	100	100	100	100	100	100
0.1	$Q(k^*)$	0	0	0	0	0	0	0	0	0	100	100
	$Q_u$	0	0	0	0	0	0	0	0	0	100	100
	$Q_c$	0	0	100	0	100	100	100	100	100	100	100
0.99	$Q(k^*)$	0	0	0	0	0	0	0	0	0	0	99.0
	$Q_u$	0	0	0	0	0	0	0	0	0	0	99.0
	$Q_c$	0	0	0	0	99.0	0	100	100	100	100	100

Table 7: Non-cooperative abatement, full-cooperative abatement and abatement under a self-enforcing IEA, with different types of lobbying, over a full sweep of the parameter space;  $\gamma = 0.99$ .

$\sigma$	$\omega$											
	0.001			0.01			0.1			0.99		
	None	B.	E.	B&E	None	B.	E.	B&E	None	B.	E.	B&E
0.001	$Q(k^*)$	0	0	0	100	100	100	100	100	100	100	100
	$Q_u$	0	0	0	100	100	100	100	100	100	100	100
	$Q_c$	100	100	100	100	100	100	100	100	100	100	100
0.01	$Q(k^*)$	0	0	0	0	0	0	0	100	100	100	100
	$Q_u$	0	0	0	0	0	0	0	100	100	100	100
	$Q_c$	100	100	100	100	100	100	100	100	100	100	100
0.1	$Q(k^*)$	0	0	0	0	0	0	0	0	0	0	0
	$Q_u$	0	0	0	0	0	0	0	0	0	0	0
	$Q_c$	0	0	0	100	100	100	100	100	100	100	100
0.99	$Q(k^*)$	0	0	0	0	0	0	0	0	0	0	0
	$Q_u$	0	0	0	0	0	0	0	0	0	0	0
	$Q_c$	0	0	0	99.0	99.0	99.1	99.1	100	100	100	100