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Abstract:

Lobbies have always been major players in the political game. Their actions range from influencing consumers beliefs to applying pressure on policymakers. This paper attempts to analyze the impact of direct lobbying and indirect lobbying through public persuasion by interests groups on the stringency of the environmental policy. Following Yu (2005), we propose a micro-founded model with imperfect competition for the polluting good and that allows to derive total welfare, the government's objective function and the resulting strategic interactions between interest groups. Our results reflect a more aggressive behavior in the public persuasion competition for the specialized green lobby. An increase in the representativeness of the green lobby leads to a more stringent environmental policy but the opposite does not necessarily hold when the producer lobby becomes more powerful. Yet, a more benevolent government, sets a more stringent environmental policy only for lower values of the public's initial environmental concern, prior to the persuasion competition.

Keywords: Direct lobbying, public persuasion, indirect lobbying, environmental taxation, specialized lobbies.

JEL classification: C73; D64; D74

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1 Introduction

Environmental NGOs have become increasingly important political actors over the last decade. At the same time, the public awareness over the environmental issues has dramatically increased in developed countries. In this paper, we provide an explanation for the concomitant nature of these two developments. With the use a political economy framework, we show that the awareness of consumers about the environmental damage caused by production elicits a more aggressive behavior from the specialized green lobby in the public persuasion stage.

There is an increasing evidence that both green and polluting-industry lobbies invest in social and mass media campaigns to support their stakes/preferences in front of the general public, whom final belief might be significantly influential in the final policy outcome. We provide two examples that are of a particular interest to this study as they reflect the power of environmentalists in changing the public opinion and hence significantly influencing the political decisions. The first example concerns the construction of the The Grand Ouest Airport commonly known by "Notre Dame des Landes" Airport in Britany, France.[1] This project has been in the center of the public debate for more than 50 years since its announcement in the late 1960s, making it subject of many postponements and re-lunches. The engagement of the environmentalists against the project started to actually take place in the 2000s, and reached its peak in 2008-2009[2] by making the site of the project the first climate camp in France. This very strong engagement of the greens made their environmental requests very salient to the rest of the country leading to many support manifestations in many cities.[3] The continuous pressure of the greens led the government of Emmanuel Macron to reconsider the decision of the previous administration of starting the construction's activities, resulting in officially cancelling the project in 2018.

The second example concerns the Keystone pipeline system project.[4] The project has gone through many phases of approval and reject from the same federal administration between 2010 and 2015. The Obama administration that was in favor of this project at the beginning, and approved the first three phases of its construction, has rejected the construction of the fourth phase "over environmental concerns". The opposition from the federal administration is the result of years of engagement from the environmentalists in public persuasion, through the organization of marches and protests and the communication of information about the environmental damage related to the project in their web sites and via social media platforms.[5] In parallel, the corporate web site of the pipeline was

[1] The Grand Ouest Airport was a project for a new airport, to be situated 30 km to the north-west of the French city of Nantes in the commune of Notre Dame des Landes. In 2008, the project was declared of public utility, giving the corporation Vinci airports the green light to start construction in 2010.

[2] The environmental concerns of the project are: the destruction of one of the department's last remaining areas of exceptional biodiversity, the loss of significant agricultural land, the acceleration of the urbanisation of region and the increase of greenhouse gazes emissions related to transportation. The major opposing group "ACIPA" has engaged in a coordinating structure counting 34 organisations including: Greenpeace, WWF and the political party "les verts".

[3] In 2012, 10000 protesters gathered in the city of Nantes. The number of protesters doubled in 2014, to reach its peak in 2016 with almost 50000 protesters affirming their opposition to the project.

[4] The Keystone Pipeline System is an oil pipeline system that runs from Alberta, Canada to Texas and Illinois, USA.

[5] The Sierra Club and 350.org organized in 2013 a protest that gathered approximately 35,000 to 50,000

communicating information about the environmental safety of the project and about its economic and social benefits. The battle between the environmentalists and the corporation ended up in the favor of the greens. In fact, a public opinion pole done by Pew research center showed that the public's support of the pipeline project has fallen from 59% in 2013 to 42% in 2017, which shows a victory for the environmentalists over the pipeline corporation in persuading the general public.[6]

In addition to their interest in public persuasion, polluting industries and environmental groups engage in directly influencing the policy makers through political contributions and transfers of information. It is well recognized that powerful industrial groups make important political donations, especially in US politics during election cycles. Environmental NGO are also increasingly active in the policy-making process by meeting with legislators and regulators. For instance, Coen et al. (2021) conducted an anonymized survey during the eighth legislature of the European Parliament (EP) that shows that the members of the EP report that they are more frequently contacted by NGOs than by other types of interest groups.[7] Hence our work accounts for the possibility of directly influencing the environmental policy through political contributions. We use a common-agency model of domestic politics *à la* Grossman and Helpman (1994) over environmental policy. There is an industry with a monopoly position that produces a polluting good. Green and producer lobbies offer political contributions to incumbent politicians in return for favorable environmental regulation policies. The incumbent government chooses a tax rate on polluting production so as to maximize a weighted sum of aggregate welfare and of political contributions offered by interest groups. The underlying justification is that political contributions can be used for campaign advertising whereas a higher level of aggregate welfare increases the probability of reelection.[8] Total welfare is based in part on consumer surplus and this last includes a disutility of environmental damage incurred by consumers. As in Yu (2005), the two lobbies can also engage in indirect lobbying in order to influence the perception of the environmental damage of consumers, upstream the stage of direct lobbying through political contributions. We consider that the producer lobby is formed by a proportion of the capitalists or the firm owners that manage to overcome the collective action problem and get organized, and similarly that the green lobby is formed by a proportion of organized environmentalists. We also assume that the lobbies are "functionally specialized" (see, e.g., Aidt, 1998 and 2005; Conconi, 2003). In other words, the green lobby is only concerned about the environmental damage, whereas the producer lobby is only concerned about profit.

It is worth pointing out that the environmental tax can only be "second-best" because of the market failures – overproduction due to the environmental damage and under-production due to monopoly pricing – and the government failure – maximization of a weighted sum of social welfare and of political contributions**.** It remains that the green lobby pushes the incumbent government to increase the environmental tax, whereas the opposite holds for

protesters in Washington, D.C. calling president Obama to reject the fourth construction phase of the pipeline.

[6]The pole website : https://www.pewresearch.org/fact-tank/2017/02/21/public-divided-over-keystone-xl-dakota-pipelines-democrats-turn-decisively-against-keystone/, visited in september 2020

[7]Polluting industries have always been considered as ones of the biggest contributors to electoral campaigns in the USA. For more details, see https://www.opensecrets.org/industries/ visited in september 2020.

[8]Since the prospects for reelection are not modelized, we could equally argue that "political contributions" represent bribes given in order to influence government policy (see, e.g., Fredriksson and Svensson, 2003).

the industrial lobby. We first show that the green lobby adopts a more aggressive strategy in the public persuasion compared to the industrial lobby. We then show that when the political representativeness of the green lobby increases, the political game for influencing the government turns to the advantage of the green lobby in that it becomes more aggressive in both direct and indirect lobbying while the industrial lobby becomes less aggressive in both activities, revealing a complementarity effect between the two types of lobbying. By contrast, when the political representativeness of the industrial lobby increases, it does not necessarily increase its political effectiveness since it induces the green lobby to be again more active in direct and indirect lobbying.

However, an increase in the weight attached to general welfare by the incumbent government reduces both the direct and indirect political activities of the green lobby and reduces those of the industrial lobby when the initial environmental belief of the general public is low, and increases then otherwise; revealing again the complementarity between the two types of influence.

The rest of the paper is organized as follows. Section 2 surveys the related literature. Section 3 introduces the model. Section 4 reports the comparative statics results, and Section 5 concludes.

2 Related literature

There is a large literature on the role of domestic politics in the making of environmental policy. Most analysis use the common agency model of Grossman and Helpman (1994) where interest groups lobby directly politicians to push them to change policies in their preferred direction. Yet, interest groups can also use other channels for influencing environmental regulation. In Yu (2005)'s seminal analysis of direct (inside) and indirect (outside) lobbying, special interest groups, in addition to offering political contributions to policy makers, launch information campaigns to the general public in order to change its preferences (or those of the median voter), which in turn modifies government policies. As argued by Yu (2005), we can expect green lobbies to rely extensively on this channel relative to producer lobbies because they have, presumably, less financial resources.

Specifically, Yu (2005) considers a reduced-form function for total welfare that enters into the objective function of the regulator together with the political contributions received. He also assumes that indirect lobbying efforts are strategic substitutes and that the green lobby has a cost advantage in sending messages. These assumptions drive his comparative static results on the greater effectiveness of the green lobby in public persuasion. By contrast, we specify the economic context characterized by imperfect competition, and where total welfare is derived explicitly from the producer surplus, the consumer surplus and tax revenues. Also, making similar assumptions on the public persuasion function to Yu (2005), we endogenously derive the nature of strategic interactions between the lobbies in the indirect lobbying competition. In our setting, we show that the best response function of the green lobby is upward sloping while that of the industrial lobby is downward sloping. This induces a complementarity between indirect and direct lobbying, while Yu (2005)'s result of substitutability between the two types of efforts results from his assumption on the nature of strategic interactions in indirect lobbying.

Prieur and Zou (2018) also developed a model with public persuasion *à la* Yu (2005), but without direct lobbying through political contributions. Their results show that the society as a whole can benefit from the outcome of this indirect lobbying game – as measured by a reduction of economic and environmental distortions – only if the public perception of the environmental damage is relatively close to that of industrialists, whereas the environmentalist group is radical in its ideology. Symmetrically, the game of political influence becomes detrimental to social welfare if industrial groups are very aggressive and people's concern is relatively close to that the environmental group. Overall, Prieur and Zou (2018) identify a strong asymmetry in the indirect lobbying game to the advantage of industrial groups. By contrast, in our setting with a competition for political influence in both direct and indirect lobbying, we show the existence of an asymmetry to the benefit of environmental groups. An other work that relates to the persuasion literature is that by Bramoullé and Orset (2018), in which they show that some industries might take the competition over public opinion to the extreme and invest in the supporting biased research, in order to create doubt around an already controverted issue, climate issue might be one of them.

Finally, this paper is related to the literature on public persuasion in democratic societies. Persuasion is the act of changing others beliefs or preferences and make them closer to ours in order to induce a change in their behavior. Hence it is usually modelled as a Bayesian mechanism that allows receivers of signals (information) to update their prior beliefs (Congleton 1986). The use of public persuasion by lobbies for political influence has been popularized by Grossman and Helpman (2001), and since then a growing literature has investigated in depth its mechanism and relationship with mass media. Petrova (2012) and Sobbrio (2011) study the role of media in the persuasion of the median voter in favor of Special Interest Groups (SIGs). They show how the media can act as a filter between the lobbies and the targeted public.

Thus, the effort provided by the interest groups in indirect lobbying is not translated immediately and effectively into gains as it depends mainly on the filtering capacity of the media, and on its ability to update the prior beliefs of the targeted public. Shapiro (2016) confirms these findings with an empirical analysis. He shows that the public may remain uninformed about controversial issues like the climate change issue when the special interests groups have high policy stakes and when the media channels are biased. Gentzkow et Kamenica (2017) study the issue of Bayesian persuasion with multiple senders and show that competition between senders tends to increase the amount of information revealed to the public. For simplification reasons, this discussion does not find its way into our model. We limit our analysis to the idea that lobbies send messages to the general public in a way to influence their environmental awareness, without formalizing the process.

3 The model

3.1 General framework

Let consider an economy with a perfectly competitive industry producing a numeraire good using labor and a monopoly producing a polluting good using labor and a specific factor, which is available in fixed supply. There are three types of agents: workers, capitalists or firm owners, and environmentalists. The population is normalized to 1. All individuals have a labor income y, which is assumed to be exogenous and constant independently of the regulation implemented in the polluting sector. Thus, it is a partial equilibrium framework and the assumption of fixed labor income can reflect the fact that the polluting sector is small compared to the numeraire good sector.[9] The preferences of each consumer are represented by the following quasi-linear utility function**:**

$$U = u(x) + x_0 - D(x), \tag{1}$$

where x_0 and x are the individual consumption of the numeraire good and of the polluting good, respectively. $u(.)$ is an increasing concave function $[u^{'}(.) > 0$ and $u''(.) \leq 0]$. We assume that the utility of consuming the polluting good is given by a quadratic function, i.e. $u(x) = x - (x^2/2)$.

Since there is a unit mass of consumers, total production of the polluting good is equal to individual consumption of that good. Furthermore, the firm producing the polluting good does not have access to an abatement technology, and we further assume that each unit of production generates one unit of pollution. As a result, $D(x)$ represents the individual disutility of pollution generated by the production in the polluting sector. Following Yu (2005), we also consider that consumers have a *subjective belief* about the environmental damage, and thus we assume that $D(x) = \mu_p d(x)$, where μ_p is the common subjective weight attached to the environmental damage by consumers in their utility functions. We make the following assumption on the $d(.)$ function:

A1: For all x, $d'(x) > 0$, $d''(x) \geq 0$ and $d'''(x) \leq 0$.

With fixed income, the inverse demand function is then $p = u'(x) = 1 - x$, which yields the following indirect utility function of the representative consumer

$$V = \frac{x^2}{2} + y - \mu_p d(x). \tag{2}$$

For simplicity, we assume that there are no fixed costs of production and that the marginal cost of production is constant so that we can set it to 0. Also, considering that the government set a tax t per unit of emission, the profit of the monopoly producing the polluting good is $\pi(x) = (p(x) - t)\, x$. Profit maximization yields $x(t) = (1-t)/2$. Substituting into the profit function, we have

$$\pi(t) = \frac{(1-t)^2}{4}. \tag{3}$$

The indirect utility function as a function of the environmental tax is given by

$$V(t) = \frac{(1-t)^2}{8} + y - \mu_p d(x(t)). \tag{4}$$

Total welfare is the sum of consumer surplus, producer surplus and tax revenues that is $W_P(t) = V(t) + \pi(t) + tx(t)$ or

$$W_P(t) = \frac{(1-t)(3+t)}{8} - \mu_p d(x(t)). \tag{5}$$

[9] We thank an anonymous reviewer for pointing out this.

3.2 Direct political competition

Following Yu (2015), the formation of the environmental policy is driven by a three-stage game. The indirect competition between lobbies takes place in the first stage. In the second stage, green and producer lobbies present the incumbent policymaker with contributions, which are contingent on the environmental tax. Then, in the third stage, the government chooses the environmental tax whereas production and consumption take place. We first examine the last two stages, which is modeled as a common agency problem *à la* Grossman and Helpman (1994).

Two groups of individuals are politically organized: a proportion α_E of the environmentalists get organized and form a green lobby, and a proportion α_I of the capitalists who own the firm manage to overcome the collective action problem and form a producer lobby.[10] We also assume that lobbies are "functionally specialized" (Aidt, 1998, 2005)[11]. The producer lobby cares only about the profit and thus its gross welfare is $W_I(t) = \alpha_I \pi(t)$. Similarly, the green lobby only cares about the environmental damage and thus its gross welfare is $W_E(t) = B - \alpha_E d(x(t))$ where B is a constant that can represent the exogenous donations received by the green lobby. Let $C_I(t)$ and $C_E(t)$ be the contingent-policy contribution functions of the industrial lobby and of the green lobby. The objective of the industrial lobby is to maximize its (net) welfare given by[12]

$$W_I(t) - C_I(t), \tag{6}$$

while that of the green lobby is to maximize

$$W_E(t) - C_E(t). \tag{7}$$

The government cares about total welfare and political contributions and chooses the tax rate on emissions so as to maximize

$$G(t) = bW_P(t) + C_I(t) + C_E(t), \tag{8}$$

where $b > 0$ represents the weight that the government attaches to social welfare relative to lobbies' contributions. To guarantee that the objective function of the government is always concave in t, we need to assume that $b \geq 2$ (see Footnote 13).

[10] We follow Aidt (2005) by assuming that there are three types of agents: workers/consumers, capitalists or firm owners, and environmentalists. Their proportions are respectively $\overline{\alpha_W}$, $\overline{\alpha_I}$, and $\overline{\alpha_E}$. The total population is normalized to 1, with $\overline{\alpha_W} + \overline{\alpha_I} + \overline{\alpha_E} = 1$. Therefore, α_E is the proportion of the environmentalists $\overline{\alpha_E}$ ($\alpha_E \leq \overline{\alpha_E}$) that form the lobby group. If all environmentalists get organized then $\alpha_E = 1$. Similarly, if all capitalists participate to the lobby group, then $\alpha_I = 1$. We consider, however, that $\alpha_k < 1$. The underlying justification is that lobbying is a public good to the firm owners, hence, subject to a collective action problem.

[11] The functionally specialized lobbies are a type of special interest groups that were initially introduced in the literature by Aidt (1998), based on the empirical evidence given by Marshall (1998). These lobby groups care and advocate only for one aspect of their welfare, as the rest of their welfare dimensions are weighted negligibly (see also Aidt, 2005). The assumption of functionally specialized lobbies is now rather standard in the literature (see, e.g., Frederikson et al. 2005, Ovaere et al. 2013, Lefebvre et Martimort, 2020). This assumption has the advantage of simplifying the theoretical analysis of the influence of interest groups, in addition to be more realistic.

[12] The members of each lobby group must pay collectively the full cost of direct or indirect lobbying, but are concerned only with a share of the full profit or the full environmental damage.

Following Bernheim and Whinston (1986) and Grossman and Helpman (1994), we focus on "thruthful" subgame perfect Nash equilibria, in which each lobby offers the government a (non-negative) "truthful contribution schedule". Such a contribution pays the government the true welfare effect of the policy, in excess of a certain reservation value. Formally, the truthful political schedule from lobby group j is given by $C_j^T(t, z_j) = \max[0, W_i(t) - z_j]$, where z_j is a constant.[13] Following Lemma 1 of Yu (2005), the equilibrium of the direct competition for political influence can be characterized as:

Lemma 1 (Yu, 2005): (i) *The equilibrium level of environmental policy t^* satisfies*

$$t^* = \arg\max_t \, bW_P(t) + W_I(t) + W_E(t); \tag{9}$$

(ii) *The equilibrium level of political contributions for the green lobby is*

$$\begin{aligned} C_E(t^*) &= \left[W_I(t^I) + bW_P(t^I)\right] - \left[W_I(t^*) + bW_P(t^*)\right] \\ \textit{where } t^I &= \arg\max_t \, bW_P(t) + W_I(t); \end{aligned} \tag{10}$$

(iii) *The equilibrium level of political contributions for the industrial lobby is*

$$\begin{aligned} C_I(t^*) &= \left[W_E(t^E) + bW_P(t^E)\right] - \left[W_E(t^*) + bW_P(t^*)\right] \\ \textit{where } t^E &= \arg\max_t \, bW_P(t) + W_E(t); \end{aligned} \tag{11}$$

Proof: See the Proof of Lemma 1 in Yu (2005). □

The intuition behind the equilibrium political contributions is the following. Let consider the equilibrium contribution of the green lobby given by (10). This lobby takes the political contribution of the industrial lobby as given and knows that if it does not enter into the political game, the government will choose the policy t^I that maximizes the sum of aggregate welfare and of the producer surplus. Therefore, if the green lobby wants to affect the policy outcome with the environmental tax given by t^*, it must offer a contribution that provides the government with at least what the government could achieve by ignoring the green lobby's preferences. In other words, one must have $C_E(t^*) + C_I(t^*) + bW_p(t^*) \geq C_I(t^I) + bW_p(t^I)$. The green lobby does not contribute more than necessary to induce the environmental policy t^*. Consequently, the equilibrium contribution of the green lobby – characterized by (10) – is exactly equal to the difference between what the government and the industrial lobby could jointly achieve when the green lobby's interest is ignored and when it is taken into account. The same reasoning applies for the political contribution of then industrial lobby.

From Lemma 1, the equilibrium value of the tax t^* is determined by the following first-order condition

$$bW'_P(t) + W'_I(t) + W'_E(t) = 0. \tag{12}$$

[13] For a detailed discussion of truthful contribution schedules, see Dixit et al., (1997).

With (3), (5) and since $x(t) = (1-t)/2$, $W_I(t) = \alpha_I \pi(t)$ and $W_E(t) = B - \alpha_E d(x(t))$, we have that t^* is given by[14]

$$-t^*(b - 2\alpha_I) - (b + 2\alpha_I) + 2(\alpha_E + b\mu_p)d'(x(t^*)) = 0, \tag{13}$$

Similarly, the environmental tax t^I maximizing the joint welfare for the government and the industrial lobby solves the following first-order condition

$$-t^I(b - 2\alpha_I) - (b + 2\alpha_I) + 2b\mu_p d'(x(t^I)) = 0. \tag{14}$$

Finally, the environmental tax t^E maximizing the joint welfare for the government and the green lobby solves the following first-order condition

$$-bt^E - b + 2(\alpha_E + b\mu_p)d'(x(t^E)) = 0. \tag{15}$$

We have the following intuitive result.

Lemma 2: *We have $t^I < t^* < t^E$.*

Proof: See Appendix A.1. □

The jointly optimal environmental tax for the green lobby and the government is greater than the equilibrium tax and this last is also greater than the jointly optimal tax for the industrial lobby and the government. This is the reason why the lobbies offer political contributions to the government to push for an environmental policy in their preferred direction.

3.3 Indirect Political Competition

We now turn to the first stage of the policy game where lobbies engage in indirect political competition by sending messages to the general population so as to change its subjective belief about the environmental damage. Thus, we now consider that μ_p is the prior belief of the public for the scale of environmental damage. People update their belief upon the messages received from the lobbies. Thus, following Yu (2005), μ_p is a function of the number of messages sent by the industrial lobby – denoted m_I – and of the number of messages sent by the environmental lobby – denoted m_E – that is $\mu_p \equiv \mu(m_E, m_I)$. Using subscripts as partial derivatives of the persuasion function with respect to the number of messages sent either by the environmental lobby (E) or the industrial lobby (I), we make the following assumptions:

A2: $\forall (m_E, m_I) \in \mathbb{R}^2_+$ (i) $\mu_1(m_E, m_I) > 0$, $\mu_2(m_E, m_I) < 0$ (ii) $\mu_{11}(m_E, m_I) \leq 0$, $\mu_{22}(m_E, m_I) \geq 0$, and $\mu_{12}(m_E, m_I) \gtreqless 0$; (iii) $\mu(m_E, m_I) = \mu_0 > 0$, when $m_E = m_I = 0$ or $m_E = m_I$.

Thus, from (i), the belief of the public for the scale of environmental damage is increasing (decreasing) in the number of messages sent by the green (industrial) lobby. Property (ii) means that there are decreasing to scale for sending messages and that they can be complements or substitutes. Property (iii) states that the general public has a prior belief $\mu_0 > 0$

[14] The second derivative of the Left-Hand-Term of (13) is negative if$-(b-2) - (\alpha_E + b\mu_p)d''(x(t^*)) \leq 0$. Since $d''(.) \geq 0$, a sufficient condition for the above inequality to be satisfied is that $b \geq 2$.

for the environmental damage (i.e. before receiving messages from lobbies). Property (iii) also states that the posterior and prior beliefs are the same in the specific case where the two lobbies send the same number of messages.

Let the cost of sending messages given by $c_j(m_j)$, with $c'(m_j) > 0$, $c''(m_j) \geq 0$ and $c(0) = 0$ for $j = I, E$. The green lobby chooses m_E so as to maximize

$$L^E(m_E, m_I) = B - \alpha_E d(x(t^*)) - C_E(t^*, t^I) - c_E(m_E). \tag{16}$$

Similarly, the industrial lobby chooses m_I so as to maximize

$$L^I(m_E, m_I) = \alpha_I \pi(t^*) - C_I(t^*, t^E) - c_I(m_I). \tag{17}$$

Substituting (10) and (11) into (16) and (17), we have

$$L^E(m_E, m_I) = [B - \alpha_E d(x(t^*)) + \alpha_I \pi(t^*) + bW_P(t^*)] - [\alpha_I \pi(t^I) + bW_P(t^I)] - c_E(m_E), \tag{18}$$

and

$$L^I(m_E, m_I) = [B - \alpha_E d(x(t^*)) + \alpha_I \pi(t^*) + bW_P(t^*)] - [B - \alpha_E d(x(t^E)) + bW_P(t^E)] - c_I(m_I). \tag{19}$$

Using the envelop theorem, (m_E^*, m_I^*) must solve the following first-order conditions

$$L_1^E = \mu_1(m_E^*, m_I^*) b[d(x(t^I)) - d(x(t^*))] - c_E'(m_E^*) = 0, \tag{20}$$

and

$$L_2^I = -\mu_2(m_E^*, m_I^*) b[d(x(t^*)) - d(x(t^E))] - c_I'(m_I^*) = 0. \tag{21}$$

We have the following Lemma.

Lemma 3: *If $c_I''(.) \gg 0$ or $\mu_{11} \gg 0$, then there exists a Subgame Perfect Nash equilibrium where the equilibrium numbers of messages (m_E^*, m_I^*), in the indirect competition of the political process, are implicitly given by* (20) *and* (21).[15]

Proof: See Appendix A.2. □

As shown in the appendix the second-order condition for L^E is always satisfied but that for L^I requires that the cost function of sending message for the industrial lobby is sufficiently convex – i.e. $c_I''(.) \gg 0$ – and/or that the marginal impact of m_I on μ_p is decreasing sufficiently rapidly – i.e. $\mu_{11} \geq 0$.

As in every policy games, the nature of strategic interactions between policy actors is crucial for the outcome of the policy game. We have the following result.

Lemma 4: (i) *The best response function of the green lobby in indirect lobbying is upward sloping and that of the industrial lobby is downward sloping for $\mu_{12}(m_E, m_I) \geq 0$, while for $\mu_{12}(m_E, m_I) < 0$, the nature of strategic interactions in indirect lobbying is ambiguous.*

[15] We assume that $\left|L_{11}^E L_{22}^I\right| \geq \left|L_{12}^E L_{21}^I\right|$ to guarantee the stability of the subgame perfect Nash equilibrium in the general framework. This condition can be easily verified with the specific functional forms proposed in Section 4.

Proof: See Appendix A.3. □

Lemma 4 shows that the nature of strategic interactions in sending messages by the industrial and green lobbies depend on the sign of the cross derivative of $\mu_p(m_E, m_I)$ – i.e. on the sign of μ_{12}. Since we do not define explicitly the persuasion process, we need to discuss the sign of this cross derivative. In fact, its sign is not evident, and there are convincing reasons for μ_{12} being negative as there are for μ_{12} being positive. One can think for example that the general public is less sensitive to the messages sent by one lobby as the number of messages received by the other lobby is relatively large, in which case $\mu_{12} \leq 0$.[16] But one can equally think that the public is all the more careful to the messages sent by the green lobby as its opponent is more active in policy persuasion, in which case $\mu_{12} \geq 0$. In this latter case, Lemma 4 shows that the nature of strategic interactions in sending messages between lobbies is unambiguously known. In any case, the present analysis shows that the nature of strategic interactions in the indirect political game depends crucially on the assumption made on the effect of the messages sent by one lobby on the effectiveness of the public persuasion of the other lobby's messages – i.e. crucially depends on the sign of the cross-derivative μ_{12}.

The strategic substitutability defined by Yu (2005) in the game for indirect political influence, follows directly from the assumption made on the cross derivative – i.e. $\mu_{12} = 0$ – suggesting that the messages sent by the two lobbies have independent effects on the perception about the environmental damage by the general public. Adopting the same assumption to the present framework, we have that the best response function of the green lobby is upward sloping while that of the industrial lobby is downward sloping. In other words, if the industrial lobby increases its number of messages, then the best response function of the green lobby is also to increase its number of messages to the general public, while a larger number of messages sent by the green lobby induces a reduction of messages sent by the industrial lobby.

This reflects a fundamental asymmetry between the two lobbies in the indirect policy game. The green lobby shows a more aggressive response in the public persuasion competition.[17] To understand this, let us return to social welfare as a function of the environmental tax. Recall that the environmental tax is set to correct for two market failures as the market is characterized by both under-production due to monopoly pricing and over-production due to the negative pollution externality. The producer surplus – given by (3) – and the gross consumer surplus – given by the first term of (4) – are decreasing with the environmental tax. In other words, the interest of the (organized) capitalists aligns with that of the general population as consumers (i.e. without taking into account the disutility from the environmental damage), for inciting the regulator to decrease the environmental tax. It urges the environmental lobby to be very aggressive in public persuasion to counteract this incentive by significantly increasing μ_p in the government's objective function.

[16] Besides, excessive communication can be counter-productive. Lyon and Montgomery (2013) have shown that excessive green self promoting by producers might backfire when it gets noticed by environmental activists.

[17] We follow the pioneering work of Bulow et al., (1989), by referring to the upward best-response function of a player as an aggressive behavior.

4 Comparative Static Results

The equilibrium levels of political contributions, of political messages and of the environmental policy are only implicit. In order, to obtain additional results on how political representativeness affects the political equilibrium, we now propose simple specific functional forms for the damage function, the cost functions of sending messages, and the function that maps the number of messages to the prior belief of the public for the scale of the environmental damage. Let $d(x) = x$, $c(m_k) = m_k$ for $k = E, I$ and $\mu_p(m_E, m_I) = \mu_0 + \sqrt{m_E} - \sqrt{m_I}$, implying that $\mu_{12} = 0$. μ_0 is the prior belief of the general public about the environmental damage, and it is supposed to be between 0 and 1. This parameter is of particular interest because it helps interpreting most of the comparative statics results.
Following the literature on lobbies formation, we assume that the environmentalists and the capitalists face a collective action problem. This problem is captured by the upper limit on α_E and α_I; the proportion of the environmentalists and the capitalists that manage to get organized and form, respectively, the green and the industrial lobbies is lower than 1. Moreover, to draw clear and conclusive results, we push further this reasoning by setting the upper limit of α_E and α_I at 1/2.[18]

We present the new expressions of the equilibrium outcomes. We first characterize the environmental taxes (t^*, t^E, t^I). Using (13), (14) and (15), we have:

$$t^*(\mu_p) = \frac{2[b\mu_p + \alpha_E] - (b + 2\alpha_I)}{b - 2\alpha_I}, \tag{22}$$

and

$$t^I(\mu_p) = \frac{2b\mu_p - (b + 2\alpha_I)}{b - 2\alpha_I}, \tag{23}$$

and

$$t^E(\mu_p) = \frac{2[b\mu_p + \alpha_E] - b}{b}. \tag{24}$$

Next, we characterize the equilibrium outcome of the subgame in political contributions, we then have:

$$C_E = \frac{\alpha_E}{2(b - 2\alpha_I)}, \tag{25}$$

and

$$C_I(\mu_p) = \frac{2\alpha_I^2[\alpha_E - b(1 - \mu_p)]^2}{b(b - 2\alpha_I)^2}. \tag{26}$$

Finally solving the system of the first order conditions given by (20) and (21), we characterize the equilibrium of the subgame in public persuasion (m_E^*, m_I^*). The following Proposition describes the political equilibrium.

Proposition 1: *If* $\mu_0 \in (\underline{\mu}, \overline{\mu})$ *– with* $\overline{\mu} > \underline{\mu} > 0$ *– there exist a unique (local) political equilibrium, with the following characteristics:*

[18] In fact, in a paper by K. Grier et al. (1991), where they study empirically the relationship between the political participation of firms (given by the percentage of firms with a political action committee (PAC)) and the industry concentration (given by the four-firm industry concentration ratio, measured as the proportion of total sales of the four largest firms to total industry sales). They found that the relationship between the two is quadratic and that the political participation reaches a maximum of 20% at a concentration ratio of 0.45.

- *The equilibrium number of messages* $(m_E^*, m_I^*) \in \mathbb{R}_+^2$ *and the equilibrium perception of the environmental damage* $\mu_p^* \equiv \mu_p(m_E^*, m_I^*) \in (0,1)$ *are given by*

$$m_E^* = \left[\frac{b\alpha_E}{2(b-2\alpha_I)}\right]^2, \tag{27}$$

$$m_I^* = \left[\frac{\alpha_I\left[b^2\left[2(1-\mu_0)-\alpha_E\right]-2b\left[\alpha_E+2\alpha_I(1-\mu_0)\right]+4\alpha_I\alpha_E\right]}{2(b-2\alpha_I)\left[b(1-\alpha_I)-2\alpha_I\right]}\right]^2, \tag{28}$$

$$\mu_p^* = \frac{b\left(\alpha_E-2\alpha_I\right)+2\alpha_I\alpha_E+2\mu_0(b-2\alpha_I)}{2\left[b(1-\alpha_I)-2\alpha_I\right]}; \tag{29}$$

- *The equilibrium political contribution of the green lobby is given by* (25), *i.e..* $C_E^* \equiv C_E$, *while that of the industrial lobby is given by substituting* (29) *into* (26), *i.e.* $C_I^* \equiv C_I(\mu_p^*)$;

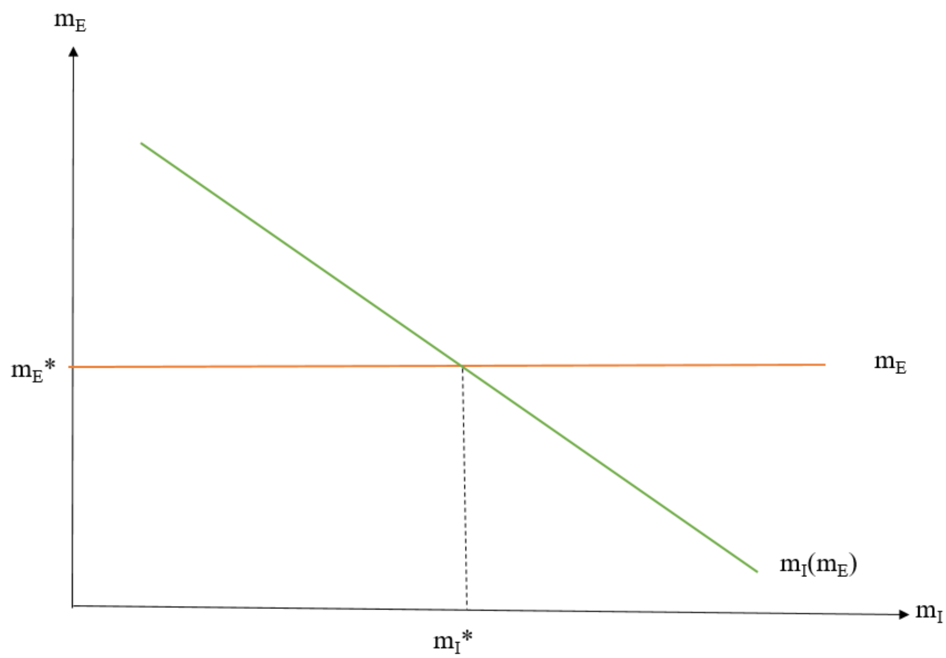
- *The equilibrium tax rate is obtained by substituting* (29) *into* (22), *i.e.* $\hat{t}^* \equiv t^*(\mu_p^*)$.[19]

Proof: See Appendix A.4. □

Let analyze the strategies of the environmental lobby. This lobby has a dominant strategy in the indirect lobbying competition (as shown in Figure 1). Indeed, with $\mu_{EI} = 0$ and a linear damage function, the best-response function of the green lobby only depends on the difference between the taxes t^* and t^I (see (20), (22) and (23)). And this difference does not depend on μ_p, and hence does not depend on m_I. This feature is due to the fact that the political contributions of the environmentalists are independent of the public persuasion outcome μ_p (as shown by (25)). Anticipating this, there is no incentive for the green lobby to use public persuasion as a strategic device for influencing the game in direct political competition. As a result, the green lobby's strategy in the game for public persuasion reflects its true preferences independently of those of the industrial lobby.

This outcome is driven by the set of assumptions behind proposed functional forms. If for instance the public persuasion function would feature a complementary effect between the messages sent by the two lobbies – i.e. $\mu_{12} > 0$ – then the best response function in messages of the green lobby would be upward sloping (see Lemma 4). As already explained, this would reflect an "aggressive" behavior of the green lobby in the public persuasion stage.

[19] The expressions of $\underline{\mu}$, $\overline{\mu}$, C_I^* and $\hat{t}^*$ are given in the appendix.



Reaction functions of the indirect lobbying

Next, considering the strategies of the industrial lobby. Both its direct and indirect strategies depend on μ_p. In fact, anticipating that its political contributions will depend on the outcome of the public persuasion competition, this lobby acts strategically in the indirect political game in a way to influence the outcome of the subgame in political competition. Hence, the capitalists lobby can only best respond to the green lobby's preferences by sending less messages as the number of messages sent by the green lobby increases.

Let analyze the impact of an increase in the proportion of organized environmentalists on the equilibrium number of messages, the equilibrium political contributions and the equilibrium environmental tax. We then have the following Proposition:

Proposition 2: *An increase in the proportion of organized environmentalists α_E:*

- *Increases both the equilibrium number of messages m_E^* and the political contributions C_E^* of the green lobby;*

- *Decreases both the equilibrium number of messages m_I^* and the political contributions C_I^* of the industrial lobby;*

- *Increases equilibrium environmental tax $\hat{t}^*$.*

Proof: See Appendix A.5. □

Thus, as the size of the environmental lobby increases, the two lobbies will adopt opposite strategies in both direct and indirect competition. The green lobby becomes more

aggressive by investing more resources in public persuasion and offers more political contributions to the regulator. In contrast, the industrial lobby best responds to an increase in the political representativeness of its antagonist by investing less resources in the two types of competition. It, hence, offers less political contributions to the regulator and sends less political messages to the general public. Consequently, the environmental policy becomes more stringent.
An increase in representativeness of the environmentalists induces a complementarity effect of direct and indirect lobbying strategies for the two interest groups.

Next, let analyze the impact of an increase in the size of the organized capitalists on the equilibrium number of messages, the equilibrium political contributions and the equilibrium environmental tax.

We then have the following Proposition:

Proposition 3: *An increase in the proportion of organized capitalists α_I:*

- *Increases both the equilibrium number of messages m_E^* and the political contributions C_E^* of the green lobby;*
- *There exists $\overline{\mu}_1 \in (\underline{\mu}, \overline{\mu})$ such that it increases both the equilibrium number of messages m_I^* and the political contributions C_I^* of the industrial lobby for $\mu_0 \in (\underline{\mu}, \overline{\mu}_1]$, and decreases them for $\mu_0 \in [\overline{\mu}_1, \overline{\mu})$;*
- *There exists $\overline{\mu}_2 \in (\underline{\mu}, \overline{\mu})$,* with $\overline{\mu}_2 \leq \overline{\mu}_1$, *such that it increases the equilibrium environmental tax $\hat{t}^*$ for $\mu_0 \in (\underline{\mu}, \overline{\mu}_2]$, and decreases it for $\mu_0 \in [\overline{\mu}_2, \overline{\mu})$.*[20]

Proof: See Appendix A.6. □

Unlike the increase in the size of the green lobby, an increase in the size of the industrial lobby makes its rival more aggressive in both types of lobbying. The green lobby reacts to an increase in α_I by investing more in public persuasion efforts as well as political contributions. This first results shows the complementarity effect that the increase in the size of organized capitalists has on the direct and indirect lobbying strategies of the green lobby.

The effect of an increase in the size of the industrial lobby on its own equilibrium strategies also reflects the complementarity effect between the direct and indirect lobbying strategies. It depends however on the prior belief of the general public μ_0. For lower values of μ_0, i.e. lower environmental awareness, both equilibrium strategies of the industrial lobby increase with α_I. They start decreasing with α_I as the environmental awareness exceeds the threshold level $\overline{\mu}_1$.
To understand this result, recall that the competition in public persuasion results in the equilibrium level μ_p^*. From (29) we can see that the equilibrium environmental belief is decreasing in α_I (i.e. $\partial\mu_p^*/\partial\alpha_I < 0$)[21] and at a lower rate as μ_0 *increases* ($\partial^2\mu_p^*/\partial\alpha_I\partial\mu_0 > 0$).

[20] The expressions of $\overline{\mu}_1$ and $\overline{\mu}_2$ are given in the appendix.
[21] The derivative of μ_p^* with respect to α_I is given by :

$$\frac{\partial\mu_p^*}{\partial\alpha_I} = -\frac{b[b(2(1-\mu_0)-\alpha_E)-4\alpha_E]}{b[b(1-\alpha_I)-2\alpha_I]^2}$$

Therefore, for lower values of μ_0, the effect of α_I on μ_p^* is more important, which induces the industrial lobby to invest even further in its indirect lobbying strategy. As μ_0 reaches $\overline{\mu}_1$ the industrial lobby can now reduce its public persuasion efforts because it is not profitable to increase them anymore, as the effect of α_I on the public environmental belief becomes less important.

Finally, the impact of a bigger industrial lobby on the final policy outcome depends also on the values of the prior environmental belief μ_0. For lower values of the initial environmental belief ($\mu_0 \leq \overline{\mu}_2$), the competition between the two lobbies ends in the favor of the green lobby as the equilibrium environmental tax increases. For $\overline{\mu}_2 \leq \mu_0 \leq \overline{\mu}_1$, the competition shifts into the favor of the industrial lobby leading to a decrease in the equilibrium environmental tax. Interestingly enough the tax continue to decrease even when the capitalists lobby decreases its direct and indirect efforts.[22]

In the last analysis, we are interested in studying the effect of b which is the parameter that reflects the degree of benevolence of the regulator on the equilibrium number of messages, the equilibrium political contributions and the equilibrium environmental tax. We then have the following Proposition:

Proposition 4: *An increase in the degree of benevolence b of the regulator:*

- *Increases both the equilibrium number of messages m_E^* and the political contributions C_E^* of the green lobby;*
- *There exists $\bar{\alpha}_E \in [\alpha_I, 1/2]$ and $\bar{\alpha}_I \in [1/3, 1/2]$ such that if $\alpha_E \geq \bar{\alpha}_E$ and $\alpha_I \leq \bar{\alpha}_I$, then it always increases the equilibrium number of messages m_I^* of the industrial lobby and decreases the equilibrium environmental tax $\hat{t}^*$; otherwise there exists $\overline{\mu}_3 \in (\underline{\mu}, \overline{\mu})$, such that it decreases m_I^* and increases $\hat{t}^*$ for $\mu_0 \in (\underline{\mu}, \overline{\mu}_3]$, and increases m_I^* and decreases $\hat{t}^*$ for $\mu_0 \in [\overline{\mu}_3, \overline{\mu})$;*
- *There exists $\overline{\mu}_4 \in (\underline{\mu}, \overline{\mu})$ such that it decreases the equilibrium political contributions C_I^* of the industrial lobby for $\mu_0 \in (\underline{\mu}, \overline{\mu}_4]$, and increases them for $\mu_0 \in [\overline{\mu}_4, \overline{\mu})$.*[23]

Proof: See Appendix A.7. $\square$

A higher degree of benevolence (b) of the regulator induces a complementarity effect on the equilibrium strategies of the green lobby as it decreases both its equilibrium messages m_E^* and its equilibrium political contributions C_E^*. The equilibrium political contributions decrease because their weight becomes relatively less important in the regulator's objective function, as it gives more importance to the general welfare compared to the monetary contributions. The decrease in the equilibrium number of messages m_E^* comes directly from the fact that the green lobby has a dominant strategy in the indirect political competition as given by (27). When adjusting its strategy to a more benevolent regulator, this lobby does not take into consideration the effect of b on the equilibrium environmental belief of the general public μ_p^*. Its reasoning internalizes only the fact that a greater b increases the

[22] The comparison of the two thresholds values shows that $\overline{\mu}_1$ is greater than $\overline{\mu}_2$.

[23] The expressions of $\overline{\mu}_3$ and μ_4 are given in the appendix.

relative weight of the damage in the objective function of the regulator. Therefore this lobby can afford to reduce its indirect competition efforts.

The reaction of the industrial lobby to a more benevolent regulator is, on the other hand, not so clear cut. In fact, for a sufficiently large proportion of organized environmentalists (i.e. $\alpha_E \geq \bar{\alpha}_E$) and a sufficiently low proportion of organized capitalists (i.e. $\alpha_I \leq \bar{\alpha}_I$), a more benevolent regulator always induces a more aggressive behavior from the industrial lobby in the public persuasion competition, as it increases its equilibrium number of messages m_I^*. Otherwise, the effect of an increase in b depends on the values of the initial belief of the general public about the environmental damage. If the general public has a sufficiently low environmental initial concern about pollution (i.e. $\mu_0 \in (\underline{\mu}, \overline{\mu}_3])$, then the industrial lobby can afford to lower its indirect lobbying efforts when the government becomes more benevolent. If, however, the general public is already relatively highly concerned about the environmental damage (i.e. $\mu_0 \in [\overline{\mu}_3, \overline{\mu}))$, the industrial lobby invests more in public persuasion with an increased degree of benevolence of the government in order to compensate for the initial higher environmental awareness of the general public.

Regarding the political contributions of this lobby, they first decrease for lower initial environmental concern of the general public ($\mu_0 \in (\underline{\mu}, \overline{\mu}_4]$) as the government becomes more benevolent. The industrial lobby can afford to reduce its political contributions when the general public is initially less concerned about the environmental damage. If however, the environmental awareness becomes greater than the threshold value $\overline{\mu}_4$, this lobby needs to strengthen its position by offering even more political contributions to the regulator even if this latter becomes more benevolent and cares less about the monetary contributions.

Finally, in the presence of a more benevolent government, the environmental policy changes in opposite way to the change in the indirect political efforts of the industrial lobby m_I^*, regardless of the reaction of the green lobby to this increase in b. A more benevolent regulator will hence, install a more stringent environmental policy when the equilibrium indirect lobbying efforts of the industrial lobby decrease, and a less stringent environmental policy when those same efforts increase. An interesting conclusion can be drawn from the previous result: the effect of a more benevolent regulator on the final policy outcome does not depend on the direct political competition, it depends only on what happens in the public persuasion stage. Therefore, the effect of b on the stringency of the environmental policy can be directly deduced from the effect of this same parameter on the indirect lobbying efforts of the industrial lobby.

5 Conclusion

This paper aims at studying the impact of direct and indirect strategies adopted by opposing interests groups on the stringency of the environmental policy set by a semi benevolent government. Using a common-agency model of domestic politics similar to the one adopted by Yu (2005) and considering two specialized lobbies, we show that public environmental awareness gives rise to a more aggressive behavior in public persuasion to the green lobby compared to the producer lobby. Indeed, as the proportion of environmentalists become more important, it becomes more active in both direct and indirect lobbying, while the opposite holds for the producer lobby. This in turn leads to a more stringent pollution tax.

In contrast, an increase in the representativeness of the producer lobby does not necessarily lead to a less stringent environmental policy. Actually, it makes the green lobby more active in both direct and indirect lobbying, whereas it increases the direct and indirect political efforts of the industrialists only if the general public has a lower initial belief about the environmental damage. Finally, a more benevolent government does not always set a more stringent environmental policy. In fact, the government is dealing with two market failures that pull in opposite directions: the overproduction due to the pollution and the underproduction due to the monopoly pricing. Consequently, a more benevolent regulator will set a more stringent environmental policy only if the general public is initially less concerned about the environmental damage.

In further work, it would be interesting to verify if the same results hold when we relax the assumptions on the market structure, while still considering a micro-founded model. One also might find it interesting to explore the impact of public persuasion on the outcome of an open economy with trade relations between countries.

Appendix

A.1 Proof of Lemma 2

Using (13) and (14), we have

$$2b\mu_p\left[d^{'}(x(t^I)) - d^{'}(x(t^*))\right] = 2\alpha_E d^{'}(x(t^*)) + (t^I - t^*)(b - 2\alpha_I). \tag{A1}$$

If $t^I \geq t^*$, then the Right-Hand-Term of (A1) is positive because $b - 2\alpha_I \geq 0$, but then the Left-Hand-Term is negative since $d^{'}(x(t^I)) \leq d^{'}(x(t^*))$. Then (A1) can be satisfied only for $t^I \leq t^*$.

Similarly, using (13) and (15), we have

$$2\left(\alpha_E + b\mu_p\right)\left[d^{'}(x(t^E)) - d^{'}(x(t^*))\right] = -2\alpha_I(1 - t^*) + b(t^E - t^*). \tag{A2}$$

If $t^E \leq t^*$, then the Right-Hand-Term of (A2) is negative, but then the Left-Hand-Term is positive since $d^{'}(x(t^E)) \geq d^{'}(x(t^*))$. Then, (A2) can be satisfied only for $t^E \geq t^*$.

A.2 Proof of Lemma 3

From (20), the second derivative of $L^E(m_E, m_I)$ with respect to m_E is

$$L^E_{11} = b\mu_{11}\left[d(x(t^I)) - d(x(t^*))\right] + \frac{b}{2}(\mu_1)^2\left[d'(x(t^*))\frac{\partial t^*}{\partial \mu_p} - d'(x(t^I))\frac{\partial t^I}{\partial \mu_p}\right] - c''_E(m_E). \tag{A3}$$

From (13) and (14) and using the implicit function theorem, we have

$$\frac{\partial t^*}{\partial \mu_p} = \frac{2bd'(x(t^*))}{b - 2\alpha_I + (\alpha_E + b\mu_p)d''(x(t^*))}, \tag{A4}$$

and

$$\frac{\partial t^I}{\partial \mu_p} = \frac{2bd'(x(t^I))}{b - 2\alpha_I + b\mu_p d''(x(t^I))}, \tag{A5}$$

which are both positive.

We have $d'(x(t^*)) \leq d'(x(t^I))$ because $t^* > t^I$, $x'(t) < 0$, and $d''(.) \geq 0$. The numerator of $\partial t^*/\partial \mu_p$ is thus lower than that of $\partial t^I/\partial \mu_p$. If $d'''(.) \leq 0$, the denominator of $\partial t^*/\partial \mu_p$ is also larger than that of $\partial t^I/\partial \mu_p$. As a result $\partial t^*/\partial \mu_p \leq \partial t^I/\partial \mu_p$ and thus the second term of (A3) is negative. The first term is also negative since $\mu_{11} \leq 0$ because $d(x(t^I)) > d(x(t^*))$. It follows that $L^E_{11}(m_E, m_I)$ is always negative.

From (21), the second derivative of $L^I(m_E, m_I)$ with respect to m_I is

$$L^I_{22}(m_E, m_I) = b\mu_{22}\left[d(x(t^E)) - d(x(t^*))\right] + \frac{b}{2}(\mu_2)^2\left[d'(x(t^*))\frac{\partial t^*}{\partial \mu_p} - d'(x(t^E))\frac{\partial t^E}{\partial \mu_p}\right] - c''_I(m_I). \tag{A6}$$

Using (15), we have

$$\frac{\partial t^E}{\partial \mu_p} = \frac{2bd'(x(t^E))}{b + (\alpha_E + b\mu_p)d''(x(t^E))}. \tag{A7}$$

We have $d'(x(t^*)) \geq d'(x(t^E))$ because $t^* < t^E$, $x'(t) < 0$ and $d''(.) \geq 0$. The numerator of $\partial t^*/\partial \mu_p$ is thus larger than that of $\partial t^E/\partial \mu_p$. If $d'''(.) \leq 0$, the denominator of $\partial t^*/\partial \mu_p$ is also *strictly* lower than that of $\partial t^E/\partial \mu_p$. As a result $\partial t^*/\partial \mu_p > \partial t^E/\partial \mu_p$ and the second term of (A6) is strictly positive. The first term of (A5) is negative because $\mu_{22} \geq 0$ and $d(x(t^E)) < d(x(t^*))$. It follows that $L^I_{22} \leq 0$ if either the cost function is sufficiently convex i.e. $c''_I(.) \gg 0$ or if $\mu_{22} \gg 0$.

A.3 Proof of Lemma 4

We now determine the strategic interactions in indirect lobbying. Using (20), the cross derivative of $L^E(m_E, m_I)$ with respect to m_E and m_I is given by

$$L^E_{12}(m_E, m_I) = b\mu_{12}[d(x(t^I)) - d(x(t^*))] + \frac{b}{2}\mu_1\mu_2\left[d'(x(t^*))\frac{\partial t^*}{\partial \mu_p} - d'(x(t^I))\frac{\partial t^I}{\partial \mu_p}\right]. \tag{A8}$$

Again, $d'(x(t^*)) \leq d'(x(t^I))$, and if $d'''(.) \leq 0$, we also have $\partial t^*/\partial \mu_p \leq \partial t^I/\partial \mu_p$. Therefore, the second term in the RHS of (A8) is positive since $\mu_1\mu_2 < 0$. If in addition $\mu_{12} \geq 0$, we have that $L^E_{12}(m_E, m_I) \geq 0$, while its sign is ambiguous for $\mu_{12} < 0$.

Similarly, using (21), the cross derivative of $L^I(m_E, m_I)$ with respect to m_I and m_E is given by

$$L^I_{21}(m_E, m_I) = b\mu_{12}[d(t^E) - d(t^*)] + \frac{b}{2}\mu_1\mu_2\left[d'(x(t^*))\frac{\partial t^*}{\partial \mu_p} - d'(x(t^E))\frac{\partial t^E}{\partial \mu_p}\right]. \tag{A9}$$

Again, $d'(x(t^*)) \geq d'(x(t^E))$, and if $d'''(.) \leq 0$, we also have $\partial t^*/\partial \mu_p > \partial t^E/\partial \mu_p$. Therefore, the second term in the RHS of (A9) is *strictly* negative since $\mu_1\mu_2 < 0$. If in addition $\mu_{12} \geq 0$, we have that $L^I_{21}(m_E, m_I) < 0$, while its sign is ambiguous for $\mu_{12} < 0$.

A.4 Proof of Proposition 1

With linear damage and cost functions, (m_E^*, m_I^*) must solve

$$L_1^E = \mu_1(m_E^*, m_I^*)\frac{b}{2}[t^*(m_E^*, m_I^*) - t^I(m_E^*, m_I^*)] - 1 = 0, \tag{A10}$$

and

$$L_2^I = -\mu_2(m_E^*, m_I^*)\frac{b}{2}[t^E(m_E^*, m_I^*) - t^*(m_E^*, m_I^*)] - 1 = 0. \tag{A11}$$

Using $\mu_p(\mu_0, m_E, m_I) = \mu_0 + \sqrt{m_E} - \sqrt{m_I}$, (A10) and (A11) can be rewritten as

$$L_1^E = \frac{b\alpha_E}{2(b-2\alpha_I)\sqrt{m_E^*}} - 1 = 0, \tag{A12}$$

and

$$L_2^I = \frac{\alpha_I\left[b(1-\mu_0 - \sqrt{m_E^*} + \sqrt{m_I^*}) - \alpha_E\right]}{(b-2\alpha_I)\sqrt{m_I^*}} - 1 = 0. \tag{A13}$$

Solving this system, we obtain the equilibrium levels of public communication, in the subgame for indirect political influence, (m_E^*, m_I^*) given by (27) and (28).

The second derivative of L^E with respect to m_E is clearly strictly negative. Let verify under which condition the second derivative of $L^I(m_E, m_I)$ with respect to m_I is also strictly negative at the equilibrium (m_E^*, m_I^*). One must have

$$L_{22}^I = -\frac{\alpha_I[b(1-\mu_0-\sqrt{m_E^*}) - \alpha_E]}{2m_I^{*3/2}(b-2\alpha_I)} < 0, \tag{A14}$$

which is verified for $b(1-\mu_0-\sqrt{m_E^*}) - \alpha_E > 0$ or

$$\frac{b^2\left[2(1-\mu_0) - \alpha_E\right] - 2b\left[\alpha_E + 2\alpha_I(1-\mu_0)\right] + 4\alpha_I\alpha_E}{2(b-2\alpha_I)} > 0. \tag{A15}$$

We have that the numerator of (A15) is positive if

$$\mu_0 < \frac{b^2(2-\alpha_E) - 2b(\alpha_E + 2\alpha_I) + 4\alpha_I\alpha_E}{2b(b-2\alpha_I)} \equiv \bar{\mu}. \tag{A16}$$

One must verify that $\bar{\mu}$ is positive. The numerator of $\bar{\mu}$ is quadratic and convex in b, so that $\bar{\mu} > 0$ if

$$b > \frac{\alpha_E + 2\alpha_I + \sqrt{\alpha_E^2 - 4(1-\alpha_E)\alpha_E\alpha_I + 4\alpha_I^2}}{2-\alpha_E} \equiv \bar{b}. \tag{A17}$$

Clearly, $\bar{b}$ is increasing in α_E and in α_I and reaches a maximum in $\alpha_E = \alpha_I = 0.5$, in which case we have $1 + 1/\sqrt{3} < 2$. Therefore, $\bar{\mu}$ is always strictly positive for any $b \geq 2$.

We also need to verify that the equilibrium perception of the environmental damage $\mu_p(\mu_0, m_E^*, m_I^*)$ given by (29) is (strictly) positive. The denominator of (29) is positive if $b \geq 2\alpha_I/(1-\alpha_I)$. The right-hand-term of this inequality is increasing in α_I and thus reaches a maximum at $\alpha_I = 0.5$, in which case it is equal to 2. Therefore, the inequality $b \geq 2\alpha_I/(1-\alpha_I)$ is always verified for $b \geq 2$. The numerator is also positive if

$$\mu_0 > \frac{b\,(2\alpha_I - \alpha_E) - 2\alpha_I\alpha_E}{2(b-2\alpha_I)} \equiv \underline{\mu}. \tag{A18}$$

We now also verify that $\mu_p(m_E^*, m_I^*) \leq 1$ for any $\mu_0 \leq \bar{\mu}$. The inequality $\mu_p(m_E^*, m_I^*) \leq 1$ reduces to

$$\mu_0 < \frac{b(2-\alpha_E) - 2\alpha_I(2+\alpha_E)}{2(b-2\alpha_I)} \equiv \hat{\mu}. \tag{A19}$$

Comparing the threshold values in (A16) and (A19), we obtain

$$\hat{\mu} - \bar{\mu} \equiv \frac{\alpha_E[b(1-\alpha_I) - 2\alpha_I]}{2(b-2\alpha_I)}, \tag{A20}$$

which is positive if $b \geq 2\alpha_I/(1-\alpha_I)$. Again, this inequality is verified for any $\alpha_I \leq 0.5$ and $b \geq 2$. Therefore, the relevant upper bound for μ_0 is $\bar{\mu}$.

Finally, we must verify that the admissible interval for μ_0 is non-empty. We have

$$\bar{\mu} - \underline{\mu} \equiv \frac{(b-\alpha_E)\,[b(1-\alpha_I) - 2\alpha_I]}{b(b-2\alpha_I)}, \tag{A21}$$

which is positive.

Finally, the equilibrium political contributions C_E^* and C_I^* are given by

$$C_E^* = \frac{\alpha_E^2}{2(b-2\alpha_I)}, \tag{A22}$$

and (with the use of (29))

$$C_I^* = \frac{\alpha_I^2\,[b^2\,[2(1-\mu_0) - \alpha_E] - 2b\,[\alpha_E + 2\alpha_I(1-\mu_0)] + 4\alpha_I\alpha_E]^2}{2b(b-2\alpha_I)^2\,[b(1-\alpha_I) - 2\alpha_I]^2}. \tag{A23}$$

Finally, using (22) and (29), the equilibrium tax rate is given by

$$t^* = \frac{-b^2\,[1-\alpha_E+\alpha_I-2\mu_0] + 2b\,[\alpha_E + \alpha_I(\alpha_I - 2\mu_0)] - 4\alpha_I(\alpha_E-\alpha_I)}{(b-2\alpha_I)\,[b(1-\alpha_I) - 2\alpha_I]}. \tag{A24}$$

The denominator is positive so that the sign of t^* is the same as the sign of its numerator which can be negative or positive. We also have

$$1 - t^* = \frac{b^2\,[2(1-\mu_0) - \alpha_E] - 2b\,[\alpha_E + 2\alpha_I(1-\mu_0)] + 4\alpha_I\alpha_E}{(b-2\alpha_I)\,[b(1-\alpha_I) - 2\alpha_I]}. \tag{A25}$$

Observe that the numerator of (A25) is the same than the numerator of (A15). Hence, under the condition that $L^I(m_E, m_I)$ is locally concave with respect to m_I, we have $1 - t^* > 0$. One can also observe that C_I^* given by (A23) can be rewritten as $C_I^* = \alpha_I^2[1-t^*]^2/2b$.

A.5 Proof of Proposition 2

Clearly m_E^* and C_E^* are both increasing in α_E. We also have

$$\begin{aligned}\frac{\partial m_I^*}{\partial \alpha_E} &= -\frac{\alpha_I^2[b(b+2)-4\alpha_I]\left[b^2\left[2(1-\mu_0)-\alpha_E\right]-2b\left[\alpha_E+2\alpha_I(1-\mu_0)\right]+4\alpha_I\alpha_E\right]}{2(b-2\alpha_I)^2\left[b(1-\alpha_I)-2\alpha_I\right]^2} \\ &= -\frac{\alpha_I^2[b(b+2)-4\alpha_I]\left[1-t^*\right]}{2(b-2\alpha_I)\left[b(1-\alpha_I)-2\alpha_I\right]}, \end{aligned} \tag{A26}$$

and

$$\begin{aligned}\frac{\partial C_I^*}{\partial \alpha_E} &= -\frac{\alpha_I^2[b(b+2)-4\alpha_I]\left[b^2\left[2(1-\mu_0)-\alpha_E\right]-2b\left[\alpha_E+2\alpha_I(1-\mu_0)\right]+4\alpha_I\alpha_E\right]}{b(b-2\alpha_I)^2\left[b(1-\alpha_I)-2\alpha_I\right]^2} \\ &= -\frac{\alpha_I^2[b(b+2)-4\alpha_I]\left[1-t^*\right]}{b(b-2\alpha_I)\left[b(1-\alpha_I)-2\alpha_I\right]}, \end{aligned} \tag{A27}$$

which are both negative.

Finally, we have

$$\frac{\partial t^*}{\partial \alpha_E} = \frac{b(b+2)-4\alpha_I}{(b-2\alpha_I)\left[b(1-\alpha_I)-2\alpha_I\right]}, \tag{A28}$$

which is positive.

A.6 Proof of Proposition 3

Clearly m_E^* and C_E^* are both increasing in α_I. We also have

$$\begin{aligned}\frac{\partial m_I^*}{\partial \alpha_I} &= \frac{b\alpha_I\left[\Omega(b,\mu_0,\alpha_E,\alpha_I)\right]\left[b^2\left[2(1-\mu_0)-\alpha_E\right]-2b\left[\alpha_E+2\alpha_I(1-\mu_0)\right]+4\alpha_I\alpha_E\right]}{2(b-2\alpha_I)^3\left[b(1-\alpha_I)-2\alpha_I\right]^3} \\ &= \frac{b\alpha_I\left[\Omega(b,\mu_0,\alpha_E,\alpha_I)\right]\left[1-t^*\right]}{2(b-2\alpha_I)^2\left[b(1-\alpha_I)-2\alpha_I\right]^2}, \end{aligned} \tag{A29}$$

and

$$\begin{aligned}\frac{\partial C_I^*}{\partial \alpha_I} &= \frac{\alpha_I\left[\Omega(b,\mu_0,\alpha_E,\alpha_I)\right]\left[b^2\left[2(1-\mu_0)-\alpha_E\right]-2b\left[\alpha_E+2\alpha_I(1-\mu_0)\right]+4\alpha_I\alpha_E\right]}{(b-2\alpha_I)^3\left[b(1-\alpha_I)-2\alpha_I\right]^3} \\ &= \frac{\alpha_I\left[\Omega(b,\mu_0,\alpha_E,\alpha_I)\right]\left[1-t^*\right]}{(b-2\alpha_I)^2\left[b(1-\alpha_I)-2\alpha_I\right]^2}, \end{aligned} \tag{A30}$$

where

$$\begin{aligned}\Omega(b,\mu_0,\alpha_E,\alpha_I) &= b^3\left[2(1-\mu_0)-\alpha_E\right]-2b^2\left[\alpha_E(1-\alpha_I^2)+4\alpha_I(1-\mu_0)\right] \\ &\quad +4b\alpha_I\left[\alpha_E(2+\alpha_I)+2\alpha_I(1-\mu_0)\right]-8\alpha_E\alpha_I^2. \end{aligned} \tag{A31}$$

Therefore, the signs of both $\partial m_I^*/\partial\alpha_I$ and $\partial C_I^*/\partial\alpha_I$ are of the same sign of $\Omega(.)$. We have that $\partial\Omega(.)/\partial\mu_0 = -2b(b-2\alpha_I)^2 < 0$. Thus, $\Omega(.)$ is decreasing in μ_0, and is equal to 0 at

$$\mu_0 = \frac{b^3(2-\alpha_E) - 2b^2[\alpha_E(1-\alpha_I^2) + 4\alpha_I] + 4b\alpha_I[\alpha_E(2+\alpha_I) + 2\alpha_I] - 8\alpha_E\alpha_I^2}{2b(b-2\alpha_I)^2} \equiv \bar{\mu}_1. \quad \text{(A32)}$$

We have

$$\bar{\mu} - \bar{\mu}_1 \equiv \frac{\alpha_I\alpha_E\,[b(1-\alpha_I) - 2\alpha_I]}{(b-2\alpha_I)^2} > 0, \quad \text{(A33)}$$

which is positive for $\alpha_I \leq 0.5$ and $b \geq 2$.

We also have

$$\bar{\mu}_1 - \underline{\mu} \equiv \frac{[b(1-\alpha_I) - 2\alpha_I]\,[b\,(b-\alpha_E-2\alpha_I-\alpha_E\alpha_I) + 2\alpha_E\alpha_I]}{(b-2\alpha_I)^2} > 0, \quad \text{(A34)}$$

which is positive for $\alpha_I \leq 0.5$, $\alpha_E \leq 0.5$, and $b \geq 2$. Consequently, $\Omega(.)$, $\partial m_I^*/\partial\alpha_I$, and $\partial C_I^*/\partial\alpha_I$ are positive for $\mu_0 \in (\underline{\mu}, \bar{\mu}_1]$, and negative for $\mu_0 \in [\bar{\mu}_1, \bar{\mu})$.

Finally, we have

$$\frac{\partial t^*}{\partial\alpha_I} = \frac{\begin{array}{c} -b^4\,[2(1-\mu_0) - \alpha_E] + 2b^3\,[\alpha_E(3-2\alpha_I) - 4(1-2\alpha_I)(1-\mu_0)] \\ +4b^2\,[\alpha_E(1-4\alpha_I) + 2\alpha_I(2-\alpha_I)(1-\mu_0)] \\ -8b\alpha_I\,[\alpha_E(2-\alpha_I) + 2\alpha_I(1-\mu_0)] + 16\alpha_E\alpha_I^2 \end{array}}{(b-2\alpha_I)^2\,[b(1-\alpha_I) - 2\alpha_I]^2}. \quad \text{(A35)}$$

The derivative of the numerator of (A35) with respect to μ_0 is equal to $2b(b+2)(b-2\alpha_I)^2 > 0$. Therefore, the numerator of $\partial t^*/\partial\alpha_I$ is increasing in μ_0, and is equal to 0 at

$$\mu_0 = \frac{\begin{array}{c} b^4(2-\alpha_E) + 2b^3\,[2(1-2\alpha_I) - \alpha_E(3-2\alpha_I)] \\ -4b^2\,[\alpha_E(1-4\alpha_I) + 2\alpha_I(2-\alpha_I)] \\ +8b\alpha_I\,[\alpha_E(2-\alpha_I) + 2\alpha_I] - 16\alpha_E\alpha_I^2 \end{array}}{2b(b+2)(b-2\alpha_I)^2} \equiv \bar{\mu}_2. \quad \text{(A36)}$$

We have

$$\bar{\mu} - \bar{\mu}_2 \equiv \frac{b\alpha_E\,[b(1-\alpha_I) - 2\alpha_I]}{(b+2)(b-2\alpha_I)^2} > 0, \quad \text{(A37)}$$

and

$$\bar{\mu}_2 - \underline{\mu} \equiv \frac{[b(1-\alpha_I) - 2\alpha_I]\,[b^3 + 2b^2(1-\alpha_E-\alpha_I) - 2b(\alpha_E(1-\alpha_I) + 2\alpha_I) + 4\alpha_E\alpha_I]}{b(b+2)(b-2\alpha_I)^2} > 0, \quad \text{(A38)}$$

Consequently, $\partial t^*/\partial\alpha_I$ is negative for $\mu_0 \in (\underline{\mu}, \bar{\mu}_2]$, and positive for $\mu_0 \in [\bar{\mu}_2, \bar{\mu})$.

A.7 Proof of Proposition 4

Clearly m_E^* and C_E^* are both decreasing in b. We also have

$$\begin{aligned}\frac{\partial m_I^*}{\partial b} &= \frac{\alpha_I^2\left[\Psi(b,\mu_0,\alpha_E,\alpha_I)\right]\left[b^2\left[2(1-\mu_0)-\alpha_E\right]-2b\left[\alpha_E+2\alpha_I(1-\mu_0)\right]+4\alpha_I\alpha_E\right]}{(b-2\alpha_I)^3\left[b(1-\alpha_I)-2\alpha_I\right]^3} \\ &= \frac{\alpha_I^2\left[\Psi(b,\mu_0,\alpha_E,\alpha_I)\right]\left[1-t^*\right]}{(b-2\alpha_I)^2\left[b(1-\alpha_I)-2\alpha_I\right]^2},\end{aligned} \tag{A39}$$

where

$$\begin{aligned}\Psi(b,\mu_0,\alpha_E,\alpha_I) &= b^2\left[\alpha_E(1+\alpha_I-\alpha_I^2)-2\alpha_I(1-\mu_0)\right]-4b\alpha_I[\alpha_E-2\alpha_I(1-\mu_0)] \\ &\quad +4\alpha_I^2[\alpha_E(1-\alpha_I)-2\alpha_I(1-\mu_0)].\end{aligned} \tag{A40}$$

We have $\partial\Psi(.)/\partial\mu_0 = 2\alpha_I(b-2\alpha_I)^2 > 0$. Therefore, $\Psi(.)$ is increasing in μ_0 and is equal to 0 at

$$\mu_0 = \frac{-b^2\left[\alpha_E(1+\alpha_I-\alpha_I^2)-2\alpha_I\right]+4b\alpha_I[\alpha_E-2\alpha_I]-4\alpha_I^2[\alpha_E(1-\alpha_I)-2\alpha_I].}{2\alpha_I(b-2\alpha_I)^2} \equiv \bar{\mu}_3 \tag{A41}$$

We have

$$\bar{\mu}-\bar{\mu}_3 \equiv \frac{\alpha_E\left[b(1-\alpha_I)-2\alpha_I\right]\left[b^2(1+\alpha_I)-4b\alpha_I+4\alpha_I^2\right]}{2b\alpha_I(b-2\alpha_I)^2}. \tag{A42}$$

The sign of $(\bar{\mu}-\bar{\mu}_3)$ is the same as the sign of the second term in [.] in the numerator. A sufficient condition for this term to be positive is that $b(1+\alpha_I) \geq 4\alpha_I$, which is verified for any $\alpha_I \leq 0.5$ and $b \geq 2$. Consequently, we have $\bar{\mu}-\bar{\mu}_3 > 0$.

We also have

$$\bar{\mu}_3-\underline{\mu} \equiv \frac{\left[b(1-\alpha_I)-2\alpha_I\right]\left[(2-b)\left(\alpha_E-2\alpha_I\right)-b\alpha_E\alpha_I\right]}{2\alpha_I(b-2\alpha_I)^2}. \tag{A43}$$

The sign of $(\bar{\mu}_3-\underline{\mu})$ is the same as the sign of the second term in [.] in the numerator of (A43), which can be positive as well as negative depending on (b,α_E,α_I). This term is decreasing in α_E and is equal to 0 at

$$\alpha_E = \frac{2(b-2\alpha_I)\alpha_I}{b(1+\alpha_I)-2\alpha_I} \equiv \bar{\alpha}_E. \tag{A44}$$

First, one can easily verify that $\bar{\alpha}_E \geq \alpha_I$, this inequality reducing to $b(1-\alpha_I)-2\alpha_I \geq 0$. Second, we must determine under which condition $\bar{\alpha}_E \leq 1/2$. This inequality reduces to $b-3b\alpha_I-2\alpha_I+8\alpha_I^2 \geq 0$, which is verified (on the interval $[0,1/2]$) only for $\alpha_I \leq (1/16)[2+3b-\sqrt{(b-2)(9b-2)}] \equiv \bar{\alpha}_I$. One can observe that $\bar{\alpha}_I$ is decreasing in b and converges to 1/3 as b goes to infinity. Therefore, if $\alpha_I \leq \bar{\alpha}_I$ – with $\bar{\alpha}_I > 1/3$ – there exists $\bar{\alpha}_E \in [\alpha_I, 1/2]$, given by (A44), such that $\mu_3-\underline{\mu}=0$. Thus, if $\alpha_I \leq \bar{\alpha}_I$, the second term in [.] in the numerator of (A43) is negative for any $\alpha_E \geq \bar{\alpha}_E$, and hence $\bar{\mu}_3 \leq \underline{\mu}$. This implies that $\Psi(.)$ and $\partial m_I^*/\partial b$ are positive for any $\mu_0 \geq \underline{\mu}$. If however, $\alpha_I \geq \bar{\alpha}_I$ or $\alpha_E \leq \bar{\alpha}_E$, then $\bar{\mu}_3 \geq \underline{\mu}$. In this case, $\Psi(.)$ and $\partial m_I^*/\partial b$ are negative for $\mu_0 \in (\underline{\mu}, \bar{\mu}_3]$, and positive for $\mu_0 \in [\bar{\mu}_3, \bar{\mu})$.

Calculating the derivative of C_I^* with respect to b, we obtain

$$
\begin{aligned}
\frac{\partial C_I^*}{\partial b} &= \frac{\alpha_I^2\left[\Phi(b,\mu_0,\alpha_E,\alpha_I)\right]\left[b^2\left[2(1-\mu_0)-\alpha_E\right]-2b\left[\alpha_E+2\alpha_I(1-\mu_0)\right]+4\alpha_I\alpha_E\right]}{2b^2(b-2\alpha_I)^3\left[b(1-\alpha_I)-2\alpha_I\right]^3} \\
&= \frac{\alpha_I^2\left[\Phi(b,\mu_0,\alpha_E,\alpha_I)\right]\left[1-t^*\right]}{2b^2(b-2\alpha_I)^2\left[b(1-\alpha_I)-2\alpha_I\right]^2},
\end{aligned} \tag{A45}
$$

where

$$
\begin{aligned}
\Phi(b,\mu_0,\alpha_E,\alpha_I) \;=\; & -b^4(1-\alpha_I)\left[2(1-\mu_0)-\alpha_E\right]+2b^3\left[2\alpha_I(1-2\alpha_I)(1-\mu_0)+\alpha_E(3-\alpha_I-\alpha_I^2)\right] \\
& -4b^2\alpha_I\left[\alpha_E(7-3\alpha_I)-2\alpha_I(1+\alpha_I)(1-\mu_0)\right] \\
& +8b\alpha_I^2\left[\alpha_E(5-3\alpha_I)-2\alpha_I(1-\mu_0)\right]-16\alpha_E\alpha_I^3.
\end{aligned} \tag{A46}
$$

We have that $\partial\Phi(.)/\partial\mu_0 = 2b(b-2\alpha_I)^2\left[b(1-\alpha_I)+2\alpha_I\right] > 0$. Thus, $\Phi(.)$ is increasing in μ_0 and is equal to 0 at

$$
\mu_0 = \frac{\begin{array}{c} b^4(2-\alpha_E)(1-\alpha_I)-2b^3[2\alpha_I(1-2\alpha_I)+\alpha_E(3-\alpha_I-\alpha_I^2)] \\ +4b^2\alpha_I[\alpha_E(7-3\alpha_I)-2\alpha_I(1+\alpha_I)]-8b\alpha_I^2[\alpha_E(5-3\alpha_I)-2\alpha_I]+16\alpha_E\alpha_I^3 \end{array}}{2b(b-2\alpha_I)^2\left[b(1-\alpha_I)+2\alpha_I\right]} \equiv \bar{\mu}_4 \tag{A47}
$$

We have

$$
\bar{\mu}-\bar{\mu}_4 = \frac{2\alpha_E\left[b(1-\alpha_I)-2\alpha_I\right]\left[b^2(1+\alpha_I)-4b\alpha_I+4\alpha_I^2\right]}{b(b-2\alpha_I)^2\left[b(1-\alpha_I)+2\alpha_I\right]}. \tag{A48}
$$

The sign of $(\bar{\mu}-\bar{\mu}_4)$ is the same as the sign of the second term in [.] in the numerator, which is the same than the term determining the sign of $(\bar{\mu}-\bar{\mu}_3)$, given by (A42). Therefore, we can conclude that $\bar{\mu}-\bar{\mu}_4 > 0$.

We also have

$$
\bar{\mu}_4-\underline{\mu} = \frac{\left[b(1-\alpha_I)-2\alpha_I\right]\Delta(b,\mu_0,\alpha_E,\alpha_I)}{b(b-2\alpha_I)^2\left[b(1-\alpha_I)+2\alpha_I\right]}, \tag{A49}
$$

where

$$
\Delta(b,\mu_0,\alpha_E,\alpha_I) = b^3(1-\alpha_I)-b^2\left[\alpha_E(3+\alpha_I)-2\alpha_I^2\right]+2b\alpha_I\left[\alpha_E(4-\alpha_I)-2\alpha_I\right]-4\alpha_E\alpha_I^2. \tag{A50}
$$

The sign of $(\bar{\mu}_4-\underline{\mu})$ is the same as the sign of $\Delta(b,\mu_0,\alpha_E,\alpha_I)$. The derivative of this expression with respect to α_E is given by $-b^2(3+\alpha_I)+2b\alpha_I(4-\alpha_I)-4\alpha_I^2$, which is negative for any $b \geq 2$ and $\alpha_I \leq 1/2$. Thus, $\Delta(.)$ is decreasing in α_E and is equal to 0 at

$$
\alpha_E = \frac{b^3(1-\alpha_I)-2b(b-2)\alpha_I^2}{b^2(3+\alpha_I)-2b\alpha_I(4-\alpha_I)+4\alpha_I^2} \equiv \tilde{\alpha}_E. \tag{A51}
$$

Calculating $\tilde{\alpha}_E - 1/2$, we obtain

$$
\tilde{\alpha}_E-\frac{1}{2} = \frac{b(1-\alpha_I)\left[2b-(3+4\alpha_I)\right]+2b\alpha_I(4-5\alpha_I)-4\alpha_I^2}{2\left[b^2(3+\alpha_I)-2b\alpha_I(4-\alpha_I)+4\alpha_I^2\right]}, \tag{A52}
$$

Clearly, the denominator is positive. The derivative of the numerator with respect to α_I is given by $-b(2b^2+b-8)+4\alpha_I(2b^2-5b-2)$, which is negative because $4\alpha_I \leq b$ and

$(2b^2+b-8) > (2b^2-5b-2)$. Therefore, the numerator of (A52) reaches a minimum in $\alpha_I = 1/2$, in which case it is equal to $(1/2)(b-2)(2b^2-b+1) > 0$. Consequently, we have $\tilde{\alpha}_E \geq 1/2$ for any $\alpha_I \leq 1/2$. It follows that for any $\alpha_E \leq 1/2$, $\Delta(.)$ is positive implying that $\bar{\mu}_4 - \underline{\mu} \geq 0$. In conclusion, $\Phi(.)$ and $\partial C_I^*/\partial b$ are negative for $\mu_0 \in (\underline{\mu}, \bar{\mu}_4]$, and positive for $\mu_0 \in [\bar{\mu}_4, \bar{\mu})$.

Finally, the derivative of t^* with respect to b is given by

$$\frac{\partial t^*}{\partial b} = \frac{-2\Psi(b, \mu_0, \alpha_E, \alpha_I)}{(b-2\alpha_I)^2 \left[b(1-\alpha_I) - 2\alpha_I\right]^2}, \tag{A53}$$

where $\Psi(b, \mu_0, \alpha_E, \alpha_I)$ also determines the sign of $\partial m_I^*/\partial b$ and is equal to 0 at $\bar{\mu}_3$. Therefore, if $\alpha_I \leq \bar{\alpha}_I$ – with $\bar{\alpha}_I > 1/3$ – there exists $\bar{\alpha}_E \in [\alpha_I, 1/2]$ such that $\bar{\mu}_3 - \underline{\mu} = 0$. Thus, if $\alpha_I \leq \bar{\alpha}_I$, the second term in [.] in the numerator of (A43) is negative for any $\alpha_E \geq \bar{\alpha}_E$, and hence $\bar{\mu}_3 \leq \underline{\mu}$. This implies that $\Psi(.)$ is positive and $\partial t^*/\partial b$ is negative for any $\mu_0 \geq \underline{\mu}$. If however, $\alpha_I \geq \bar{\alpha}_I$ or $\alpha_E \leq \bar{\alpha}_E$, then $\bar{\mu}_3 \geq \underline{\mu}$. In this case, $\Psi(.)$ is negative and $\partial t^*/\partial b$ is positive for $\mu_0 \in (\underline{\mu}, \bar{\mu}_3]$, while $\Psi(.)$ is positive and $\partial t^*/\partial b$ is negative for $\mu_0 \in [\bar{\mu}_3, \bar{\mu})$.

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