Regulators and Environmental Groups: Substitutes or Complements?*

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Abstract

This paper examines green alliances between environmental groups and polluting firms, which have become more common in the last decades, and analyzes how they affect policy design. We first show that the activities of regulators and environmental groups are strategic substitutes, giving rise to free-riding incentives on both agents. Nonetheless, we find that the presence of the environmental group alone yields no welfare benefit, as firms have no incentives to alter their abatement decisions when they do not face regulation. Therefore, the introduction of environmental groups yields a welfare gain when firms are already subject to regulation, suggesting that the former cannot completely replace environmental policy.

KEYWORDS: Environmental groups; Green alliances; Abatement; Environmental policy; Strategic substitutes; Welfare gains.

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1 Introduction

In the last two decades, the relationship of environmental groups towards businesses has evolved, from antagonistic —such as campaigns disclosing firms' practices and lobbying to promote stringent environmental regulation[1]— to more constructive partnerships, commonly known as "green alliances"; see Rondinelli and London (2003). Prominent examples include the joint effort by McDonald's and Environmental Defense Fund to evaluate and redesign packaging materials and food processing methods[2]; the pioneering effort of Greenpeace and the German company Foron to create and popularize hydrocarbon refrigeration technology to address ozone-destroying chlorofluorocarbons[3]; the joint effort of International Paper and The Conservation Fund to protect natural habitats, see Hartman and Stafford (1997); and the partnership between Starbucks Coffee and Alliance for Environmental Innovation to find new ways for Starbucks to serve coffee with disposable beverage cups.

Firms can benefit from these partnerships since the environmental group (EG) offers specialized technical expertise. Indeed, the EG is often aware of environmentally superior technologies that firms overlook; see Yaziji and Doh (2009).[4] Alliances with EGs may help firms identify new environmentally friendly products and technologies, since firms' internal development may be too costly, and acquiring the EG is highly unlikely; see Rondinelli and London (2003). In addition, the programmes that firms develop with EGs can provide greater credibility and commitment than self-developed initiatives; see Hartman and Stafford (1997). Furthermore, firms consider many regulations inefficient, as these are generally too broadly formulated, too costly from an economic point of view, and do not always stimulate best practices and most innovative technologies; see Livesey (1999) and Kolk (2000).

EGs can also benefit from these partnerships, often originated out of frustration with government policies setting too slow, lax or bureaucratic environmental regulations. As World Wide Fund for Nature (WWF) Francis Sullivan said, while emphasizing the need for green alliances, "You cannot just sit back and wait for governments to agree, because this could take forever," Bendell and

[1] For examples of disclosing campaigns, see Heijnen and Schoonbeek (2008), Friehe (2013), Heijnen (2013), and van der Made (2014), among others. For examples of lobbying to promote stringent policies, see Fredriksson (1997), Aidt (1998), and Fredriksson et al. (2005).

[2] Environmental Defense Fund proposed a 42-step action plan on how McDonald's can reduce its ecological footprint caused by the lack of waste management techniques (Hartman and Stafford, 1997). In particular, McDonald's switched from polystyrene foam "clamshells" to paper-based wraps resulting in a 70-90% reduction in sandwich packaging volume, reducing landfill space consumed, energy used and pollutant releases over the lifecycle of the package. They also converted to bleached paper carry-out bags, coffee filters and Big Mac wraps and reduced paper use by 21% in napkins. In the decade following the partnership, McDonald's eliminated over 300 million pounds of packaging, recycled 1 million tons of corrugated boxes, and reduced restaurant waste by 30%.

[3] For more information, visit https://www.greenpeace.org/international/story/15323/how-greenpeace-changed-an-industry-25-years-of-greenfreeze-to-cool-the-planet/.

[4] The partnership between Greenpeace and Foron illustrates this argument. After the Montreal Protocol called for the elimination of CFCs, the chemical industry encouraged appliance makers to replace CFCs with HCFCs, a less-harmful gas. While DuPont and ICI invested more than 500 million in research into HCFCs, Greenpeace developed a refrigerator prototype in a few months using a mix of natural hydrocarbons which was efficient and good for the ozone layer and the climate. In 1994, most German manufactures started to employ this technology and today this type of refrigerators are common in many European countries.

Murphy (2000, p. 69).[5] Additionally, EGs expect "ripple effects" from some partnerships, where a firm's competitors follow the lead adopting a similar practice, thus strengthening the environmental benefits of the partnership.[6]

Green alliances are then regarded as a good alternative to standard environmental policy since firms themselves design and implement the program; see Arts (2002). But are they a substitute or complement of environmental regulation? In the first case, free-riding incentives would arise, implying that regulatory agencies respond with less stringent policies when green alliances are present. If free-riding incentives are strong enough, environmental policy could be completely replaced by green alliances between EGs and firms. While alliances are often more flexible and cost-effective than regulation, EGs represent a specific pool of individuals within a society, potentially giving rise to representability problems. If, in contrast, green alliances are complementary to environmental policy, regulation would become more effective at curbing pollution when the EGs are present than otherwise. Our paper seeks to answer this question, identifying in which contexts green alliances and environmental regulation are substitutes or complements. We then evaluate the welfare gains from EGs, and whether these gains are larger when environmental policy is present or absent.

We consider a sequential-move game where, in the first stage, the EG chooses a collaboration level with each firm, which helps this firm reduce its abatement cost. In the second stage, every firm responds selecting its abatement level. In the third stage, the regulator sets an emission fee, responding to firms' abatement decisions; while in the last stage firms compete in quantities. We show that environmental policy becomes less stringent as aggregate investment in abatement increases. This gives rise to free-riding incentives in firms' abatement decisions, since every firm can benefit from the tax-saving effect of its rivals' investment in abatement. We also find that a more generous collaboration effort from the EG induces the regulator to respond with a less stringent emission fee; in other words, collaboration effort and emission fees become strategic substitutes since both agents seek to curb pollution.

We nonetheless identify synergies between the EG and regulator. First, when environmental policy is absent, the EG's task becomes ineffective. This suggests that green alliances cannot completely replace environmental regulation since firms need tax incentives to invest in abatement. Otherwise, they would not abate regardless of how subsidized this investment is by the EG, leading to the same outcomes as under no regulation and no EGs.

We then evaluate the welfare benefit of introducing emission fees, showing that it becomes larger when the EG is present than otherwise. In other words, environmental regulation becomes more effective when both EG and regulator are active than when only the regulator is.

Finally, we extend our model along several dimensions. First, we consider several EGs, showing

[5] A coordinator at WWF expected more direct results from agreements made with companies than with officials when he said "The government can develop policy, but that is always subject to long-term implementation. The private sector can actually get something meaningful off the ground."

[6] This was the case, for instance, of the McDonald's-EDF partnership where Burger King and other fast food chains followed McDonald's lead by adopting a comparable wrapping.

that, when a new EG enters, existing EGs respond reducing their collaboration effort (free-riding incentives between EGs). However, this reduction in individual collaboration may be offset by the collaboration of the new EG, ultimately increasing aggregate collaboration. Second, we examine an alternative timing where the EG chooses its collaboration effort after the firm invests in abatement, demonstrating that the EG in this setting has no incentives to collaborate with firms since abatement decisions are already made. As a consequence, the EG's presence becomes inconsequential. Finally, we show that our equilibrium results are robust to alternative welfare functions and to the introduction of regulatory uncertainty in the EG's problem.

Related literature. The literature on EGs is relatively recent and can be essentially grouped according to the effect that the EG's activity has on polluting firms. First, several articles assume that EGs take a confrontational approach against firms, reducing market demand for the firm's good (e.g., negative advertising campaigns) or boycotting their sales; see, respectively, Heijnen and Schoonbeek (2008) and Innes (2006).[7] Heyes and Oestreich (2018) develop a delegation model with the EPA auditing the firms and the EG investing in whipping up "community hostility" against the firm's product. They show that, when the EG represents a hostile society with the firm, the actions of the EPA and EG are strategic substitutes; but they can become strategic complements when this hostility is low enough. Similarly, we show that, in contexts where the EG seeks to reduce firm emissions, the actions of regulator and EG are strategic substitutes but their coexistence is welfare improving. We also find that the presence of only one agent may lead to the same results that arise when both agents are absent. We generalize our results to settings with more than one EG, and alternative welfare functions.

Still using a demand approach, a second branch of the literature focuses on EGs investing in advertising and educational campaigns to increase consumers' environmental awareness, so individuals can identify the environmental impact of different products; see van der Made and Schoonbeek (2009).[8] Heijnen (2013) considers a similar problem, where consumers cannot perfectly observe a monopolistic firm's environmental damage, and rely on the advertising campaigns of an EG to infer this information, showing that the EG's presence can be beneficial for both consumers and firm.[9]

A third line of articles examines the EG's role, and its interaction with environmental regulation, using a lobbying rent-seeking approach, where polluting firms (EGs) lobby in favor of (against) projects with environmental implications and, depending on their relative lobbying intensity and effectiveness, the regulator responds approving or denying the project; see Liston-Heyes (2001)[10]

[7] In Heijnen and Schoonbeek's (2008), an environmental group can enter a monopolistic market and set up a campaign to influence consumers' perceived environmental damage. The article finds that the group's campaign might threaten the monopolist to produce employing a cleaner production technology. Similarly, in Innes (2006), an environmental group threatens firms with a boycott in order to promote green production techniques.

[8] In this paper, the EG increases consumers environmental concerns, helping entry in the industry (which newcomers are assumed to use less polluting technologies than incumbents). Entrants are then attracted to the market when the EG is present but stay out when the EG is absent, and aggregate pollution may actually increase when the EG is present depending on the entrant's pollution intensity.

[9] This connects with the literature examining firms' decisions to use EGs as providers of eco-label certifications, when for-profit private certifiers are also available; see, for instance, Bottega and De Freitas (2009).

[10] Using a rent-seeking contest, the paper finds that the firm developing the polluting project, anticipating the

and, for an empirical approach, Riddel (2003).[11]

Finally, a fourth branch of the literature considers EGs as providers of green certificates that firms can place in their packaging to signal certain attributes to consumers; see Heyes and Maxwell (2004). This literature has also examined whether government standards, industry standards and eco-labels, or EGs eco-labels are more effective at reducing pollution. Fisher and Lyon (2014), for instance, show that even when labels provide perfectly reliable information to consumers, environmental damages may be worse when both industry and EGs provide labels to the same product than when only the EG offers the label.

We also consider the interaction of EGs, polluting firms, and regulators, but within a more constructive setting than those described in the above examples where EGs recently collaborated with a polluting firm to develop a green technology the firm would not develop otherwise. We show that, even in the absence of demand effects, lobbying, or green certificates, EGs may have incentives to collaborate with firms to reduce aggregate emissions via green R&D development. In other words, we identify an additional rationale for EGs to collaborate with firms, potentially reinforcing their collaboration incentives stemming from the reasons considered by the previous literature. In addition, we show that the EG's collaboration acts as an strategic substitute of environmental policy, but that the EG becomes useless in the absence of this policy.

The remainder of the paper is organized as follows. Section 2 outlines the model. Section 3 analyzes equilibrium behavior solving for equilibrium output, collaboration effort, abatement levels, and emission tax. In Section 4, we isolate the EG's effect, looking at the case where there is only an EG in the market without a regulator, as well as the case with only a regulator and no EG; exploring the welfare implications in each case. Section 5 shows that the results remain qualitatively unaffected when we allow for several EGs, alternative timings of the game, and the introduction of uncertainty in the EG's problem. Section 6 discusses our results and conclusions.

2 Model

Consider a polluting industry with N firms, each facing an inverse demand function $p(Q) = a - Q$, where Q denotes aggregate output, and a symmetric marginal cost of production c, and $a > c > 0$. Every unit of output, q_i, generates e_i units of emissions, where $e_i = q_i - z_i$, and z_i denotes firm i's abatement effort. We consider the following time structure:

1. In the first stage, the EG chooses a collaboration level with firm i, b_i, which reduces the firm's abatement cost.

contest it will face in a subsequent stage against the EG, partially reduces the potential environmental damage of the project; approaching the equilibrium outcome to the first best. As a consequence, lobbying expenditure is lower in equilibrium than in a setting where the project characteristics are exogeneous, reducing wasteful lobbying efforts.

[11] This paper finds that environmental political action committees (E-PACs) choose to donate to candidates that are both likely to win the election and to advocate environmental positions once elected. Examples include the Sierra Club and the League of Conservation Voters.

2. In the second stage, every firm i independently and simultaneously chooses its abatement level, z_i.

3. In the third stage, the regulator sets an emission fee t.

4. In the fourth stage, every firm i independently and simultaneously selects its output level, q_i.

The next section analyzes equilibrium behavior in this sequential-move game, starting from the last stage. For completeness, our extensions in section 5 examine how our equilibrium results are affected if stages 1 and 2 are switched, so firms choose their abatement effort z_i and the EG then responds with a collaboration effort b_i; as well as allowing for several EGs.

3 Equilibrium analysis

3.1 Fourth stage - Output

In this period, firms observe the emission fee $t > 0$ that the regulator sets in the third stage, their own abatement effort in the second stage, z_i, and the EG's collaboration effort in the first stage, b_i. Every firm i then solves

$$\max_{q_i \geq 0} \ (a - Q)q_i - cq_i - t(q_i - z_i). \tag{1}$$

where the last term, $q_i - z_i$, denotes emissions. The next lemma identifies equilibrium output and profits in this stage.

Lemma 1. *In the fourth stage, every firm i chooses individual output $q_i(t) = \frac{a-(c+t)}{N+1}$, earning profits $\pi_i(t) = \left(\frac{a-(c+t)}{N+1}\right)^2 + tz_i$. In addition, profits are increasing in abatement effort, z_i, but decreasing in firm i's production cost, c, the number of firms, N, and in the emission fee if abatement effort is sufficiently low, i.e., $z_i < \frac{2[a-(c+t)]}{(N+1)^2}$.*

Intuitively, profits are decreasing in the firm's production costs, in the emission fee it pays per unit of output when the abatement effort is insufficient, and in the number of firms in the market; but increases in the abatement effort that the firm selects in the third stage, z_i, since abatement makes the firm's production cleaner in the fourth stage, reducing its tax burden.

Firms' output decisions in the last stage are not directly affected by the presence of the EG in previous periods. However, as we show next, the EG affects the firm's incentives to invest in green R&D, thus impacting its equilibrium profits in the fourth stage.

3.2 Third stage - Emission fee

In the third stage, the regulator anticipates the output function $q_i(t)$ that firms will choose in the subsequent stage, and solves

$$\max_{t \geq 0} \ CS(t) + PS(t) + T - Env(t) \tag{2}$$

where term $CS(t) + PS(t)$ denotes the sum of consumer and producer surplus, $T \equiv t \times Q(t)$ represents total tax collection (so emission fees are revenue neutral), and $Env(t) \equiv d\,[Q(t) - Z]^2$ measures the environmental damage from aggregate net emissions, where $Q(t)$ and Z denote aggregate output and abatement, respectively[12], and $d > 1/2$. For simplicity, we do not include the EG's objective function into the above social welfare, as otherwise net emissions would be double counted. Intuitively, this can be rationalized by assuming that the EG is a foreign entity seeking to reduce emissions in every country where it operates or, alternatively, by considering that the regulator puts a small weight on the EG's objective function if it represents fringe voters. (Section 5.3 considers an alternative welfare function including the EG's collaboration cost, showing that our results are qualitatively unaffected.)

The next lemma identifies the equilibrium emission fee.

Lemma 2. *In the third stage, the regulator sets an emission fee*

$$t(Z) = \frac{(a-c)(2dN-1) - 2dZ(N+1)}{N(1+2d)}$$

which is positive if and only if $Z < \frac{(a-c)(2dN-1)}{2d(N+1)} \equiv \tilde{Z}$. *In addition,* $t(Z)$ *is unambiguously decreasing in the production cost,* c, *and in aggregate abatement,* Z, *but increasing in the number of firms,* N, *if and only if* $Z < \min\left\{\tilde{Z}, \frac{a-c}{2dN}\right\}$. *Finally, the fee is increasing in the environmental damage from pollution,* d, *at a decreasing rate.*

Therefore, the emission fee $t(Z)$ becomes less stringent in the aggregate investment in abatement, Z. Intuitively, the regulator anticipates that a higher abatement reduces net emissions in the subsequent stage, thus requiring a less stringent emission fee today.[13] This result gives rise to free-riding incentives in firms' abatement decisions, as every firm can benefit from the tax-savings effect of other firms' abatement.

In addition, the emission fee is decreasing when firms become more inefficient (higher c), since in that context the regulator expects lower production (and pollution) levels in the subsequent stage, calling for less stringent policies. The opposite argument applies when every unit of output becomes more damaging (higher d), inducing the regulator to set a more stringent emission fee, and when more firms compete in the industry (higher N) if aggregate abatement is relatively low. Intuitively, when more firms enter the industry aggregate emissions increase (unless aggregate abatement Z is sufficiently large), leading the regulator to set more stringent fees.

[12] We write $Q(t)$ since firms respond with their output to the emission fee t set in the third stage. However, we write aggregate abatement as Z, rather than $Z(t)$, since firms do not respond to t with their abatement efforts, as these are chosen in the second stage.

[13] Lemma 2 also identifies that, when aggregate abatement is sufficiently large, $Z \geq \tilde{Z}$, the emission fee becomes negative (i.e., a subsidy). This goes in line with standard models of polluting oligopolies, where the optimal emission fee is positive if the market failure from environmental damage dominates that originating from a socially insufficient production, yielding a socially excessive output level. Otherwise, aggregate output is insufficient, leading the regulator to offer production subsidies.

3.3 Second stage - Abatement

Every firm i anticipates the equilibrium profits it obtains in the fourth stage, $\pi_i(t) = \left(\frac{1-(c+t)}{N+1}\right)^2 + tz_i$, and evaluates them at the equilibrium emission fee that the regulator sets in the third stage, $t(Z)$, to obtain equilibrium profit $\pi_i(Z) \equiv \pi_i(t(Z))$. We can now insert $\pi_i(Z)$ in the firm's problem in this stage, as follows

$$\max_{z_i \geq 0} \; \pi_i(Z) - \frac{1}{2}\left(\gamma_i - \theta_i b_i\right)(z_i)^2 \tag{3}$$

where $Z = z_i + Z_{-i}$ denotes aggregate abatement. Parameter γ_i represents the firm i's initial cost of investing in abatement, while term $\gamma_i - \theta_i b_i$ represents the firm i's final (or net) cost of abatement; after reducing it by the EG's collaboration effort, b_i. Intuitively, when $\theta_i = 0$ firms' abatement costs are unaffected by the EG activity, while when $\theta_i > 0$ firms' abatement costs decrease in the EG's collaboration effort b_i. Therefore, parameter θ_i captures how sensitive the firm's abatement costs are to the EG's collaboration effort or, alternatively, how effective collaboration is. Finally, note that abatement costs are increasing and convex in z_i. The following lemma identifies the equilibrium abatement effort that solves problem (3).

Proposition 1. *In the second stage, every firm i selects an equilibrium abatement effort*

$$z_i(b_i) = \frac{(a-c)\left[2d(2+N(N+2dN-1)-N\right]}{N\left[N\left(\gamma_i - \theta_i b_i\right) + 2d(N(2+N+2(\gamma_i - \theta_i b_i)) + 1) + 4d^2(N(2+N+\gamma_i - \theta_i b_i) - 1)\right]}.$$

which decreases in the production cost, c, and in the net cost of investing in abatement, $\gamma_i - \theta_i b_i$, but increases in the collaboration effort, b_i.

Equilibrium abatement is decreasing in the firm's production cost, c, and in the net cost of abatement, $\gamma_i - \theta_i b_i$, which considers the cost-reduction effect the firm enjoys from the EG's collaboration effort b_i. Comparative statics for parameters N and d are, however, less tractable; so figure 1 evaluates equilibrium abatement $z_i(b_i)$ at parameter values $a = 10$, $c = 0$, $\gamma_i = d = 1$, $\theta_i = 1/2$, and $N = 2$.[14] Figure 1 indicates that, as Proposition 1 states, firm i increases its abatement in the EG's collaboration, b_i. In addition, the individual abatement effort from each firm i shifts downwards when the number of firms increases (figure 1 considers that N increases from $N = 2$ to $N = 5$). As discussed in the previous section, every firm free rides off the tax-saving benefit from its rivals' abatement, implying that individual abatement decreases in the number of firms.

[14] Other parameter values yield similar results and can be provided by the authors upon request.

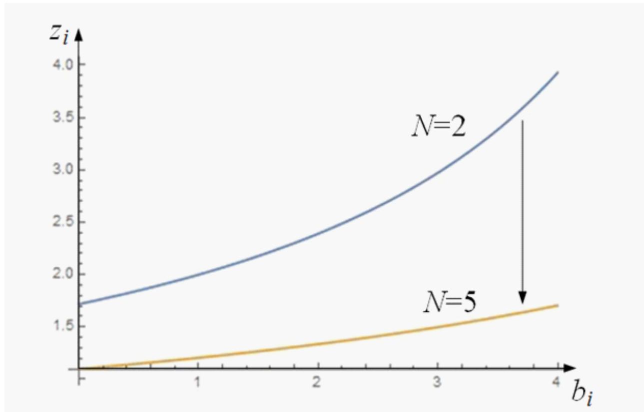

Figure 1. Abatement effort.

3.3.1 Strategic substitutes

Connecting our above results with those in the previous section, the following corollary identifies an interesting point.

Corollary 1. *The optimal emission fee $t(Z)$ is decreasing in the EG's collaboration effort, b_i.*

Therefore, an increase in the EG's collaboration effort, b_i, increases firm i's abatement, z_i, in the third stage —thus increasing aggregate abatement, Z— which ultimately decreases the emission fee that the regulator sets in the third stage, $t(Z)$. In short, a more generous collaboration effort from the EG induces a less stringent emission fee from the regulator or, in other words, collaboration effort and emission fees become strategic substitutes. The intuition of this result is straightforward: as the collaboration from the EG intensifies, firms respond with a larger abatement, entailing that the presence of the regulator is less necessary and, thus, softens regulation.

3.4 First stage - Collaboration effort

In the first stage, the EG anticipates the equilibrium abatement $z_i(b_i)$ from Lemma 3, considering it into the regulator's emission fee from Lemma 2 obtaining, $t^* \equiv t(z_i(b_i), Z_{-i}(b_{-i}))$. We can then insert this emission fee t^* into firm i's output function from Lemma 1, yielding $q^*(b_i) \equiv q_i(t^*)$. Firm i's net emissions when EG is present can then be expressed as $e_i^{EG} \equiv q^*(b_i) - z_i(b_i)$. We also consider firm i's net emissions when EG is absent, $e_i^{NoEG} \equiv q^*(t^{NoEG}) - z_i(t^{NoEG})$, where emission fee and abatement effort are evaluated at $b_i = 0$ and superscript $NoEG$ denotes that the EG is absent. The difference

$$ER_i \equiv e_i^{NoEG} - e_i^{EG}$$

represents the emission reduction in firm i's pollution that can be attributed to the EG's presence, which we interpret as the EG's benefit.

Therefore, the EG chooses a collaboration level $b_i \geq 0$ towards firm i that solves

$$\max_{\frac{\gamma_i}{\theta_i} \geq b_i \geq 0} \quad \beta \left(ER_i\right)^{\frac{1}{2}} - c_{EG} \left(b_i\right)^2 \tag{4}$$

where the first term captures the benefit to the EG in the form of emissions reduction, which is increasing and concave in ER_i, and scaled by $\beta > 0$, which denotes the weight that the EG assigns to emission reduction. The second term measures the cost of exerting collaboration effort, which is increasing and convex in b_i, and $c_{EG} > 0$ represents the cost of effort. To guarantee weakly positive abatement costs, $\gamma_i - \theta_i b_i \geq 0$, we set an upper bound on the collaboration effort so that b_i cannot exceed $\frac{\gamma_i}{\theta_i}$.

Differentiating with respect to b_i in problem (4) yields an intractable expression, which does not allow for an explicit solution of b_i^*. Considering the same parameter values as in figure 1, we obtain

$$MB_i \equiv \frac{2\left(\frac{66}{5}\right)^{1/2}\left(\frac{1}{64-9b_i}\right)^{3/2}}{b_i^{1/2}} = 2c_{EG}b_i \equiv MC_i$$

where the left-hand side denotes the marginal benefit the EG obtains from collaborating with firm i to reduce its emissions, MB_i, while the right-hand side measures the marginal cost of its collaboration effort, MC_i. Figure 2 depicts MB_i and MC_i as a function of b_i.[15]

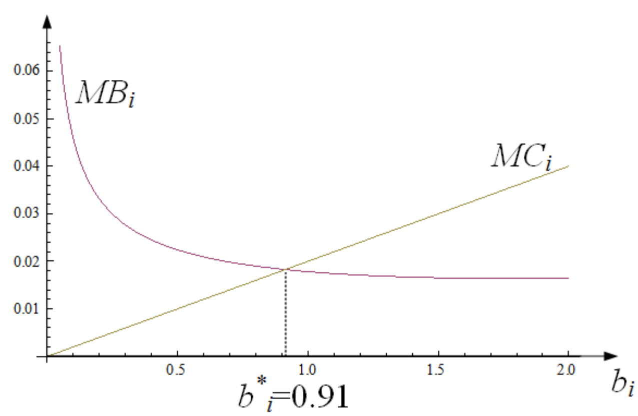

Figure 2. Marginal benefits and costs of collaboration.

Marginal benefit MB_i is positive but decreasing in b_i, indicating that the first units of effort bring a substantial benefit in emission reductions for the EG, but subsequent efforts do not provide large emission reduction benefits. In contrast, the marginal cost MC_i is increasing in b_i, suggesting that additional units of effort become more costly for the EG. In our parametric example, MB_i and MC_i cross at $b_i^* = 0.91$, and similar results emerge for other parameter values as reported

[15] Figure 2 constrains b_i to its admissible set, $\frac{\gamma_i}{\theta_i} \geq b_i \geq 0$, which in this parametric example entails $2 \geq b_i \geq 0$ since $\gamma_i = 1$ and $\theta_i = 1/2$.

in Table I.[16] Overall, equilibrium collaboration b_i^* increases in the benefit that the EG obtains from emission reductions, β, in the strength of demand, a, and in the sensitivity of firm i to the EG's collaboration, θ_i. However, b_i^* decreases in the firm's production cost, c, its initial abatement cost, γ_i, the environmental damage from pollution, d, the EG's collaboration cost, c_{EG}, and in the number of firms in the industry, N. Intuitively, as pollution becomes more damaging, the EG anticipates a more stringent emission fee from the regulator in the third stage of the game, leading the EG to reduce its collaboration effort, as shown in Proposition 1.[17]

	β	a	c	γ_i	θ_i	d	c_{EG}	N	b_i^*	z_i^*	t_i^*	q_i^*
Benchmark	1/10	10	0	1	1/2	1	1/100	2	0.91	1.97	1.06	2.98
Higher β	**2/10**	10	0	1	1/2	1	1/100	2	1.64	2.23	0.53	3.16
Higher a	1/10	**20**	0	1	1/2	1	1/100	2	1.21	4.14	1.72	6.09
Higher c	1/10	10	**1/2**	1	1/2	1	1/100	2	0.89	1.87	1.01	2.83
Higher γ_i	1/10	10	0	**2**	1/2	1	1/100	2	0.74	1.46	2.08	2.64
Higher θ_i	1/10	10	0	1	**3/4**	1	1/100	2	1.23	2.32	0.36	3.21
Higher d	1/10	10	0	1	1/2	**2**	1/100	2	0.75	2.18	1.78	2.74
Higher c_{EG}	1/10	10	0	1	1/2	1	**1/10**	2	0.18	1.76	1.48	2.84
Higher N	1/10	10	0	1	1/2	1	1/100	**10**	0.44	0.73	0.99	0.82

Table I. Equilibrium collaboration effort.

For completeness, the last columns of Table I report the equilibrium abatement effort, z_i^*, emission fee, t_i^*, and output level, q_i^*, evaluated at each vector of parameter values. As expected, when the EG's collaboration effort b_i^* increases, the firm responds increasing the investment in abatement, z_i^*, which is subsequently responded by the regulator setting a less stringent fee t_i^* in the third stage, leading to a larger output q_i^* in the fourth stage.

A natural question is whether collaboration effort and emission fees help reduce net emissions, as evaluated in Table II which considers the same vectors of parameter values of Table I. Overall, net emissions increase in the initial cost of abatement, γ_i, since that reduces firm i's investment; and in the EG's collaboration cost, c_{EG}, since the EG reduces its collaboration with the firm, thus decreasing abatement. In contrast, net emissions decrease in the EG's benefit from reducing emissions, β, since collaboration effort is more intense, increasing the firm's abatement; in the firm's sensitivity to the EG's collaboration, θ_i, as its investment in abatement becomes less costly; in the environmental damage from pollution, d, since the regulator sets more stringent fees leading the

[16] The first row in Table I considers the same parameter values as in figure 2. The second row increases parameter β from $\beta = 1/10$ to $\beta = 2/10$, leaving all other parameter values unchanged. A similar argument applies to all subsequent rows, which change one parameter at a time.

[17] In addition, individual collaboration b_i^* decreases in N but aggregate collaboration, Nb_i^*, can increase in the number of firms. In our current example, aggregate collaboration increases from $Nb_i^* = 2 \times 0.91 = 1.82$ when $N = 2$ firms to $Nb_i^* = 10 \times 0.44 = 4.46$ when $N = 10$ firms.

firm to invest more in abatement[18]; and in the number of firms, N, since each firm's individual output (and pollution) becomes smaller.[19]

	β	a	c	γ_i	θ_i	d	c_{EG}	N	$e_i^* \equiv q_i^* - z_i^*$	SW
Benchmark	1/10	10	0	1	1/2	1	1/100	2	1.01	37.77
Higher β	**2/10**	10	0	1	1/2	1	1/100	2	0.93	39.80
Higher a	1/10	**20**	0	1	1/2	1	1/100	2	1.95	154.22
Higher c	1/10	10	**1/2**	1	1/2	1	1/100	2	0.96	34.05
Higher γ_i	1/10	10	0	**2**	1/2	1	1/100	2	1.18	33.28
Higher θ_i	1/10	10	0	1	**3/4**	1	1/100	2	0.89	40.43
Higher d	1/10	10	0	1	1/2	**2**	1/100	2	0.56	37.23
Higher c_{EG}	1/10	10	0	1	1/2	1	**1/10**	2	1.08	36.02
Higher N	1/10	10	0	1	1/2	1	1/100	**10**	0.09	47.54

Table II. Net emissions in equilibrium and social welfare

Collaborating with only some firms. Our above results allow for the EG to exert asymmetric collaboration efforts in equilibrium, thus collaborating with some firms but not with others. As reported in Table I, the EG collaborates more intensively with firms that are more sensitive to its collaboration (high θ_i), with firms making a high per unit margin (high $a - c$), but less intensively with firms with relatively high initial abatement costs (high γ_i) or in dispersed industries (high N). A similar outcome emerges if the collaboration cost, as captured by c_{EG}, is relatively high with certain firms, yielding a low value of b_i^*, but low for other firms, entailing a high collaboration b_i^*. This may occur when the EG's collaboration requires the development of new, relatively expensive, technologies. Overall, our results suggest that, if firms are relatively asymmetric —exhibiting different technologies, and/or different willingness to work with the EG— the EG may choose to focus its attention in one (or a few) firm(s), rather than displaying a symmetric collaboration effort with each firm.

[18] Intuitively, if environmental damage d increases, the EG anticipates the regulator will set a more stringent emission fee reducing emissions, which the EG can free-ride, thus reducing its equilibrium collaboration b_i^*. However, an increase in d produces a significant increase in emission fee t_i^*, which completely offsets the decrease in EG's collaboration b_i^*, ultimately leading to a reduction in net emissions.

[19] Tables I and II show that the EG's collaboration, b_i^*, decreases in the number of firms, N, as the EG has more firms to help, reducing its individual collaboration effort with each firm. This reduces every firm's abatement, z_i^*, but it also reduces every firm's output level, q_i^*. In our setting, an increase in N reduces individual emissions, from $e_i^* = 1.01$ with $N = 2$ firms to 0.09 with $N = 10$ firms. In this setting, aggregate emissions also decrease, from $2 \times 1.01 = 2.02$ with two firms to $10 \times 0.09 = 0.9$ with 10 firms. Therefore, entry of more firms, while reducing each firm's abatement effort, produces a more significant decrease in individual output, yielding an overall reduction in aggregate emissions.

4 Isolating the EG's effect

4.1 Benchmark A - Regulator, but no EG

To better understand the effect of the EG in the setting of an emission fee, we now consider a context where the EG is absent, but still allow firms to invest in abatement, $z_i \geq 0$. That setting is strategically equivalent to our model, but assuming that the EG's collaboration effort is $b_i = 0$. Equilibrium results in the fourth stage (output decisions) and in the third stage (emission fees) are, obviously, unaffected since they were not a function of collaboration effort b_i; while abatement decision in the second stage, $z_i(b_i)$, is now evaluated at $b_i = 0$, yielding

$$z_i^{NoEG} \equiv z_i(0) = \frac{(a-c)\left[2d\left[N(N(1+2d)-1)+2\right]-N\right]}{N\left[N\gamma+2d\left[2N\gamma+(N+1)^2\right]+4d^2(N(2+N+\gamma)-1)\right]}$$

Since $z_i(b_i)$ is increasing in b_i from Lemma 3, abatement levels satisfy $z_i^{NoEG} < z_i(b_i)$. In words, firms invest less in abatement when the EG is absent.

Inserting equilibrium abatement, z_i^{NoEG}, into the regulator's emission fee from Lemma 2, we obtain $t^{NoEG} \equiv t(z_i^{NoEG}, Z_{-i}^{NoEG})$. For consistency, figure 3a plots this emission fee considering the same parameter values as in previous figures. For comparison purposes, we also depict the fee when the EG is present, t^*, as found in the previous section. Figure 3a indicates that the presence of the EG induces the regulator to set less stringent emission fees. Intuitively, she free-rides off the EG, as the latter helps curb pollution, making environmental policy less necessary.

Figure 3a. Effect of EGs on emission fees.

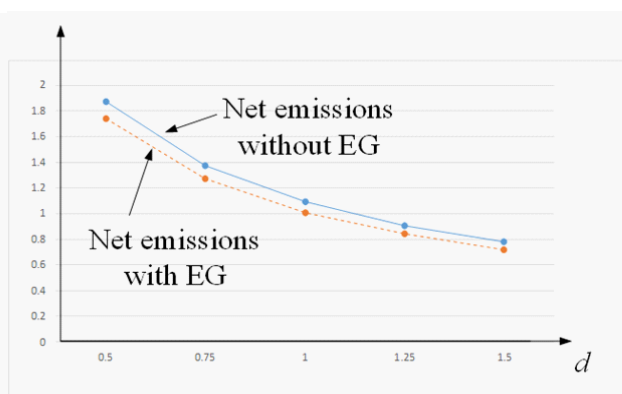

Figure 3b. Effect of EG on net emissions.

Figure 3b compares net emissions when the EG is present, against those when the EG is absent. When the environmental damage is relatively low, net emissions are lower when the EG is present than absent. In this case, the collaboration effort per firm is generous enough to induce firms to invest in relatively high levels of abatement, which complements environmental policy. However, when environmental damage increases, emission fees becomes more stringent, entailing a substantial decrease in pollution, ultimately generating a similar amount of net emissions as in the case in which EG is absent.

4.2 Benchmark B - EG, but no regulator

Let us now consider an alternative benchmark, where the regulator is absent but the EG is present. As in Benchmark A, the fourth stage of the game (output decisions) is unaffected. However, the emission fee that the regulator selects in the third stage is now absent, that is, $t = 0$. In the second stage, every firm i chooses its investment in abatement by, first, evaluating its profits at $t = 0$, that is, $\pi_i(0) = \left(\frac{1-c}{N+1}\right)^2$, and solving a problem analogous to (3), but without the effect of future taxes, as follows

$$\max_{z_i \geq 0} \ \pi_i(0) - \frac{1}{2} (\gamma - \theta b_i) (z_i)^2 . \tag{3'}$$

In problem (3), profit $\pi_i(t(Z))$ was evaluated at the equilibrium fee $t(Z)$ chosen by the regulator in the subsequent stage, making this profit a function of abatement effort, Z, thus playing a role in the first-order conditions. In contrast, in problem (3'), profit $\pi_i(0)$ does not include taxes, and thus becomes independent of abatement efforts, Z. As a result, when differentiating (3') with respect to z_i, we find $-(\gamma - \theta b_i)(z_i)$, which yields a corner solution where the firm chooses a zero abatement level, $z_i = 0$, regardless of how large the collaboration effort of the EG, b_i, becomes.

In the first stage, the EG anticipates that its collaboration will not alter the firm's abatement decision, and thus chooses a zero collaboration effort, $b_i^* = 0$. This is a rather negative result: in essence, the absence of regulators makes the EG's role irrelevant, inducing the firm to behave as if neither regulator or EG where active. Nonetheless, benchmark B also offers a positive implication, namely, that the EG can become effective when regulation is in place. That is, the presence of both agents is critical to induce firms increase their investments in abatement. In other words, while their task become strategic substitutes, inducing one of the agents to free-ride on the other, the absence of the regulator makes the EG completely ineffective.[20]

4.3 Welfare comparison

In this section, we evaluate the welfare that emerges in equilibrium when the EG is present and absent, to measure the welfare gain of environmental regulation in each context. In particular, when the EG is present, the welfare gain from the introduction of environmental regulation is

$$WG_{EG} = W_{EG,R} - W_{EG,NR}$$

where subscript EG denotes that the EG is present, while R (NR) indicates that regulation is present (absent, respectively). A similar definition applies for the welfare benefit from introducing

[20] Equilibrium behavior in this setting coincides with that in alternative model where the first and second stages are reversed, that is, the firm chooses its abatement effort in the first stage, z_i, and the EG responds selecting its collaboration effort in the second stage, b_i. (For compactness, we relegate its analysis to Appendix 1.)

environmental regulation in a setting where the EG is absent

$$WG_{NoEG} = W_{NoEG,R} - W_{NoEG,NR}$$

Evaluating them at our ongoing parameter values, we obtain figure 4a, which indicates that the introduction of emission fees produces a larger welfare benefit when the EG is already present, WG_{EG}, than when it is absent, WG_{NoEG}. Intuitively, environmental regulation becomes more effective when the EG is present than absent, yielding larger welfare gains when EG and regulator are active than when only the regulator is.

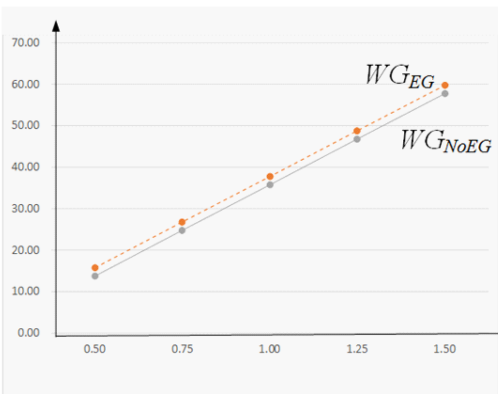

Figure 4a. Welfare gains from regulation.

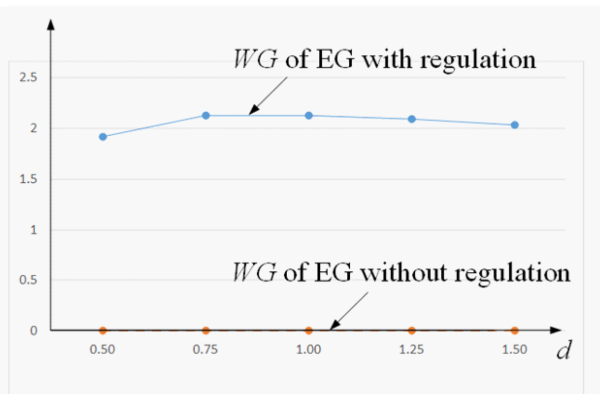

Figure 4b. Welfare gains from EG.

Alternatively, we could evaluate the welfare gains of introducing an EG in an industry subject to emission fees,

$$WG_{EG,R} = W_{EG,R} - W_{NoEG,R},$$

or not subject to regulation, $WG_{NR} = W_{EG,NR} - W_{NoEG,NR}$. Figure 4b plots these welfare gains, showing that the presence of the EG is welfare improving only if firms were already subject to environmental regulation. In contrast, when emission fees are absent, firms do not have incentives to invest in abatement, and the EG's collaboration effort does not alter these incentives, that is, $W_{EG,NR} = W_{NoEG,NR}$. This connects with our previous results about the synergies between regulator and EG's tasks.

5 Extensions

5.1 Allowing for several EGs

In this section, we examine how our previous results are affected when more than one EG chooses to exert collaboration effort with firms. Assume the same time structure as above, but in the first stage every EG j, where $j = \{1, ..., M\}$, simultaneously and independently chooses its collaboration effort with firm i, denoted as $b_{ij} \geq 0$. Equilibrium behavior in the fourth and third stages is unaffected, leading to output function $q(t)$ and emission fee $t(Z)$ obtained in section 3, as none of them are a function of collaboration efforts.

However, second-stage investment in abatement by firm i is now

$$z_i(B_i) = \frac{(a-c)\left[2d(2+N(N+2dN-1)-N\right]}{N\left[N\left(\gamma_i - \theta_i B_i\right) + 2d(N(2+N+2(\gamma_i - \theta_i B_i)) + 1) + 4d^2(N(2+N+\gamma_i - \theta_i B_i) - 1)\right]}$$

where $B_i \equiv \sum_{j=1}^{M} b_{ij}$ denotes the aggregate collaboration effort directed to firm i. Abatement $z_i(B_i)$ is symmetric to equilibrium abatement $z_i(b_i)$, but evaluated at aggregate collaboration towards firm i stemming from all EGs rather than the individual collaboration from a single EG. This suggests free-riding incentives from every EG, that is, an increase in firm i's collaboration by EG j, b_{ij}, induces firm i to increase its abatement, which benefits all other EGs which did not incur in the collaboration cost.

In the first stage, the EG anticipates the equilibrium abatement $z_i(B_i)$. We can insert it into the regulator's emission fee from Lemma 2 obtaining $t^* \equiv t(z_i(B_i), Z_{-i}(B_{-i}))$. The EG considers this emission fee t^* into firm i's output function, yielding $q^*(B_i) \equiv q_i(t^*)$. Firm i's net emissions when EGs are present can then be expressed as $e_i^{EG} \equiv q^*(B_i) - z_i(B_i)$, yielding an emission reduction from firm i of $ER_i(B_i) \equiv e_i^{NoEG} - e_i^{EG}$. Therefore, the jth EG chooses a collaboration level $b_{ij} \geq 0$ towards firm i that solves

$$\max_{\frac{\gamma_i}{\theta_i} \geq b_{ij} \geq 0} \beta \left(ER_i\right)^{\frac{1}{2}} - c_{EG} \left(b_{ij}\right)^2 \qquad (4_j)$$

Differentiating with respect to b_{ij} and rearranging, we obtain a highly non-linear expression. Evaluating it at the same parameter values as in figure 2, we obtain

$$MB_{ij} \equiv \frac{2\left(\frac{66}{5}\right)^{1/2}}{\left[9(b_{ij} + B_{-j}) - 64\right]^2 \left[\frac{64}{64 - 9(b_{ij} + B_{-j})} - 1\right]^{1/2}} = 2c_{EG} b_{ij} \equiv MC_{ij}$$

where $B_{-j} \equiv \sum_{k \neq j}^{M} b_{ik}$ represents the collaboration directed to firm i by EGs different than j. Figure 5 depicts this marginal benefit and cost of collaboration effort b_{ij}. For comparison purposes, the figure includes the marginal benefit evaluated at $B_{-j} = 0$, which coincides with that in figure 2 where a single EG chooses its collaboration effort. This marginal benefit, however, shifts downwards when other EGs increase their collaboration, $B_{-j} > 0$, inducing EG j to collaborate less intensively with firm i. Intuitively, EGs free ride off each other's collaboration effort with firm i, as this effort reduces i's net emissions, implying that collaboration is a strategic substitute. In other words, individual collaboration effort decreases when more EGs enter the industry.

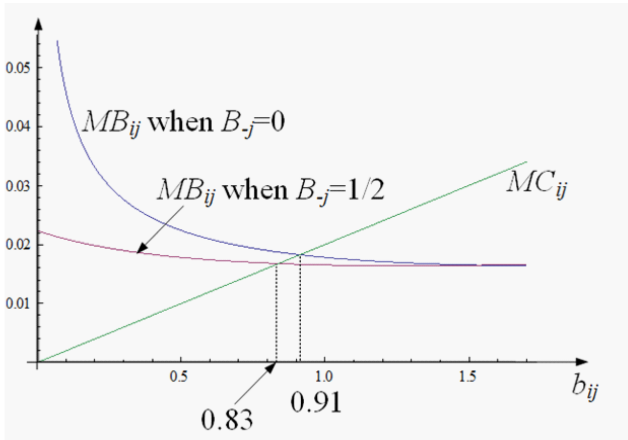

Figure 5. Marginal benefit and cost of bij with several EGs.

In this parametric example, equilibrium collaboration effort becomes

$$b_{ij}^* = \frac{32}{9M} - \frac{\left[1,024M^{2/3} - 90 \times 2^{2/3} \times 33^{1/3} M^{4/3}\right]^{1/2}}{9M^{4/3}}.$$

For instance, when $M = 2$, equilibrium collaboration becomes $b_{ij}^* = 0.82$ entailing an aggregate collaboration of $B_i^* = M \times b_{ij}^* = 1.64$. Therefore, an increase in the number of EGs (from $M = 1$ in previous section to $M = 2$) produces a decrease in individual collaboration, b_{ij}^*, but increases aggregate collaboration, B_i^*. Intuitively, when a new EG enters, the free-riding incentives of each existing EG leads them to reduce their individual collaboration effort, but by a smaller amount than the collaboration effort that the new EG exerts, ultimately increasing aggregate collaboration.

5.2 Alternative timing: The EG moves after the firm

Consider now an alternative time structure in which the first and second stages are reversed. In particular, the firm chooses its abatement effort in the first stage, z_i, and the EG responds selecting its collaboration effort in the second stage, b_i. All subsequent stages are unaffected, and so is equilibrium output $q_i(t)$ in the fourth stage and emission fee t^* in the third stage. We analyze the second and first stage below.

Second stage. In the second stage, the EG seeks to solve a problem analogous to (4). To compute net emissions, we insert emission fee t^* (from Lemma 2) into firm i's output function (from Lemma 1), obtaining

$$q^* \equiv q_i(t^*) = \frac{a - c + 2dZ}{N(1 + 2d)}.$$

In this setting, abatement effort is written as z_i, rather than $z_i(b_i)$, since the firm chooses its abatement before the EG sets its collaboration effort. That is, b_i responds now to z_i, as opposed to our benchmark model where z_i responded to b_i. The emission reduction is now independent on b_i.[21] The EG chooses a collaboration level b_i towards firm i that solves

$$\max_{\frac{\gamma_i}{\theta_i} \geq b_{ij} \geq 0} \beta \left(ER_i\right)^{\frac{1}{2}} - c_{EG} \left(b_{ij}\right)^2 \tag{4'}$$

Differentiating with respect to b_i, we obtain a corner solution where $b_i^* = 0$ for all firms. Intuitively, firms' abatement decisions are already made, implying that a more generous collaboration effort does not alter abatement.

First stage. In the first stage, every firm i solves a problem analogous to (3), but evaluated at $b_i^* = 0$ since the firm can anticipate this response by the EG in the subsequent stage, that is,

$$\max_{z_i \geq 0} \ \pi_i(Z) - \frac{1}{2}\gamma \left(z_i\right)^2 \tag{3'}$$

where $Z = z_i + Z_{-i}$ denotes aggregate abatement. Differentiating with respect to z_i and solving, we find

$$z_i^* = \frac{(a-c)\left[2d\left[N(N(1+2d)-1)+2\right]-N\right]}{N\left[N\gamma + 2d\left[2N\gamma + (N+1)^2\right] + 4d^2(N(2+N+\gamma)-1)\right]}$$

which coincides with $z_i^{NoEG} \equiv z_i(0)$ in Benchmark A where the EG was absent. In summary, when the EG chooses its collaboration effort after the firm selects its investment in abatement, equilibrium results coincide with those of a game where the EG is absent (Benchmark A). Informally, this result can be interpreted as that, if the EG acts too late (after the firm chooses its abatement level) is like having no EG at all.[22]

5.3 Alternative welfare function

In our previous analysis, the regulator did not consider the EG's collaboration cost. Including it in the welfare function, however, would not affect equilibrium behavior, only shifting the welfare that society reaches in equilibrium. To see this point, note that, in the fourth stage, output level $q_i(t)$ is unaffected; in the third stage, the regulator's problem in (2) would include a new cost, $c_{EG}b_i$, which operates as a constant since b_i is not a function of the emission fee $t(Z)$. Therefore, the optimal emission fee in Lemma 2 still applies in this setting. In the second stage, firm i's investment in abatement $z_i(b_i)$ also coincides with that in Proposition 1, implying that the EG's collaboration effort b_i^* is unaffected too.

Equilibrium welfare is, therefore, evaluated at the same equilibrium variables as in previous sections, but shifts down given the additional cost that the welfare function considers in this context,

[21] Since $ER_i \equiv e_i^{NoEG} - e_i^{EG}$, where $e_i^{EG} \equiv q_i^* - z_i$, and both q_i^* and z_i are independent of b_i.

[22] Appendix 1 considers an alternative time structure where the second and third stages are switched. We identify equilibrium behavior in each stage showing that, relative to our baseline model, the EG anticipates that the firm cannot alter the emission fee by investing in z_i (the firm can only lower its overall tax bill reducing emissions), leading the EG to chooses a more intense collaboration effort b_i^* to induce a higher abatement from the firm.

relative to the welfare levels we identified in section 4.3. Specifically, the welfare in $W_{EG,R}$ shifts down, while that in $W_{EG,NR}$ is unaffected since the EG chooses $b_i^* = 0$ under no regulation. Therefore, the welfare gain from introducing regulation when the EG is present,

$$WG_{EG} = W_{EG,R} - W_{EG,NR},$$

decreases relative to our baseline. In contrast, equilibrium welfare $W_{NoEG,R}$ and $W_{NoEG,NR}$ are unaffected by this alternative welfare function, implying that the welfare gain from regulation when the EG is absent $WG_{NoEG} = W_{NoEG,R} - W_{NoEG,NR}$ is unchanged. Finally, the welfare gain of introducing the EG when regulation is already in place, $WG_R = W_{EG,R} - W_{NoEG,R}$, shrinks since $W_{EG,R}$ ($W_{NoEG,R}$) decreases (is unaffected) in this setting, relative to the baseline model.

5.4 Allowing for regulatory uncertainty

Our analysis can be extended to settings where the EG faces uncertainty about the weight that the regulator assigns to environmental damage, d, which is resolved after the EG collaborates with firms. For instance, parameter d can be relatively high (inducing the regulator to set a positive emission fee as in our baseline model) with probability $p \in (0, 1)$, or low (which, for simplicity, we assume to yield no emission fees, as in the model without regulation) with probability $1 - p$. Intuitively, this environment may describe settings in which the EG deals with a new administration which may or may not implement emission fees on a polluting industry, depending on their environmental concerns (which are unclear at the moment that the EG chooses its collaboration effort).

Stages 2-4 in this model resemble our baseline model, when d is relatively high and the regulator sets emission fees, or the model in Benchmark B, where the EG is present but there is no subsequent regulation. In the first stage, the EG anticipates that it faces either of these two models, solving an expected maximization problem

$$\max_{\frac{\gamma_i}{\theta_i} \geq b_i \geq 0} p \left[\beta \left(ER_i \right)^{\frac{1}{2}} - c_{EG} \left(b_i \right)^2 \right] + (1 - p) 0 \tag{4”}$$

where the first term represents the EG's expected payoff when the regulator sets emission fees, and the second term reflects its expected payoff when the regulator's concerns for environmental damage are low enough to not set emission fees. Recall from Benchmark B that, in the absence of fees, every firm does not invest in abatement $z_i(b_i) = 0$, and the EG's task is futile, choosing a zero collaboration effort in equilibrium, $b_i^* = 0$. In this case, the EG has no emission reduction and no costs. Ultimately, problem (4”) coincides with (4) in our baseline model, except for probability p, which does not change the EG's collaboration effort in equilibrium, although it shifts down the EG's equilibrium payoff.

In summary, the introduction of uncertainty in the regulator's environmental concerns (as captured by d) does not change equilibrium behavior, and importantly, still leads the EG to exert a positive collaboration effort with polluting firms in equilibrium.

6 Discussion

Environmental groups and regulation are substitutes. Our results showed that the activities of regulator and EGs are strategic substitutes, that is, the EG reduces its collaboration effort when emission fees become more stringent and, similarly, the regulator sets less stringent fees when the EG is present (and exerts a positive collaboration effort) than when it is absent.

Strategic substitutes but with synergies. At first glance, one could interpret the above results as saying that green alliances can be welfare reducing since they lead to less stringent environmental policies. In contrast, we show that their presence produces a strict welfare improvement when regulation is already in place, but no welfare change when regulation is absent. Informally, firms need the "stick" of more stringent emission fees in subsequent stages to be attracted by the "carrot" of the EG's collaboration to reduce their abatement costs. This means that both regulators and EGs, while seeking similar objectives and thus being subject to free-riding incentives, can yield welfare gains, as their coexistence generates an unambiguously larger welfare than when only one of them is present.

Our results also contribute to the policy debate about EGs being a potential replacement of environmental policy —since regulation is often criticized by several groups, including EGs, as ineffective— since we demonstrated that EGs alone provide no welfare gain whatsoever; instead, being welfare improving when acting in regulated markets.

Promoting EG entry. Our findings then indicate that policies should promote the green alliances between EGs and polluting firms, since they yield a welfare improvement relative to regulation alone. Examples could include subsidies to EG that help firms reduce their abatement costs. In addition, our results also show that promoting the entry of more EGs in an industry is beneficial since aggregate collaboration and abatement increases.

Further research. Our model can be extended along different dimensions. First, we could assume the EG is uninformed about the firm's initial abatement cost, thus choosing its collaboration effort in expectation. This could happen, for instance, if the EG has extensive experience in similar industries in foreign countries but does not know the specific cost structure of firms in this region. Second, the regulator and EG could coordinate their decisions (jointly choosing b and t in the first stage) to internalize their free-riding incentives; although to our knowledge EGs rarely coordinate their collaboration efforts with public officials. Third, we consider for simplicity that firms sell homogeneous goods are and are symmetric in their production costs, but our setting could be extended to allow for heterogeneous goods and/or cost asymmetries, identifying how our above results and welfare implications are affected. Finally, our extension to consider regulatory uncertainty assumed that uncertainty was resolved after the EG chooses its collaboration effort. In a different setting, uncertainty could persist until the period when the regulator sets the emission fee. In that context, not only the EG would face uncertainty when choosing its collaboration effort, but firms would when investing in abatement.

7 Appendix

7.1 Appendix 1 - Alternative time structure

In this appendix, we consider an alternative timing where the second and third stages are switched, that is, the EG still chooses its collaboration b_i in the first stage, the regulator responds choosing fee t in the second stage, every firm i chooses its abatement effort z_i in the third stage, followed by firms competing a la Cournot in the last stage.

Fourth stage. In the last stage, our results coincide with those in the baseline model, producing output level $q_i(t) = \frac{a-(c+t)}{N+1}$, and earning profits $\pi_i(t) = \left(\frac{a-(c+t)}{N+1}\right)^2 + tz_i$.

Third stage. In the third stage, the firm solves

$$\max_{z_i \geq 0} \ \pi_i(t) - \frac{1}{2}(\gamma_i - \theta_i b_i)(z_i)^2$$

Relative to problem (3) in the baseline model (section 3.3), the firm now cannot alter the emission fee with its investment in abatement, z_i, since the emission fee is already set by the regulator in the second stage. Differentiating with respect to z_i and solving, yields

$$z_i(t) = \frac{t}{2(\gamma - b_i\theta)}.$$

Intuitively, the firm now cannot alter the emission fee t, but only its overall tax bill $t \times (q_i - z_i)$, reducing its incentives to invest in abatement relative to our baseline model.

Second stage. In this stage, the regulator anticipates the output function $q_i(t)$ that firms will choose in the fourth stage, and their abatement investment $z_i(t)$ in the third stage, solving

$$\max_{t \geq 0} \ CS(t) + PS(t) + T - Env(t)$$

Relative to problem (2) in section 3.2, this welfare function is evaluated at $q_i(t)$ and at $z_i(t)$, while (3) is only evaluated at $q_i(t)$ and a generic z_i. Differentiating with respect to t, and solving we obtain a fee

$$t(b_i) = \frac{2(a-c)(\gamma - b_i\theta)\left[dN(1+N+2(\gamma - b_i\theta)) - (\gamma - b_i\theta)\right]}{N\left[d(1+N+2(\gamma - b_i\theta))^2 + 2(\gamma - b_i\theta)^2\right]}$$

which, relative to the fee in the main body of the paper, $t(Z)$, this fee is not a function of aggregate abatement (since abatement is selected in the subsequent stage), thus being only a function of the EG's collaboration effort, b_i.

First stage. At the beginning of the game, the EG solves a problem analogous to (4) in section 3.4, but evaluated at a different emission reduction term ER_i. As in problem (4), differentiating with respect to b_i yields a highly non-linear equation which cannot be solved analytically. We next evaluate the first-order condition at the same parameter values as in the main body of the paper (Table I), obtaining the results in Table AI.

	β	a	c	γ_i	θ_i	d	c_{EG}	N	b_i^*
Benchmark	1/10	10	0	1	1/2	1	1/100	2	5.08
Higher β	**2/10**	10	0	1	1/2	1	1/100	2	5.17
Higher a	1/10	**20**	0	1	1/2	1	1/100	2	5.13
Higher c	1/10	10	**1/2**	1	1/2	1	1/100	2	5.08
Higher γ_i	1/10	10	0	**2**	1/2	1	1/100	2	7.05
Higher θ_i	1/10	10	0	1	**3/4**	1	1/100	2	3.46
Higher d	1/10	10	0	1	1/2	**2**	1/100	2	5.07
Higher c_{EG}	1/10	10	0	1	1/2	1	**1/10**	2	5.00
Higher N	1/10	10	0	1	1/2	1	1/100	**10**	13.01

Table AI. Equilibrium collaboration effort.

Relative to our baseline model, the EG anticipates that the firm will not increase its investment in abatement as significantly, since the firm cannot alter the emission fee by investing in z_i (only its overall tax bill), leading the EG to choose a more intense collaboration effort b_i^*.

7.2 *Proof of Lemma 1*

Differentiating the objective function in problem (1) with respect to q_i, yields

$$a - Q_{-i} - 2q_i - c - t = 0,$$

where Q_{-i} denotes aggregate output by all firm i's rivals. Solving for q_i, we obtain firm i's best response function

$$q_i(Q_{-i}) = \begin{cases} \frac{a-(c+t)}{2} - \frac{1}{2}Q_{-i} & \text{if } Q_{-i} < a-(c+t) \\ 0 & \text{otherwise.} \end{cases}$$

In a symmetric equilibrium, individual output levels satisfy $q_i(t) = q_j(t) = q(t)$, which entails $Q_{-i} = (N-1)q(t)$. Inserting this result in the above best response function $q_i(Q_{-i})$, and solving for $q(t)$, yields an equilibrium output of $q(t) = \frac{a-(c+t)}{N+1}$. This output function is positive as long as $t < a - c$.

Inserting this equilibrium output into the firm's objective function in (1), we find

$$\begin{aligned} \pi_i(t) &= \left(a - N\frac{a-(c+t)}{N+1}\right)\frac{a-(c+t)}{N+1} - c\frac{a-(c+t)}{N+1} - t\left(\frac{a-(c+t)}{N+1} - z_i\right) \\ &= \left(\frac{a-(c+t)}{N+1}\right)^2 + tz_i. \end{aligned}$$

Finally, consider that

$$\begin{aligned}
\frac{\partial \pi_i(t)}{\partial c} &= \frac{-2(a-(c+t))}{(N+1)^2} < 0 \text{ since } a > c \text{ and } t < a-c \text{ by assumption,} \\
\frac{\partial \pi_i(t)}{\partial t} &= \frac{-2(a-(c+t))}{(N+1)^2} + z_i < 0 \text{ if } z_i < \frac{2(a-(c+t))}{(N+1)^2}, \\
\frac{\partial \pi_i(t)}{\partial N} &= -\frac{2(a-(c+t))^2}{(N+1)^3} < 0 \text{ and} \\
\frac{\partial \pi_i(t)}{\partial z_i} &= t > 0.
\end{aligned}$$

7.3 *Proof of Lemma 2*

The regulator sets emission fee t to solve

$$\max_{t \geq 0} \frac{1}{2}\left[Q(t)\right]^2 + N\pi_i(t) + t\left[Q(t) - Nz_i\right] - d\left[Q(t) - Nz_i\right]^2$$

where $Q(t) = Nq_i(t) = N\frac{1-(c+t)}{N+1}$. Differentiating with respect to t, we obtain

$$-\frac{N\left[a - c - 2adN + N(t + 2d\left[(c+t) + (N+1)z_i\right]) + 2Zd(N+1)\right]}{(N+1)^2} = 0.$$

Solving for t, we find emission fee

$$t(Z) = \frac{(a-c)(2dN-1) - 2dZ(N+1)}{N(1+2d)}$$

where $t(Z) > 0$ if and only if $Z < \frac{(a-c)(2dN-1)}{2d(N+1)}$.

This emission fee $t(Z)$ is decreasing in c if and only if

$$\frac{\partial t(Z)}{\partial c} = \frac{1-2dN}{N(1+2d)} < 0$$

or if $d > \frac{1}{2N}$, which holds by definition, since parameter d satisfies $d > \frac{1}{2}$. The emission fee is unambiguously decreasing in Z since

$$\frac{\partial t(Z)}{\partial Z} = -\frac{2d(N+1)}{N(1+2d)} < 0,$$

and increasing in d if and only if

$$\frac{\partial t(Z)}{\partial d} = \frac{2(N+1)(a-c-Z)}{N(1+2d)^2}$$

which holds as long as $Z < a-c$. Since a positive fee requires $Z < \frac{(a-c)(2dN-1)}{2d(N+1)}$, then this condition is more demanding than $Z < a-c$ since $\frac{2dN-1}{2d(N+1)} < 1$. In addition, $\frac{\partial^2 t(Z)}{\partial d \partial d} = -\frac{8(N+1)(a-c-Z)}{N(1+2d)^3} < 0$ so fee $t(Z)$ is increasing and concave in d.

Finally, emission fee increases in the number of firms N if

$$\frac{\partial t(Z)}{\partial N} = \frac{a - c - 2dNZ}{N^2(1+2d)} > 0,$$

which holds if $Z < \frac{a-c}{2dN}$. Given that $Z < \frac{(a-c)(2dN-1)}{2d(N+1)}$ for the emission fee to be positive, we have that

$$\frac{a-c}{2d} > \frac{(a-c)(2dN-1)}{2d(N+1)}$$

which holds if $d < \frac{N+2}{2N}$. Hence, when $d < \frac{N+2}{2N}$ holds, the condition for a positive fee, $Z < \frac{(a-c)(2dN-1)}{2d(N+1)}$, becomes a sufficient condition for $\frac{\partial t(Z)}{\partial N} > 0$. Otherwise, $Z < \frac{a-c}{2dN}$ is more demanding and the condition on positive emission fee is not sufficient. Therefore, for emission fee $t(Z)$ to be increasing in N, we need $Z < \min\left\{\frac{a-c}{2dN}, \frac{(a-c)(2dN-1)}{2d(N+1)}\right\}$.

7.4 *Proof of Proposition 1*

We first evaluate equilibrium profits $\pi_i(Z) \equiv \pi_i(t(Z))$, where $t(Z) = \frac{a(2dN-1)+c-2d[Z+N(c+Z)]}{N(1+2d)}$ is the emission fee found in Lemma 2. This profit is

$$\pi_i(Z) = \frac{\left[a - c + 2d(z_i + Z_{-i})\right]^2 + N(1+2d)z_i\left[a(2dN-1) + c - 2d\left(z_i + N(c+z_i) + (N+1)Z_{-i}\right)\right]}{N^2(1+2d)^2}$$

Inserting this result into problem (3), and differentiating with respect to z_i, we find

$$\frac{(a-c)\left[2d(2+N(2dN+N-1)) - N\right] - 4d\left[N + N^2 + 2d(N^2+N-1)\right]z_i - 2dZ_{-i}A}{N^2(1+2d)^2} = (\gamma_i - \theta b_i)\, z_i$$

where $A \equiv N^2 + N + 2d(N^2+N-2)$. In a symmetric equilibrium, $z_i = z_j$ for any two firms $i \neq j$, which entails $Z_{-i} = (N-1)z_i$. Inserting this property in the above first-order condition, we obtain

$$\frac{(a-c)\left[2d(2+N(2dN+N-1)) - N\right] - 2dN\left[(N+1) + 2d(N(2+N))\right]z_i}{N^2(1+2d)^2} = (\gamma_i - \theta_i b_i)\, z_i$$

Solving for z_i, we find the equilibrium abatement effort

$$z_i(b_i) = \frac{(a-c)\left[2d(2+N(N+2dN-1) - N\right]}{N\left[N(\gamma_i - \theta_i b_i) + 2d(N(2+N+2(\gamma_i - \theta_i b_i)) + 1) + 4d^2(N(2+N+\gamma_i - \theta_i b_i) - 1)\right]}.$$

The numerator of the abatement effort is always positive, since $d > 1/2$ and $N \geq 1$. The denominator, however, is positive if $\gamma_i - \theta_i b_i \geq \frac{2d[2d(1-N(2+N))-(1+N)^2]}{N(1+2d)^2} \equiv \Delta$, where Δ is negative since $N \geq 1$.

Comparative statics. Differentiating $z_i(b_i)$ with respect to the EG's collaboration effort, b_i, yields

$$\frac{\partial z_i(b_i)}{\partial b_i} = \frac{(a-c)(1+2d)^2\theta_i\left[2d\left[2+N(N+2dN-1)\right]-N\right]}{N\left[N\left(\gamma_i-\theta_i b_i\right)+2d(N(2+N+2(\gamma_i-\theta_i b_i))+1)+4d^2(N(2+N+\gamma_i-\theta_i b_i)-1)\right]^2} > 0$$

which is positive since $2d\left[2+N(N+2dN-1)\right]-N > 0$ given that $d > 1/2$ and $N \geq 1$ by definition. In addition, differentiating $z_i(b_i)$ with respect to the production cost, c, yields

$$\frac{\partial z_i(b_i)}{\partial c} = \frac{N-2d\left[2+N((1+2d)N-1)\right]}{N\left[N\left(\gamma_i-\theta_i b_i\right)+2d(N(2+N+2(\gamma_i-\theta_i b_i))+1)+4d^2(N(2+N+\gamma_i-\theta_i b_i)-1)\right]} < 0$$

in this case the denominator is positive by definition since $N \geq 1$ and $\gamma_i - \theta_i b_i \geq \Delta$. The numerator, however, is negative if $2d\left[2+N((1+2d)N-1)\right] > N$, which holds by definition since $N \geq 1$ and $d > 1/2$.

7.5 *Proof of Corollary 1*

We seek to sign the derivative $\frac{\partial t(Z)}{\partial b_i}$, where

$$\frac{\partial t(Z)}{\partial b_i} = \underbrace{\frac{\partial t(Z)}{\partial Z}}_{(-)}\underbrace{\frac{\partial Z}{\partial z_i}}_{(+)}\underbrace{\frac{\partial z_i(b_i)}{\partial b_i}}_{(+)}$$

We know that $\frac{\partial t(Z)}{\partial Z} < 0$ from Lemma 2, $\frac{\partial Z}{\partial z_i} > 0$ by definition since $Z = \sum_{j=1}^{N} z_j$, and $\frac{\partial z_i(b_i)}{\partial b_i} > 0$ from Proposition 1. Therefore, $\frac{\partial t(Z)}{\partial b_i} < 0$, implying that an increase in the EG's collaboration effort in the first stage, b_i, decreases the emission fee $t(Z)$ that the regulator sets in the third stage.

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