

# Regulators and Environmental Groups: Better Together or Apart?\*

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## Abstract

This paper examines green alliances between environmental groups (EGs) 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, the presence of the environmental group yields larger welfare benefits when firms are subject to regulation than when they are not. In addition, the introduction of environmental policy yields welfare gains when the EG is absent but may lead to welfare losses when the EG is already present.

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<sup>1</sup>— 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<sup>2</sup>; the pioneering effort of Greenpeace and the German company Foron to create and popularize hydrocarbon refrigeration technology to address ozone-destroying chlorofluorocarbons<sup>3</sup>; 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).<sup>4</sup> 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 (improved public image); 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

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<sup>1</sup>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).

<sup>2</sup>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%.

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

<sup>4</sup>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 manufacturers started to employ this technology and today this type of refrigerators are common in many European countries.

Murphy (2000, p. 69).<sup>5</sup> 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.<sup>6</sup>

Green alliances are then regarded as a good alternative to standard environmental policy since firms themselves design and implement the program; see Arts (2002). We examine their policy implications by first exploring whether green alliances are 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 and identify if the presence of EGs, regulators, or both, yields the highest social welfare. Understanding the interaction between regulators and EGs in the context of green alliances can help us provide policy recommendations about promoting or hindering EG activities in polluting industries.

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.

In our setting, a firm experiences two benefits from investing in abatement: (1) an increase in its demand, as its product becomes more attractive to customers (which we refer as “public image”); and (2) a reduction in the emission fee that the regulator sets in the subsequent stage since abatement decreases emissions (which we refer as “tax savings”). Public image works as a private good, since only the firm investing in abatement benefits from it, but tax savings work as a public good, since every firm enjoys a lower emission fee regardless of which firm invested in abatement. The public good nature of tax savings introduces free-riding incentives in abatement which are, however, ameliorated by the public image benefit. We show that, when the former effect dominates the latter, firms’ abatement decisions are strategic substitutes, but otherwise abatement efforts can become strategic complements. Interestingly, the EG can exploit this relationship with its collaboration effort in the first stage. Specifically, the EG can increase its collaboration with firms by a relatively small amount in the first period to make abatement efforts strategic complements (or less strategic substitutable), inducing firms to significantly increase their abatement. This abatement reduces emissions, thus benefiting both the EG and the regulator, who responds setting

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<sup>5</sup> 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.”

<sup>6</sup> 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.

a less stringent emission fee.

The above results suggest that green alliances may be welfare enhancing, since they help firms invest more in abatement, or welfare reducing, as emission fees are less stringent. To answer this question, we evaluate the welfare gain from introducing an EG in a polluting industry, showing that its presence yields an unambiguous welfare gain, both when firms are subject to environmental regulation and when they are not, since the EG helps ameliorate free-riding incentives in abatement (tax-saving effects). In other words, environmental regulation becomes more effective when both EG and regulator are active than when only the regulator is.

We then identify the welfare gain from introducing environmental policy, showing that it is positive when the EG is absent, and thus pollution was not being addressed by any agent. When the EG is present, however, the introduction of emission fees gives rise to free-riding incentives in abatement, leading firms to decrease their investment, with a corresponding increase in pollution, ultimately decreasing social welfare.

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. We demonstrate that EGs provide welfare gains in the absence of regulation, but their presence in regulated markets can yield even further welfare improvements. Nonetheless, our results also suggest that unregulated industries where EGs actively collaborate with firms should be left unregulated, as in developing countries with no environmental regulation but an active international EG.

**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).<sup>7</sup> 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 can be welfare improving.

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).<sup>8</sup> Heijnen (2013) considers a similar problem, where consumers cannot perfectly observe a

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<sup>7</sup>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.

<sup>8</sup>In this paper, the EG increases consumers environmental concerns, helping entry in the industry (which new-

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.<sup>9</sup>

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)<sup>10</sup> and, for an empirical approach, Riddel (2003).<sup>11</sup>

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 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 a 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 discusses our results and conclusions. Appendix 1 shows that the results remain qualitatively unaffected when we allow for an alternative timing of the game.

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comers 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.

<sup>9</sup>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).

<sup>10</sup>Using a rent-seeking contest, the paper finds that the firm developing the polluting project, anticipating the 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 exogenous, reducing wasteful lobbying efforts.

<sup>11</sup>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 Model

Consider a polluting industry with two firms, each facing an inverse demand function  $p_i(Q) = (a + \lambda z_i) - Q$ , where  $Q \equiv q_i + q_j$  denotes aggregate output and  $\lambda \in [0, 1]$  measures how firm  $i$ 's abatement  $z_i$  increases its demand. When  $\lambda = 0$ , demand is unaffected by abatement indicating that consumers ignore firm's clean practices, while when  $\lambda = 1$  every unit of investment in abatement increases demand proportionally.<sup>12</sup> Firms have a symmetric marginal cost of production  $c$ , and  $a > c > 0$ . Every unit of output,  $q_i$ , generates  $e_i$  units of emissions, where  $e_i = q_i - z_i$ . We consider the following time structure:

1. In the first stage, the EG chooses a collaboration level with firm  $i$ ,  $b_i$ .<sup>13</sup>
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, Appendix 1 examines how our equilibrium results are affected if stages 2 and 3 are switched, so the regulator sets emission fee  $t$  in the second stage and firms respond with their abatement effort  $z_i$  in the third stage.

## 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 efforts in the second stage,  $z_i$  and  $z_j$ , and the EG's collaboration efforts with firms  $i$  and  $j$  in the first stage,  $b_i$  and  $b_j$ . Every firm  $i$  then solves

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

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

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<sup>12</sup>Public image benefits are mainly appropriated by the firm investing in abatement, that is,  $p_i(Q)$  increases in  $z_i$  but is unaffected by  $z_j$ . For instance, when McDonalds announced an increase in abatement efforts, such as investing in recyclable packaging materials and beverage cups, its rival (Burger King) did not experience an increase in sales.

<sup>13</sup>The green alliance between McDonald's and Environmental Defense Fund (EDF) started in 1990 and is still in place. We could not find records of EDF not carrying out its announced collaborations with McDonalds, suggesting that EGs tend to commit to a collaboration level once they announce it to the public. A similar argument applies to EDF's collaboration with FedEx, which collaborated since 2010 in developing one of the largest hybrid fleets in the industry; and to the collaboration of Greenpeace in Foron to produce ten prototype hydrocarbon refrigerators (Stafford et al., 2000; Seitanidi and Crane, 2013).

**Lemma 1.** *In the fourth stage, every firm  $i$  chooses individual output  $q_i(t) = \frac{[a+\lambda(2z_i-z_j)]-(c+t)}{3}$ , earning profits  $\pi_i(t) = (q_i(t))^2 + tz_i$ . Output  $q_i(t)$  is positive if and only if  $z_i > \frac{\lambda z_j + t - (a-c)}{2\lambda}$ .*

*In addition, profits are increasing in firm  $i$ 's abatement effort,  $z_i$ , and in public image,  $\lambda$ , but decreasing in firm  $j$ 's abatement effort,  $z_j$ , in production cost,  $c$ , and in the emission fee  $t$  if abatement effort is sufficiently low, i.e.,  $z_i < \frac{2[a-\lambda z_j-(c+t)]}{9-4\lambda}$ .*

Intuitively, profits are increasing in the abatement effort that the firm chooses in the third stage,  $z_i$ , since abatement provides: (i) a tax-saving benefit, since  $z_i$  reduces emissions for a given emission fee  $t$ ; and (ii) a public image benefit, since a cleaner production attracts more customers. Similarly, an increase in public image,  $\lambda$ , increases profits, since the firm's demand increases more significantly in each unit of abatement,  $z_i$ . In contrast, profits decrease in the abatement effort from firm  $i$ 's rival,  $z_j$ , since a better public image reduces firm  $i$ 's sales, i.e., a business stealing effect. Finally, note that firm  $i$ 's output  $q_i(t)$  is positive as long as its abatement is relatively larger than its rival's.

Firms' output decisions in the last stage are not directly affected by the presence of the EG in previous periods. However, the EG affects the firm's incentives to invest in green R&D in the second stage, 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

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

where term  $CS(t) + PS(t)$  denotes the sum of consumer and producer surplus,  $T \equiv t \times [Q(t) - Z]$  represents total tax collection on net emission<sup>14</sup>, and  $Env(t) \equiv d[Q(t) - Z]^2$  measures the environmental damage from aggregate net emissions, where  $Q(t) = q_i(t) + q_j(t)$  and  $Z = z_i + z_j$  denote aggregate output and abatement, respectively<sup>15</sup>, and  $d > 1/2$  represents the weight that the regulator assigns on environmental damages.<sup>16</sup>

The next lemma identifies the equilibrium emission fee.

<sup>14</sup>Emission fees are then revenue neutral. Intuitively, while fees induce firms to alter their production (and pollution) decisions, tax collection is completely returned to society in the form of a lump-sum subsidy, implying that tax revenue does not increase social welfare.

<sup>15</sup>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.

<sup>16</sup>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.

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

$$t(Z) = \frac{2(a-c)(4d-1) - Z[\lambda + 4d(3-\lambda)]}{4(1+2d)}$$

which is positive if and only if  $Z < \frac{(a-c)(4d-1)}{4d(3-\lambda)+\lambda} \equiv \tilde{Z}$ . In addition,  $t(Z)$  is unambiguously decreasing in the production cost,  $c$ , and in aggregate abatement,  $Z$ , unambiguously increasing in public image,  $\lambda$ , but increasing in the regulator's weight on environmental damage,  $d$ , if and only if  $Z < \frac{2(a-c)}{2-\lambda} \equiv \bar{Z}$ , where cutoff  $\bar{Z}$  satisfies  $\bar{Z} > \tilde{Z}$  under all parameter conditions.

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.<sup>17</sup> 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 the regulator assigns a larger weight on environmental damage (higher  $d$ ), inducing him to set a more stringent emission fee.<sup>18</sup> Finally,  $t(Z)$  increases in public image since, for a given aggregate abatement  $Z$ , a higher value of  $\lambda$  expands demand more significantly. A stronger demand leads firms to increase output in the last stage of the game, thus increasing net emissions. Anticipating this output expansion due to public image, the regulator sets a more stringent fee in the third stage.

### 3.3 Second stage - Abatement

Every firm  $i$  anticipates the equilibrium profits it obtains in the fourth stage,  $\pi_i(t) = (q_i(t))^2 + tz_i$ , 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

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

where  $z_i + z_j < \bar{Z}$ , to guarantee that the emission fee is increasing in  $d$ . Parameter  $\gamma \geq 1$  represents the firm  $i$ 's initial cost of investing in abatement, while term  $\gamma - \theta b_i$  represents the firm  $i$ 's final (or net) cost of abatement; after reducing it by the EG's collaboration effort,  $b_i$ . Intuitively, when  $\theta = 0$  firms' abatement costs are unaffected by the EG activity, while when  $\theta > 0$  firms' abatement costs

<sup>17</sup>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.

<sup>18</sup>This property holds when  $Z < \bar{Z}$ . The following section restricts firm abatement choices in the second stage to satisfy this property.



decrease in the EG's collaboration effort  $b_i$ . Therefore, parameter  $\theta$  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  $z_i$ .

We first identify firm  $i$ 's best response function  $z_i(z_j)$  and examine whether abatement efforts are strategic substitutes or complements.

**Lemma 3.** *Firm  $i$ 's best response function in the second stage is*

$$z_i(z_j) = \frac{2(a-c)[4d(2A+\lambda)-2+3\lambda] - [2\lambda + \widehat{A}[\lambda^2 + 4d(2+\lambda(\lambda-1))]]z_j}{16d[3+5d+2(1+d)\gamma] - 32dA\lambda - \widehat{A}^2\lambda^2 + 4(2\gamma+\lambda) - 8A^2\theta b_i}$$

where  $A \equiv 1+2d$  and  $\widehat{A} \equiv 3+4d$ . In addition:

1. when  $b_i = 0$  and  $\lambda = 0$ ,  $z_i(z_j)$  is unambiguously decreasing in  $z_j$ ;
2. when  $b_i = 0$  and  $\lambda > 0$ ,  $z_i(z_j)$  is decreasing in  $z_j$  if and only if  $\gamma > \bar{\gamma}$ ; and
3. when  $b_i, \lambda > 0$ ,  $z_i(z_j)$  is decreasing in  $z_j$  if and only if  $\gamma > \bar{\gamma} + \theta b_i$  when  $b_i, \lambda > 0$ ,

where  $\bar{\gamma} \equiv \frac{\lambda(9\lambda-4)+8d[\lambda(4+3\lambda)-6]-16d^2(1-\lambda)(5+\lambda)}{8(1+2d)^2}$ . Cutoff  $\bar{\gamma}$  decreases in the weight that the regulator assigns to environmental damage,  $d$ , but increases in public image  $\lambda$ .

Therefore, when the EG is absent and consumers ignore public image,  $b_i = 0$  and  $\lambda = 0$ , firms' abatement efforts are strategic substitutes for all parameter values. In this setting, an increase in firm  $j$ 's abatement,  $z_j$ , only produces a benefit on firm  $i$ 's profits, namely, tax savings since an increase in abatement efforts today reduce emission fees tomorrow on both firms. Firm  $i$ , hence, responds to an increase in  $z_j$  reducing its own abatement  $z_i$ , indicating that firms free-ride each other's abatement efforts.

When the EG is absent but there are public image effects,  $b_i = 0$  and  $\lambda > 0$ , abatement efforts are strategic substitutes if the initial abatement cost is sufficiently high,  $\gamma > \bar{\gamma}$ . In this context, an increase in  $z_j$  produces two opposite effects on firm  $i$ 's profits: (i) a positive tax-savings effect as discussed above; and (ii) a negative business stealing effect since  $\lambda > 0$ . Hence, when the positive effect in (i) is larger than the negative effect in (ii), abatement efforts remain strategic substitutes. This occurs, in particular, when firms face a relatively high initial abatement cost, yielding a minor business-stealing effect. Otherwise, firms' abatement become strategic complements. A similar argument applies when both EG and public image are present, but abatement efforts are now strategic substitutes under more restrictive conditions. Intuitively, the EG's collaboration effort enlarges the business stealing effect, making less likely that free-riding incentives dominate.

Finally, abatement efforts become strategic substitutes under larger conditions when  $d$  increases. In this context, the regulator sets a more stringent emission fee, enlarging the tax saving benefits, which ultimately makes free riding more pervasive. The opposite argument applies when  $\lambda$  increases,

as the business stealing effect is more significant, making more difficult for abatement efforts to be strategic substitutes.

The following proposition identifies the equilibrium abatement effort.

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

$$z_i(b_i, b_j) = \frac{(a - c) [4d(2A + \lambda) + 3\lambda - 2] [4\gamma + \lambda(1 - 6\lambda) + B - 4A\theta b_j]}{[4\gamma + \lambda(1 - 6\lambda) + B] F - 2A\theta [(D - 32dA\lambda + C) b_j + b_i(D - 32dA\lambda + C - 8A^2\theta b_j)]}.$$

where  $A \equiv 1 + 2d$ ,  $B \equiv 4d[3 + 2\gamma - \lambda(3 + 2\lambda)]$ ,  $C \equiv 4(2\gamma + \lambda) - (3 + 4d)^2\lambda^2$ ,  $D \equiv 16d(3 + 5d + 2(1 + d)\gamma)$  and  $F \equiv 4\gamma + 8d^2(7 + 2\gamma - 5\lambda) + 3\lambda(1 - \lambda) + 2d[18 + 8\gamma - \lambda(11 + 2\lambda)]$ . In addition,  $z_i(b_i, b_j) + z_j(b_i, b_j) < \bar{Z}$ , which guarantees that the emission fee increases in  $d$ , holds if  $b_i < \bar{b}_i$ , where cutoff  $\bar{b}_i$  is provided, for compactness, in the appendix.

Equilibrium abatement is clearly decreasing in the firm's production cost,  $c$ . Comparative statics for the EG's collaboration efforts,  $b_i$  and  $b_j$ , and the public image effect,  $\lambda$ , are, however, less tractable; so figure 1 evaluates equilibrium abatement  $z_i(b_i, b_j)$  at parameter values  $a = \gamma = d = 1$ ,  $c = 0$ ,  $\theta = 0.5$ ,  $b_j = 1$  and  $\lambda = 0.1$ .<sup>19</sup> The positive slope of  $z_i(b_i, b_j)$  in figure 1a indicates that firm  $i$  increases its abatement in the EG's collaboration,  $b_i$ . In addition, the upward shift in this figure illustrates that, as public image increases (from  $\lambda = 0.1$  to  $\lambda = 0.2$ ), individual abatement effort also increases. Figure 1b indicates that firm  $i$  decreases its abatement effort when its rival is more generously helped by the EG (higher  $b_j$ ).

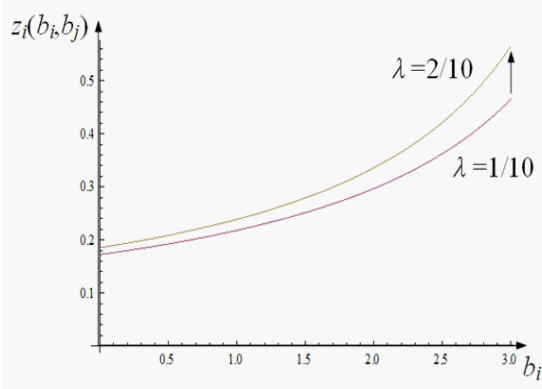


Fig. 1a. Effect of  $\lambda$  on  $z_i(b_i, b_j)$

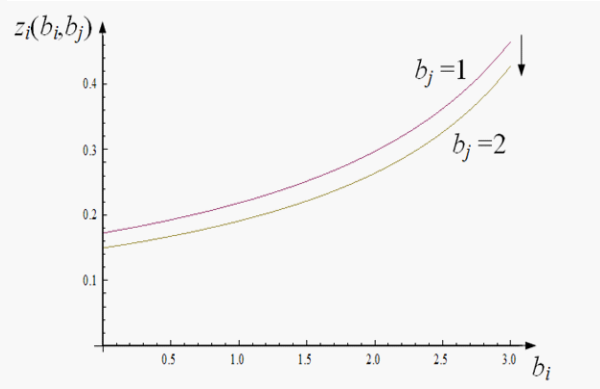


Fig. 1a. Effect of  $b_j$  on  $z_i(b_i, b_j)$

In the previous section, we found that the optimal emission fee  $t(Z)$  is decreasing in aggregate abatement  $Z$ . Since  $z_i(b_i, b_j)$  is increasing in the EG's collaboration effort  $b_i$ , emission fee  $t(Z)$  is then decreasing in  $b_i$ . In short, a more generous collaboration effort from the EG makes the presence of the regulator less necessary, inducing a less stringent emission fee or, in other words, collaboration effort and emission fees are strategic substitutes.

<sup>19</sup>Other parameter values yield similar results and can be provided by the authors upon request.

### 3.4 First stage - Collaboration effort

In the first stage, the EG anticipates the equilibrium abatement  $z_i(b_i, b_j)$  from Proposition 1, and inserts it into the regulator's emission fee from Lemma 2,  $t(Z)$ , obtaining,  $t^* \equiv t(z_i(b_i, b_j), z_j(b_i, b_j))$ . We can then insert this emission fee  $t^*$  into firm  $i$ 's output function from Lemma 1, yielding  $q^*(b_i, b_j) \equiv q_i(t^*)$ . Firm  $i$ 's net emissions when EG is present can then be expressed as  $e_i^{EG} \equiv q^*(b_i, b_j) - z_i(b_i, b_j)$ . 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  $b_i = b_j = 0$  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

$$\max_{\frac{\gamma}{\theta} \geq b_i \geq 0} \beta (ER_i)^{\frac{1}{2}} - c_{EG} (b_i)^2 \quad (4)$$

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,  $\gamma - \theta b_i \geq 0$ , we set an upper bound on the collaboration effort so that  $b_i$  cannot exceed  $\frac{\gamma}{\theta}$ .

Differentiating with respect to  $b_i$  in problem (4) yields an intractable expression, which does not allow for an explicit solution of  $b_i^*$ . Figure 2 considers the same parameter values as in figure 1, and depicts the marginal benefit the EG obtains from collaborating with firm  $i$  to reduce its emissions,  $MB_i$  (the derivative of the first term in (4) with respect to  $b_i$ ), and the marginal cost of

its collaboration effort,  $MC_i$  (the derivative of the second term in (4) with respect to  $b_i$ ).<sup>20</sup>

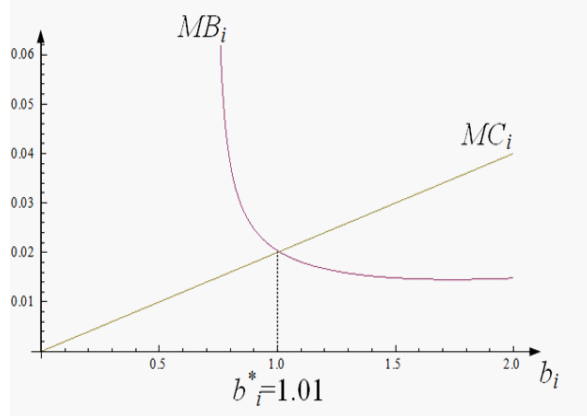


Fig. 2.  $MB$  and  $MC$  of the EG.

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  $b_i^* = 1.01$ , and similar results emerge for other parameter values as reported in Table I.<sup>21</sup> Overall, equilibrium collaboration  $b_i^*$  increases in the benefit that the EG obtains from emission reductions,  $\beta$ , in the strength of demand,  $a$ , in firm sensitivity to the EG's collaboration,  $\theta$ , in the weight the regulator assigns on environmental damage,  $d$ , and in the public image,  $\lambda$ . However,  $b_i^*$  decreases in the firm's production cost,  $c$ , its initial abatement cost,  $\gamma$ , and the EG's collaboration cost,  $c_{EG}$ .

The last row evaluates equilibrium results in the special case where consumers ignore public image,  $\lambda = 0$ , showing that the firm has less incentives to invest in abatement, which the regulator responds with a more stringent fee. The EG in this case anticipates that the firm only benefits from the tax-saving effect, not from business-stealing effects, making the firm less receptive to its collaboration.

<sup>20</sup>Figure 2 constrains  $b_i$  to its admissible set,  $\frac{\gamma}{\theta} \geq b_i \geq 0$ , which in this parametric example entails  $2 \geq b_i \geq 0$  since  $\gamma = 1$  and  $\theta = 1/2$ .

<sup>21</sup>The first row in Table I considers the same parameter values as in figure 2. The second row increases parameter  $\beta$  from  $\beta = 0.1$  to  $\beta = 0.15$ , leaving all other parameter values unchanged. A similar argument applies to all subsequent rows, which change one parameter at a time. Note that all our numerical simulations satisfy condition  $z_i + z_j < \bar{Z}$ . For instance, at our benchmark, this condition entails  $b_i < 3.79$ , which holds in equilibrium.

	$\beta$	$a$	$c$	$\gamma$	$\theta$	$d$	$c_{EG}$	$\lambda$	$b_i^*$	$z_i^*$	$t_i^*$	$q_i^*$	$e_i^* \equiv q_i^* - z_i^*$
Benchmark	0.10	1	0	1	0.5	1	0.01	0.1	1.01	0.22	0.07	0.32	0.10
Higher $\beta$	<b>0.15</b>	1	0	1	0.5	1	0.01	0.1	1.59	0.24	0.02	0.33	0.09
Higher $a$	0.10	<b>2</b>	0	1	0.5	1	0.01	0.1	1.47	0.48	0.07	0.66	0.18
Higher $c$	0.10	1	<b>0.5</b>	1	0.5	1	0.01	0.1	0.75	0.10	0.05	0.15	0.05
Higher $\gamma$	0.10	1	0	<b>2</b>	0.5	1	0.01	0.1	0.68	0.08	0.10	0.14	0.06
Higher $\theta$	0.10	1	0	1	<b>0.6</b>	1	0.01	0.1	1.25	0.24	0.03	0.33	0.09
Higher $d$	0.10	1	0	1	0.5	<b>2</b>	0.01	0.1	1.20	0.25	0.12	0.30	0.05
Higher $c_{EG}$	0.10	1	0	1	0.5	1	<b>0.1</b>	0.1	0.18	0.19	0.13	0.30	0.11
Higher $\lambda$	0.10	1	0	1	0.5	1	0.01	<b>0.2</b>	1.05	0.24	0.04	0.34	0.09
$\lambda = 0$	0.10	1	0	1	0.5	1	0.01	<b>0</b>	0.05	0.17	0.15	0.28	0.11

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, except when the regulator assigns a larger weight on environmental damages (higher  $d$ ) where fees becomes more stringent.

A natural question is whether collaboration effort and emission fees help reduce net emissions, as evaluated in the last column of Table I. Overall, net emissions increase in the EG's collaboration cost,  $c_{EG}$ , since the EG reduces its collaboration with the firm; and in the demand strength,  $a$ , since production (and pollution) increase. In contrast, net emissions decrease in the EG's weight on reducing emissions,  $\beta$ , since collaboration effort is more intense; in the firm's sensitivity to the EG's collaboration,  $\theta$ , as its investment in abatement becomes less costly; and in the regulator's weight on environmental damage,  $d$ , since the regulator sets more stringent fees leading the firm to invest more in abatement.

## 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 unaffected since they were not a function of collaboration efforts  $b_i$  and  $b_j$ ; while the abatement

decision in the second stage,  $z_i(b_i, b_j)$ , is now evaluated at  $b_i = b_j = 0$ , yielding

$$z_i^{NoEG} \equiv z_i(0, 0) = \frac{(a - c) [4d(2 + 4d + \lambda) + 3\lambda - 2]}{4\gamma + 8d^2(7 + 2\gamma - 5\lambda) + 3(1 - \lambda)\lambda + 2d [18 + 8\gamma - \lambda(11 + 2\lambda)]}.$$

Equilibrium abatement when the EG is present,  $z_i(b_i, b_j)$ , is increasing in  $b_i$  but decreasing in  $b_j$ ; see section 3.3. As a consequence, we cannot analytically rank abatement levels when the EG is present,  $z_i(b_i, b_j)$ , and absent,  $z_i^{NoEG}$ . In the parameter values considered in previous sections (benchmark), we find  $z_i^{NoEG} = 0.19$  and  $z_i(b_i, b_j) = 0.22$ , thus indicating that 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  $t^{NoEG} \equiv t(z_i^{NoEG}, z_j^{NoEG})$ . 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.

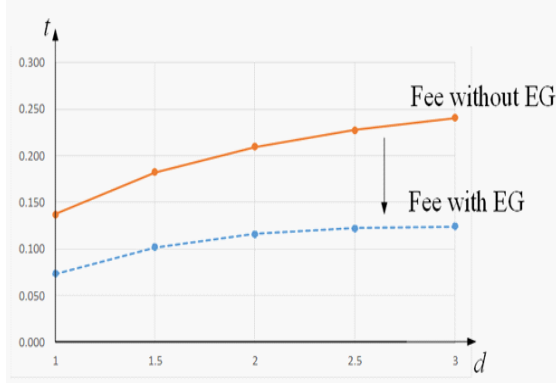


Fig. 3a. Effect of EGs on emission fees.

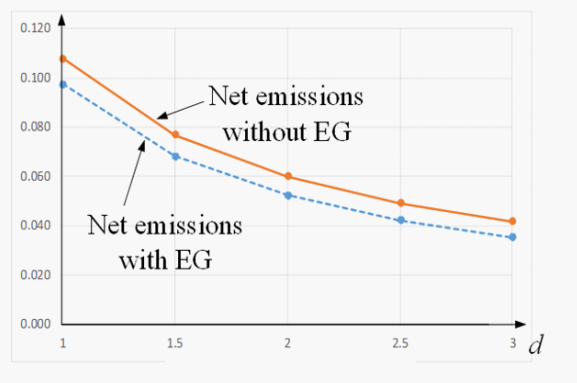


Fig. 3b. Effect of EG on net emissions.

Figure 3b shows that net emissions are lower when the EG is present than absent. Therefore, when the EG is present, while emission fees are less stringent, the collaboration effort induces firms to invest more intensively in abatement, curbing net emissions.

## 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. In the fourth stage of the game, we obtain the same results as in Section 3.1, but evaluated at an emission fee  $t = 0$  since the regulator is absent, i.e., output  $q_i(0) = \frac{[a + \lambda(2z_i - z_j)] - c}{3}$  and profits  $\pi_i(0) = (q_i(0))^2$ . The third stage is inconsequential since the regulator is absent. In the second

stage, every firm  $i$  chooses its investment in abatement by solving a problem analogous to (3), but without the effect of future taxes, as follows

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

Differentiating with respect to  $z_i$  we obtain firm  $i$ 's best response function  $z_i(z_j) = \frac{4\lambda(a-c-\lambda z_j)}{9(\gamma-\theta b_i)-8\lambda^2}$ , thus indicating that abatement efforts of firm  $i$  and  $j$  are strategic substitutes if  $\gamma > \frac{8\lambda^2}{9} + \theta b_i$ , thus exhibiting a similar interpretation as in Lemma 2. Firm  $j$ 's best response function,  $z_j(z_i)$ , is symmetric. Simultaneously solving for  $z_i$  and  $z_j$  in  $z_i(z_j)$  and  $z_j(z_i)$ , yields abatement effort

$$z_i^{NoReg}(b_i, b_j) = \frac{4\lambda(a-c) [3(\gamma - \theta b_j) - 4\lambda^2]}{27\gamma^2 - 48\gamma\lambda^2 + 16\lambda^4 + 3\theta(8\lambda^2 - 9\gamma)b_j + 3\theta b_i [8\lambda^2 - 9(\gamma - \theta b_j)]}$$

which collapses to zero when  $\lambda = 0$ . Intuitively, when the regulator is absent and public image effects are nil, firms do not experience any of the two possible benefits of investing in abatement (tax savings and public image), leading them to abstain from investing.

In the first stage, the EG anticipates  $z_i^{NoReg}(b_i, b_j)$  and solves problem (4) to find the equilibrium collaboration effort with firm  $i$ ,  $b_i^*$ . As in the model with regulator, the EG's first-order condition yields non-linear expressions that do not provide an explicit solution for  $b_i^*$ . It is straightforward to numerically show, however, that collaboration efforts are generally higher in this context than when the regulator is present. Intuitively, the EG increases his collaboration to compensate for the void left by the regulator. We use our numerical results below to evaluate welfare gains from regulation alone, from the EG alone, and from both.

### 4.3 Benchmark $C$ - No EG and no regulator

Finally, we consider a setting in which both the regulator and the EG are absent. In the fourth stage, firms choose the same output as in Benchmark  $B$ , that is,  $q_i(0) = \frac{[a+\lambda(2z_i-z_j)]-c}{3}$ , which yields profits  $\pi_i(0) = (q_i(0))^2$ .

In the second stage, every firm solves problem (3') but evaluated at  $b_i = b_j = 0$  since the EG is absent, which produces a best response function  $z_i(z_j) = \frac{4\lambda(a-c-\lambda z_j)}{9\gamma-8\lambda^2}$ . Abatement efforts of firm  $i$  and  $j$  are then strategic substitutes in this setting if  $\gamma > \frac{8\lambda^2}{9}$ . Firm  $j$ 's best response function,  $z_j(z_i)$ , is symmetric. Simultaneously solving for  $z_i$  and  $z_j$  in  $z_i(z_j)$  and  $z_j(z_i)$ , yields abatement effort  $z_i^{NoReg, NoEG} = \frac{4\lambda(a-c)}{9\gamma-4\lambda^2}$ , which is increasing in public image,  $\lambda$ , but decreasing in the initial cost of abatement,  $\gamma$ .

### 4.4 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 absent, the welfare gain from the introduction of environmental regulation is

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

where subscript *NoEG* denotes that the EG is absent, while *R* (*NR*) indicates that regulation is present (absent, respectively).<sup>22</sup>

A similar definition applies for the welfare benefit from introducing environmental regulation in a setting where the EG is present  $WGR_{EG} = W_{EG,R} - W_{EG,NR}$ . Alternatively, we can evaluate the welfare gains of introducing an EG in an industry not subject to regulation

$$WGEG_{NR} = W_{EG,NR} - W_{NoEG,NR},$$

or subject to regulation,  $WGEG_R = W_{EG,R} - W_{NoEG,R}$ . Evaluating these welfare gains at our ongoing parameter values, we obtain Table II, which indicates that the introduction of emission fees produces a welfare benefit when the EG is absent, i.e.,  $WGR_{NoEG} > 0$  in the first column for all values of *d*. However, introducing environmental regulation in a context where an EG is already present can actually be welfare reducing, as illustrated in the second column. Intuitively, firms now face free-riding incentives that were absent when they are not subject to regulation. Specifically, the abatement of firm *i*'s rivals decreases the emission fee that the regulator sets in the third stage of the game (tax-saving effect), inducing every firm to reduce its investment in abatement.

	Introducing regulation		Introducing EG	
	when EG is absent	when EG is present	when reg. is absent	when reg. is present
<i>d</i>	$WGR_{NoEG}$	$WGR_{EG}$	$WGEG_{NR}$	$WGEG_R$
1	0.235	-0.490	0.765	0.040
1.5	0.396	-0.487	0.933	0.050
2	0.560	-0.484	1.102	0.058
2.5	0.726	-0.480	1.270	0.065
3	0.892	-0.475	1.439	0.071

Table II. Welfare gains from regulation and from EG.

The third column indicates that introducing an EG in a setting where the regulator is absent improves social welfare since abatement increases. A similar argument applies to the fourth column which examines the welfare gain of introducing an EG where regulation is already present. In this context, the EG's collaboration  $(b_i^*, b_j^*)$  ameliorates firms' free-riding incentives from tax savings. As shown in Lemma 3, when collaboration efforts are strong enough, firms' abatement decisions can become strategic complements, yielding a welfare gain.

<sup>22</sup>All welfare expressions in this section use our welfare definition in Section 3.2.



In summary, introducing an EG is welfare improving regardless of whether pollution was being tackled with environmental regulation or not. The welfare gain is, as expected, larger when regulation is absent than when firms were already subject to emission fees. The introduction of environmental regulation, however, produces a welfare gain only when no EG was present in the industry. When one is present, emission fees introduce new free-riding incentives in abatement that firms did not experience in the absence of regulation, leading to a welfare loss under large parameter conditions. Therefore, while the presence of EG should be promoted in all regulatory settings, the introduction of emission fees should only be considered when no EGs exist in that industry.

Table III evaluates our results in Table II at a higher public image ( $\lambda = 0.2$  rather than  $\lambda = 0.1$ ), showing that the welfare gain of introducing regulation when the EG is absent is still positive but smaller than in Table II (first column), while the welfare loss of regulation when the EG is present becomes smaller in absolute value (second column). Intuitively, public image provides firms with stronger incentives to invest in abatement, even when regulation and EG are absent, reducing the amount of pollution that regulation needs to curb. A similar argument applies to the introduction of an EG, which yields smaller welfare gains than in Table II, both when firms are not subject to regulation (third column) and when they are (fourth column).

	Introducing regulation		Introducing EG	
	when EG is absent	when EG is present	when reg. is absent	when reg. is present
$d$	$WGR_{NoEG}$	$WGR_{EG}$	$WGEG_{NR}$	$WGEG_R$
1	0.161	-0.465	0.658	0.034
1.5	0.277	-0.443	0.782	0.061
2	0.397	-0.438	0.906	0.071
2.5	0.518	-0.432	1.029	0.079
3	0.640	-0.425	1.153	0.088

Table III. Welfare gains from regulation and from EG, higher  $\lambda$ .

## 5 Discussion

*Environmental groups and regulation are substitutes.* We examine the interplay of the EG and the regulator. Our results show that the collaboration effort from the EG makes the presence of the regulator less necessary, inducing a less stringent emission fee. However, the absence of regulation induces the EG to collaborate more intensively with firms.

*Welfare gains from EGs.* 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 the presence of EGs produce a strict welfare improvement, both when firms are subject to regulation and when they are not, since the EG helps ameliorate free-riding incentives

in abatement efforts (tax-saving effects). 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. We demonstrate that EGs provide welfare gains, but their presence in regulated markets can yield further welfare improvements.

*Welfare losses from regulation?* Unlike EGs, we show that environmental policy is welfare improving only when pollution is not addressed by any agent, i.e., when the EG is absent. When the EG is present, however, environmental policy introduces free-riding incentives in abatement, leading firms to reduce their investment, which can reduce social welfare relative to the setting where only the EG is active.

*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. Finally, we consider for simplicity that firms sell homogeneous goods 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.

## 6 Appendix

### 6.1 Appendix 1 - Alternative time structure

In this appendix, we consider an alternative timing in which 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  $q_i(t) = \frac{[a+\lambda(2z_i-z_j)]-(c+t)}{3}$ , and earning profits  $\pi_i(t) = (q_i(t))^2 + tz_i$ .

**Third stage.** In the third stage, the firm solves

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

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 best response function

$$z_i(z_j) = \frac{4\lambda(a-c-t) + 9t}{9(\gamma - \theta b_i) - 8\lambda^2} - \frac{4\lambda}{9(\gamma - \theta b_i) - 8\lambda^2} z_j.$$

While the slope of best response function  $z_i(z_j)$  is unaffected by emission fee  $t$ , its vertical intercept is increasing in  $t$  since

$$\frac{\partial \left( \frac{4\lambda(a-c-t) + 9t}{9(\gamma - \theta b_i) - 8\lambda^2} \right)}{\partial t} = \frac{9 - 4\lambda}{9(\gamma - \theta b_i) - 8\lambda^2}$$

and  $\gamma \geq 1$  by definition. Intuitively, a more stringent emission fee  $t$  in the second stage does not alter whether firms regard their investment in abatement as strategic substitutes or complements, yet provides firms with stronger incentives to invest.

The best response function of firm  $j$ ,  $z_j(z_i)$ , is symmetric. Simultaneously solving for  $z_i$  and  $z_j$  in best response functions  $z_i(z_j)$  and  $z_j(z_i)$ , yields an abatement level

$$z_i(t) = \frac{[4\lambda(a-c) + t(9-4\lambda)] [3(\gamma - \theta b_j) - 4\lambda^2]}{27\gamma^2 - 48\gamma\lambda^2 + 16\lambda^4 + 3\theta(8\lambda^2 - 9\gamma)b_j + 3\theta b_i [8\lambda^2 - 9(\gamma - \theta b_j)]}$$

which is similar to equilibrium abatement when the regulator is absent,  $z_i^{NoReg}(b_i, b_j)$ , except for term  $t(9-4\lambda)$  in the numerator. Firms then invest more significantly when the emission fee is set in the second stage than when the regulator is absent.

**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  $t(b_i)$  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,  $b_i$ . (The expression of fee  $t(b_i)$  is rather large but can be provided by the authors upon request.)

**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.

	$\beta$	$a$	$c$	$\gamma$	$\theta$	$d$	$c_{EG}$	$\lambda$	$b_i^*$
Benchmark	0.10	1	0	1	0.5	1	0.01	0.10	1.98
Higher $\beta$	<b>0.15</b>	1	0	1	0.5	1	0.01	0.10	1.98
Higher $a$	0.10	<b>2</b>	0	1	0.5	1	0.01	0.10	1.98
Higher $c$	0.10	1	<b>0.5</b>	1	0.5	1	0.01	0.10	1.98
Higher $\gamma$	0.10	1	0	<b>2</b>	0.5	1	0.01	0.10	0.82
Higher $\theta$	0.10	1	0	1	<b>0.6</b>	1	0.01	0.10	1.65
Higher $d$	0.10	1	0	1	0.5	<b>2</b>	0.01	0.10	1.98
Higher $c_{EG}$	0.10	1	0	1	0.5	1	<b>0.10</b>	0.10	0.22
Higher $\lambda$	0.10	1	0	1	0.5	1	0.01	<b>0.20</b>	1.92

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  $b_i^*$  under most parameter conditions.

## 6.2 Proof of Lemma 1

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

$$a + \lambda z_i - 2q_i - q_j - c - t = 0,$$

Solving for  $q_i$ , we obtain firm  $i$ 's best response function

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

A symmetric expression applies when solving problem (1) for firm  $j$ . Simultaneously solving for  $q_i$  and  $q_j$  in  $q_i(q_j)$  and  $q_j(q_i)$  we obtain equilibrium output

$$q_i(t) = \frac{[a + \lambda(2z_i - z_j)] - (c + t)}{3}.$$

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

$$\begin{aligned} \pi_i(t) &= (a + \lambda z_i - q_i(t) - q_j(t))q_i(t) - cq_i(t) - t(q_i(t) - z_i) \\ &= \left( \frac{[a + \lambda(2z_i - z_j)] - (c + t)}{3} \right)^2 + tz_i. \end{aligned}$$

or, more compactly,  $\pi_i(t) = (q_i(t))^2 + tz_i$ . Equilibrium profits are then increasing in firm  $i$ 's

abatement effort,  $z_i$ , and in public image,  $\lambda$ , but decreasing in firm  $i$ 's production cost,  $c$ , and in its rival's abatement,  $z_j$ . Finally, if we differentiate equilibrium profit  $\pi_i(t)$  with respect to emission fee  $t$ , we obtain

$$\frac{\partial \pi_i(t)}{\partial t} = \frac{(9 - 4\lambda) z_i - 2(a - \lambda z_j - c - t)}{9}$$

which is negative if  $z_i$  satisfies  $z_i < \frac{2[a - \lambda z_j - (c + t)]}{9 - 4\lambda}$ .

### 6.3 Proof of Lemma 2

The regulator sets emission fee  $t$  to solve

$$\begin{aligned} \max_{t \geq 0} & \frac{1}{2} [q_i(t) + q_j(t)]^2 + [\pi_i(t) + \pi_j(t)] \\ & + t [q_i(t) + q_j(t) - Z] - d [q_i(t) + q_j(t) - Z]^2 \end{aligned}$$

Differentiating with respect to  $t$ , we obtain

$$\frac{2(a - c)(4d - 1) - 4t(1 + 2d) - Z[\lambda + 4d(3 - \lambda)]}{9} = 0.$$

Solving for  $t$ , we find emission fee

$$t(Z) = \frac{2(a - c)(4d - 1) - Z[\lambda + 4d(3 - \lambda)]}{4(1 + 2d)}$$

where  $t(Z) > 0$  if and only if  $Z < \frac{(a - c)(4d - 1)}{4d(3 - \lambda) + \lambda} \equiv \tilde{Z}$ .

In addition,  $t(Z)$  is unambiguously decreasing in the production cost,  $c$ , and in aggregate abatement,  $Z$ . Differentiating  $t(Z)$  with respect to the regulator's weight on environmental damage,  $d$ , we find

$$\frac{\partial t(Z)}{\partial d} = \frac{3[2a - 2(c + Z) + \lambda Z]}{2(1 + 2d)^2}$$

which is positive if and only if  $Z < \frac{2(a - c)}{2 - \lambda} \equiv \bar{Z}$ . Comparing cutoff  $\bar{Z}$  against that guaranteeing a positive emission fee,  $\tilde{Z}$ , we obtain

$$\frac{2(a - c)}{2 - \lambda} - \frac{(a - c)(4d - 1)}{4d(3 - \lambda) + \lambda} = \frac{4(a - c)(1 + 2d)}{(2 - \lambda)[\lambda + 4d(3 - \lambda)]}$$

which is unambiguously positive since  $\lambda \in [0, 1]$ . Therefore, the cutoffs are ranked as  $\bar{Z} > \tilde{Z}$ , implying that three regions of  $Z$  arise: (1) when  $Z < \tilde{Z}$ , the emission fee is positive and it increases in  $d$ ; (2) when  $\tilde{Z} \leq Z < \bar{Z}$ , the emission fee is negative (a subsidy) but it still increases in  $d$ ; and (3) when  $Z > \bar{Z}$ , the emission fee is negative and decreasing in  $d$ .

Finally,  $t(Z)$  increases in public image since

$$\frac{\partial t(Z)}{\partial \lambda} = \frac{(4d - 1)Z}{4(1 + 2d)}$$

is positive given that  $d > 1/2$  by definition.

#### 6.4 Proof of Lemma 3

We first evaluate equilibrium profits  $\pi_i(Z) \equiv \pi_i(t(Z))$ , where  $t(Z) = \frac{2(a-c)(4d-1)-Z[\lambda+4d(3-\lambda)]}{4(1+2d)}$  from Lemma 2. Inserting this result into problem (3),

$$\max_{z_i \geq 0} \pi_i(Z) - \frac{1}{2} (\gamma - \theta b_i) (z_i)^2$$

and differentiating with respect to  $z_i$ , we find

$$\frac{2(a-c)[3\lambda + 2 + 4d(2(1+2d) + \lambda)] + z_i [8d(\lambda(4+3\lambda) - 6) + \lambda(9\lambda - 4) - 16d^2(1-\lambda)(5+\lambda)]}{8(1+2d)^2} - \frac{z_j [2\lambda + (3+4d) [\lambda^2 + 4d(2 + \lambda(\lambda - 1))]]}{8(1+2d)^2} = (\gamma - \theta b_i) z_i.$$

Solving for  $z_i$ , we obtain firm  $i$ 's best response function  $z_i(z_j)$ , as follows

$$z_i(z_j) = \frac{2(a-c)[4d(2A + \lambda) - 2 + 3\lambda] - [2\lambda + \widehat{A} [\lambda^2 + 4d(2 + \lambda(\lambda - 1))]] z_j}{16d[3 + 5d + 2(1+d)\gamma] - 32dA\lambda - \widehat{A}^2\lambda^2 + 4(2\gamma + \lambda) - 8A^2\theta b_i} z_j$$

where, for compactness,  $A \equiv 1 + 2d$  and  $\widehat{A} \equiv 3 + 4d$ . Differentiating  $z_i(z_j)$  with respect to  $z_j$ , we find the slope of the best response function, as follows

$$\frac{\partial z_i(z_j)}{\partial z_j} = \frac{2\lambda + \widehat{A} [\lambda^2 + 4d(2 + \lambda(\lambda - 1))]}{8A^2\theta b_i + (\widehat{A})^2 \lambda^2 + 4\lambda(8dA - 1) - 8[\gamma + 2d(2 + 5d + 2(1+d)\gamma)]}$$

which is positive if  $\gamma$  satisfies  $\gamma > \bar{\gamma} + \theta b_i$ , where  $\bar{\gamma} \equiv \frac{\lambda(9\lambda-4)+8d[\lambda(4+3\lambda)-6]-16d^2(1-\lambda)(5+\lambda)}{8(1+2d)^2}$ . When  $b_i = 0$  and  $\lambda = 0$ , condition  $\gamma > \bar{\gamma} + \theta b_i$  collapses to  $\gamma > -\frac{2d(3+5d)}{(1+2d)^2}$ , which holds for all values of  $d$ . When  $b_i = 0$  but  $\lambda > 0$ , condition  $\gamma > \bar{\gamma} + \theta b_i$  simplifies to  $\gamma > \frac{\lambda(9\lambda-4)+8d[\lambda(4+3\lambda)-6]-16d^2(1-\lambda)(5+\lambda)}{8(1+2d)^2}$ .

Finally, differentiating cutoff  $\bar{\gamma} + \theta b_i$  with respect to  $d$ , yields

$$\frac{\partial(\bar{\gamma} + \theta b_i)}{\partial d} = -\frac{(3+4d)(2-\lambda)^2}{2(1+2d)^3}$$

which is unambiguously negative; while differentiating cutoff  $\bar{\gamma} + \theta b_i$  with respect to  $\lambda$ , we obtain

$$\frac{\partial(\bar{\gamma} + \theta b_i)}{\partial \lambda} = \frac{9\lambda + 8d[2 + 3\lambda + 2d(2 + \lambda)] - 2}{4(1+2d)^2}$$

which is unambiguously positive since  $d > 1/2$  and  $\lambda \in [0, 1]$  by assumption.

## 6.5 Proof of Proposition 1

Simultaneously solving for  $z_i$  and  $z_j$  in best response functions  $z_i(z_j)$  and  $z_j(z_i)$ , we obtain equilibrium abatement

$$z_i(b_i, b_j) = \frac{(a - c) [4d(2A + \lambda) + 3\lambda - 2] [4\gamma + \lambda(1 - 6\lambda) + B - 4A\theta b_j]}{[4\gamma + \lambda(1 - 6\lambda) + B] F - 2A\theta [(D - 32dA\lambda + C) b_j + b_i(D - 32dA\lambda + C - 8A^2\theta b_j)]}$$

where  $A \equiv 1 + 2d$ ,  $B \equiv 4d[3 + 2\gamma - \lambda(3 + 2\lambda)]$ ,  $C \equiv 4(2\gamma + \lambda) - (3 + 4d)^2\lambda^2$ ,  $D \equiv 16d(3 + 5d + 2(1 + d)\gamma)$  and  $F \equiv 4\gamma + 8d^2(7 + 2\gamma - 5\lambda) + 3\lambda(1 - \lambda) + 2d[18 + 8\gamma - \lambda(11 + 2\lambda)]$ . Therefore, condition  $z_i + z_j < \bar{Z}$ , which guarantees that the emission fee increases in  $d$ , holds if and only if

$$b_i < \bar{b}_i \equiv \frac{[4(1 + \gamma) + 4d(3 + 2\gamma - 3\lambda)] [4\gamma + \lambda - 6\lambda^2 + B]}{4A\theta [2 + 4\gamma - \lambda(2 + 3\lambda) + 4d(3 + 2\gamma - \lambda(3 + \lambda)) - 4A\theta b_j]} - \frac{4A\theta [2 + 4\gamma - \lambda(2 + 3\lambda) + 4d(3 + 2\gamma - \lambda(3 + \lambda))] b_j}{4A\theta [2 + 4\gamma - \lambda(2 + 3\lambda) + 4d(3 + 2\gamma - \lambda(3 + \lambda)) - 4A\theta b_j]}$$

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