Picking Green Teams: How Environmental Groups Choose Collaboration when Firms are Asymmetric*

John C. Strandholm†
George Dean Johnson, Jr. College of Business and Economics
University of South Carolina Upstate
Spartanburg, SC 29306

Ana Espinola-Arredondo‡
School of Economic Sciences
Washington State University
Pullman, WA 99164

Felix Munoz-Garcia§
School of Economic Sciences
Washington State University
Pullman, WA 99164

Abstract

In this paper, we analyze the collaboration between environmental groups (EGs) and polluting firms when firms are asymmetric in their abatement costs and emissions are taxed. We find that when the firms are asymmetric, the EG collaborates more with the inefficient firm, but the increase in collaboration does not overcome firms' cost asymmetry, producing an overall decrease in abatement and an increase in total emissions. We also look at the welfare impacts of introducing an EG and/or a regulator, finding that the regulation generally yields larger welfare gains than the EG. Unlike previous studies, we show that the welfare benefits from a second agent are, under most settings, largest when firms become more asymmetric.

Keywords: Environmental groups; Green alliances; Abatement; Environmental policy; Welfare gains; Asymmetric firms.
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†Address: George 272, George Dean Johnson, Jr. College of Business and Economics, 160 East St. John Street, Spartanburg, SC 29306. E-mail: jstrandh@uscupstate.edu

‡Address: 101B Hulbert Hall, Washington State University, Pullman, WA 99164. E-mail: anaespinola@wsu.edu

§Address: 103H Hulbert Hall, Washington State University, Pullman, WA 99164. E-mail: fmunoz@wsu.edu

1 Introduction

We investigate the collaboration between environmental groups (EGs) and polluting firms facing environmental regulation, and focus on how this collaboration is affected by firms' asymmetry in their abatement costs. Examples of collaboration between firms and EGs include McDonald's and Environmental Defense Fund,[1] Foron and Greenpeace,[2] and The Conservation Fund and International Paper,[3] among others. See Hartman and Stafford (1997) and Rondinelli and London (2003) for more examples.

In the baseline case, where both a regulator (who taxes emissions) and an EG are present, an increase in firm asymmetry induces the EG to collaborate more with the inefficient firm since otherwise the firm would choose a low abatement level. Even though the EG collaborates more with the inefficient firm, this collaboration does not eliminate firms' cost asymmetry, driving the more efficient firm to invest more in abatement than its inefficient rival. This investment increase, however, does not offset the investment decrease of the inefficient firm, leading to a decrease in overall abatement. A similar pattern applies to individual and aggregate emissions, yielding an increase in overall emissions, inducing the regulator to set a more stringent emission fee as firm asymmetry increases.

In addition, we look at the welfare impacts of introducing an EG (when a regulator is already present or not) or a regulator (when an EG is already present or not). We find that the introduction of regulation generally yields larger welfare gains than the introduction of the EG. When the EG's cost of collaboration is high, the introduction of the EG without the presence of regulation can actually decrease welfare. We also find that the welfare gains of having only one agent (either the regulator or EG) are generally large when firms are symmetric, but decrease as firms become asymmetric. Nonetheless, when a second agent is added (regulator or EG), welfare increases under most settings, and welfare gains are the largest when firms become more asymmetric. In contrast to the previous literature, our results suggest that firm asymmetry emphasizes the welfare benefits of having both environmental regulation and EGs in place.

We then examine how our results are affected by changes in parameter values. First, when the collaboration effort of the EG is more effective, its presence becomes more welfare improving, especially in the absence of regulation. When the EG assigns a large value on emissions reduction, it yields small (large) welfare gains when regulation is present (absent, respectively). Finally, when firms' pollution generates more severe environmental damage, the introduction of the EG yields relatively small welfare gains, but introducing regulation generates large welfare gains whether the EG is already present or not.

[1] This collaboration reduced restaurant waste by 30%, recycled 1 million tons of corrugated boxes, and eliminated over 300 million pounds of packaging in the decade following the partnership, visit www.edf.org/partnerships/mcdonalds and see Hartman and Stafford (1997).

[2] This collaboration helped replace ozone-destroying chlorofluorocarbons with hydrocarbon in refrigeration technology, visit www.greenpeace.org/international/story/15323/how-greenpeace-changed-an-industry-25-years-of-greenfreeze-to-cool-the-planet/.

[3] Visit http://investor.internationalpaper.com/news-releases/press-r/2006/International-Paper-The-Nature-Conservancy-and-The-Conservation-Fund-Protect-218000-Acres-of-US-Forestland-Through-Historic-Land-Acquisition-Project/default.aspx.

1.1 Related Literature

The literature on EGs largely falls within four categories based on the impact the EG has on polluting firms: (1) a confrontational approach aimed at reducing demand for the firm's good or more expansive boycotts, see Innes (2006), Baron and Diermeier (2007), and Heijnen and Schoonbeek (2008); (2) EGs invest in campaigns to increase consumers' environmental awareness of the goods firms offer, see van der Made and Schoolbeek (2009) and Heijnen (2013); (3) EGs use a lobbying approach for or against projects with environmental impacts and relative effectiveness, see Liston-Heyes (2001) and Riddel (2003); and (4) EGs provide green certificates to indicate certain environmental attributes of the good, see Heyes and Maxwell (2004), Harbaugh et al. (2011), and Fisher and Lyon (2014).

Our model builds on Stathopoulou and Gautier (2019), which allows for EGs to either collaborate with or be in conflict against a firm. The decision impacts both the firm's demand and abatement in a discrete matter. Espinola-Arredondo et al. (2021) extend the Stathopoulou and Gautier (2019) model to allow for firms, in collaboration with the EG, to invest in abatement technology to investigate the role that EGs have on the abatement investment decision. Our paper extends their model to a setting with asymmetric firms, evaluating collaboration efforts, abatement investments, and social welfare impacts of markets with asymmetric firms. We show that, while EGs may bring small welfare gains when firms are symmetric, their presence can yield large welfare benefits in industries with asymmetric firms.

2 Model

Consider a polluting industry with two firms, each facing an inverse demand function $p_i(Q) = (1 + \lambda z_i) - Q$, 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.[4] Every unit of output, q_i, generates e_i units of emissions, implying that net emissions are $e_i = q_i - z_i$.

Every firm's marginal cost of production is symmetric and normalized to zero, but its abatement cost is $\frac{1}{2}(\gamma_i - \theta b_i)(z_i)^2$, where $\gamma_i \geq 0$ denotes firm i's initial cost of investing in abatement, while term $\gamma_i - \theta b_i$ represents firm i's 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 $\theta > 0$ these costs decrease in the EG's collaboration effort b_i. Therefore, parameter θ captures how sensitive the firm's abatement costs are to the EG's collaboration effort or, alternatively, how effective collaboration is. In addition, to examine the role of cost asymmetry, we consider that $\gamma_i > \gamma_j$, indicating that firm i has a higher initial cost of abatement.

The regulator chooses an emission fee, t, to solve,

$$\max_t CS(t) + PS(t) + T - Env(t)$$

which includes consumer and producer surplus $(CS(t) + PS(t))$, emission fee revenue (T),

[4] Alternatively, $\lambda = 0$ can apply for an upstream firm whereas $\lambda > 0$ is more relevant for a downstream firm that directly deals with end-consumer markets.

and the environmental damage from aggregate net emissions, $Env(t) \equiv d[Q-Z]^2$, where $d > 1/2$ represents the weight of the environmental damage and $Z = z_i + z_j$.

For comparison purposes, we consider the same time structure as in Espinola-Arredondo et al. (2021), which assumes that the EG acts in the first stage to identify the effect of its collaboration effort on the regulator's environmental policy decision in the later stage of the game. Hence, the time structure of the game is:

1. In the first stage, the EG chooses a collaboration level with every firm i, b_i.
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.

3 Equilibrium analysis

The results for the fourth and third stages, in which output and the fee are set, respectively, coincide with that in Espinola-Arredondo et al. (2021), and we include them in appendix A.1 as a reference.

3.1 Second stage - Abatement

In the second stage, every firm i chooses its abatement effort anticipating fourth-stage profit $\pi_i(z_i, z_j)$ and the emission fee set by the regulator in the third stage. Each firm i's problem is

$$\max_{z_i \geq 0} \pi_i(z_i, z_j) - \frac{1}{2}(\gamma_i - \theta b_i)(z_i)^2,$$

Differentiating with respect to z_i yields firm i's best response function

$$z_i(z_j) = \frac{8ad(4d+\lambda+2) + 6a\lambda - 4a - [2\lambda + (4d+3)(\lambda^2 + 4d(2+\lambda(\lambda-1)))]z_j}{16d(5d+3+2(d+1)(\gamma_i - \theta b_i)) + 8(\gamma_i - \theta b_i) - (4d+3)^2\lambda^2 - 32d(2d+1)\lambda + 4\lambda},$$

which simplifies to that in Espinola-Arredondo et al. (2021) when $\gamma_i = \gamma_j$, and thus exhibits the same properties (see Lemma 3 and subsequent discussion). Firms have symmetric best response functions up to their abatement cost parameters (γ_i and γ_j). A larger γ_i, keeping γ_j constant, increases the denominator in firm i's best response function, which shifts this best response function downward and flattens it. Intuitively, firm i decreases its abatement effort for every level of abatement effort of firm j and, in addition, decreases its own abatement effort less rapidly for a given increase in z_j, making abatement decision less strategic substitutes as γ_i increases.

The following proposition identifies the equilibrium abatement effort by each firm.

Proposition 1. *In the second stage, each firm i chooses (interior) equilibrium abatement effort*

$$z_i(b_i, b_j) = \frac{1}{B}\left[a(4d(4d+\lambda+2)+3\lambda-2)\left(4d(3+2(\gamma_j-\theta b_j)-\lambda(2\lambda+3))+4(\gamma_j-\theta b_j)-6\lambda^2+\lambda\right)\right]$$

where B is defined, for compactness, in the proof of proposition 1. Firm j's abatement effort is larger if $\gamma_i - \theta b_i > \gamma_j - \theta b_j$.

Firm j's abatement exceeds that of its rivals if its effective cost of investing in the technology is less than that of its rival, $\gamma_i - \theta b_i > \gamma_j - \theta b_j$ or, alternatively, if $b_j > b_i + \frac{\gamma_j - \gamma_i}{\theta}$. Since firm j is more efficient at investing in abatement technology, in order for firm i to invest more in abatement, the EG's collaboration with firm i must be great enough to overcome the initial cost disadvantage.[5]

When the EG is absent, or $b_i = b_j = 0$, each firm i's equilibrium abatement effort is

$$z_i(0,0) = \frac{1}{C}\left[a(4d(4d+\lambda+2)+3\lambda-2)\left(4\gamma_j + 4d(2\gamma_j - \lambda(2\lambda+3)+3) - 6\lambda^2 + \lambda\right)\right],$$

where C is defined at the end of the proof of Proposition 1. The next subsections compare equilibrium abatement effort with and without the EG.

3.2 First stage - Collaboration effort

In the first stage, the EG anticipates the decisions in subsequent stages and uses that information to decide collaboration levels with each firm, b_i and b_j. The EG's benefit is the decrease in emissions that results from its collaboration. To find this, we define each firm i's net emissions as $e_i^{EG} \equiv q^*(b_i, b_j) - z_i(b_i, b_j)$ where $q^*(b_i, b_j)$ comes from the fourth stage results, and $z_i(b_i, b_j)$ comes from Proposition 1. Firm i's emissions when the EG is absent are $e_i^{NoEG} \equiv q^*(0,0) - z_i(0,0)$. Therefore, firm i's reduction in emissions due to the EG's collaboration effort is

$$ER_i = e_i^{NoEG} - e_i^{EG}.$$

The EG solves the following maximization problem

$$\max_{b_i, b_j \geq 0} \underbrace{[\beta(ER_i)^{\frac{1}{2}} - c_{EG}(b_i)^2]}_{\text{Firm } i} + \underbrace{[\beta(ER_j)^{\frac{1}{2}} - c_{EG}(b_j)^2]}_{\text{Firm } j}$$

The benefit from the EG's collaboration is the first term in each set of brackets, which is increasing and concave in ER_i (ER_j, respectively) and scaled by parameter $\beta > 0$ which measures the weight that the EG assigns on emissions reduction. The second term within each set of brackets is the EG's cost of collaborating, which is increasing and convex in its efforts b_i and b_j, and $c_{EG} > 0$ represents the effort's cost.

The first-order conditions for the EG's problem do not allow for an explicit solution to b_i^* and b_j^*. We next discuss the analytic first-order conditions to the EG's problem. Starting with the EG's marginal cost of collaboration effort, $MC_i = 2c_{EG}b_i$, is unambiguously positive and increasing in b_i. The next proposition presents the marginal benefit.

Proposition 2. *The EG's marginal benefit from increasing collaboration* b_i *is*

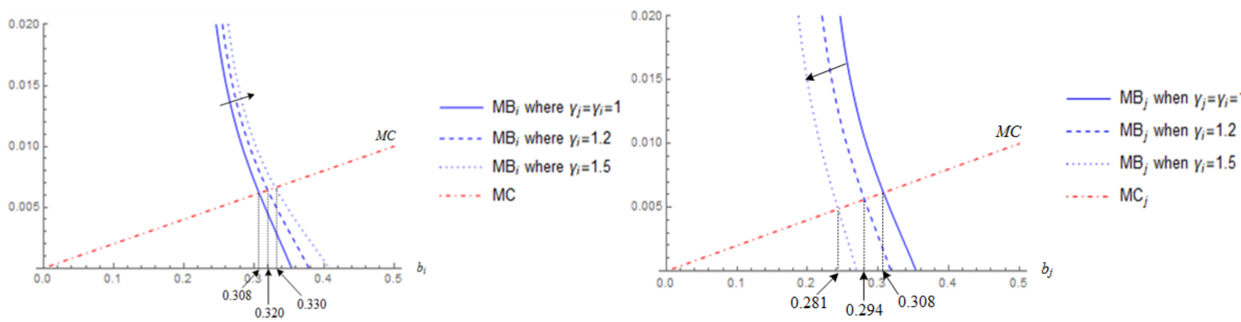
$$MB_i \equiv \frac{1}{2}\beta(ER_i)^{-\frac{1}{2}}\left[\frac{\partial z_i}{\partial b_i} - \frac{\partial q}{\partial t}\frac{\partial t}{\partial z_i}\left(\frac{\partial z_i}{\partial b_i} + \frac{\partial z_j}{\partial b_i}\right)\right] + \frac{1}{2}\beta(ER_j)^{-\frac{1}{2}}\left[\frac{\partial z_j}{\partial b_i} - \frac{\partial q}{\partial t}\frac{\partial t}{\partial z_i}\left(\frac{\partial z_i}{\partial b_i} + \frac{\partial z_j}{\partial b_i}\right)\right].$$

[5] The denominator term B for every firm i depends on both its cost of investing and that of its rival's, γ_i and γ_j.

The marginal benefit from collaborating with firm i originates from the firm's increase in abatement, which reduces emissions. However, MB_i also considers the change in firm j's abatement (and resulting emissions reduction) from collaborating more intensively with firm i.

The marginal cost of collaboration effort coincides when firms are symmetric and asymmetric in their abatement efforts, but the marginal benefit does not. At higher levels of asymmetry, the marginal benefit of collaborating with the inefficient firm grows, as it induces this firm to increase its investment in abatement, thus reducing emissions.

For illustration purposes, figure 1a plots MB_i and MC_i considering parameter values $a = d = 1$, $\beta = \lambda = 0.1$, $\theta = 0.25$, and $c_{EG} = 0.01$. The figure shows that, when firms are symmetric, $\gamma_i = \gamma_j = 1$, the crossing point between MB_i and MC_i (the EG's collaboration effort) lies at $b_i^* = 0.308$. However, when firm i's initial abatement cost increases (while that of firm j remains unchanged), the MB_i curve shifts rightward, increasing the point where MB_i and MC_i cross and, as a consequence, the equilibrium collaboration effort, to $b_i^* = 0.320$ when γ_i increases to $\gamma_i = 1.2$, and to $b_i^* = 0.330$ when this cost further increases to $\gamma_i = 1.5$. In figure 1b, MB_j shifts to the left as firm i's abatement cost increases, as well as the intersection of MB_j and MC_j. When $\gamma_i = 1.2$, the EG's collaboration effort with firm j decreases to $b_j^* = 0.294$, and when $\gamma_i = 1.5$ the equilibrium collaboration effort decreases further to $b_j^* = 0.281$.



(a) Inefficient firm

(b) Efficient Firm

Figure 1: EG's marginal benefits and costs for different asymmetries in abatement costs.

3.3 Numerical Simulations

The first-order conditions from the EG's problem are highly nonlinear, so table 1 provides numerical simulations to find the equilibrium levels of collaboration, the resulting abatement, emission fee, and emissions at different levels of asymmetry in the initial abatement costs (the difference between γ_i and γ_j increases in rows).[6]

Table 1a shows that as firms become more asymmetric in their abatement costs, the EG collaborates more intensively with the most inefficient firm. This asymmetric collaboration helps to partially reduce the differential in effective cost of abatement between firms, as reported in columns 5 and 6. In the absence of the EG, however, this cost asymmetry would be higher, entailing a more differentiated investment profile across firms. Despite the EG's collaboration, the inefficient firm still has a larger effective cost than its efficient rival,

[6] For comparison purposes, table 1 considers the same parameter values as figures 1a and 1b.

	γ_j	γ_i	b_j^*	b_i^*	$\gamma_j - \theta b_j$	$\gamma_i - \theta b_i$	z_j^*	z_i^*	t^*	e_j^*	e_i^*	SW
Benchmark	1	1	0.308	0.308	0.923	0.923	0.190	0.190	0.129	0.106	0.106	0.348
	1	1.1	0.294	0.314	0.927	1.021	0.192	0.182	0.134	0.103	0.112	0.345
	1	1.2	0.281	0.320	0.930	1.120	0.194	0.176	0.139	0.100	0.116	0.342
	1	1.3	0.268	0.324	0.933	1.219	0.196	0.169	0.144	0.097	0.121	0.339
	1	1.4	0.255	0.328	0.936	1.318	0.197	0.163	0.149	0.094	0.125	0.337
	1	1.5	0.243	0.330	0.939	1.417	0.199	0.158	0.153	0.092	0.129	0.334

Table 1a. Equilibrium collaboration efforts when the EG collaborates with both firms.

	γ_j	γ_i	z_j^*	z_i^*	t^*	e_j^*	e_i^*	SW
Benchmark	1	1	0.186	0.186	0.137	0.108	0.108	0.345
	1	1.1	0.188	0.179	0.142	0.104	0.113	0.342
	1	1.2	0.190	0.172	0.147	0.101	0.118	0.339
	1	1.3	0.192	0.166	0.152	0.098	0.122	0.336
	1	1.4	0.193	0.160	0.156	0.096	0.126	0.334
	1	1.5	0.195	0.154	0.159	0.093	0.130	0.332

Table 1b. Equilibrium collaboration efforts in the absence of the EG.

inducing the former to invest less in abatement than the latter. The decrease in abatement increases emissions and environmental damage, which increases the fee, ultimately producing an overall welfare reduction (we provide more welfare comparisons in the next section).

In the absence of the EG, as shown in table 1b, both firms exhibit lower levels of abatement and higher levels of emissions than when the EG is present, while social welfare is lower. However, the same patterns as in Table 1a emerge: the efficient firm increases its abatement as the cost asymmetry grows while the inefficient firm decreases its abatement. Emissions move in the opposite direction. Table 2 evaluates the equilibrium results of table 1a in elasticity terms.

	γ_j	γ_i	ε_{b_j}	ε_{b_i}	ε_{z_j}	ε_{z_i}	ε_t	$\varepsilon_{e_i+e_j}$	ε_{e_j}	ε_{e_i}	ε_{SW}
Benchmark	1	1.1	-0.44	0.22	0.10	-0.40	0.43	0.08	-0.32	0.49	-0.09
	1	1.2	-0.50	0.19	0.10	-0.42	0.42	0.08	-0.33	0.47	-0.10
	1	1.3	-0.55	0.17	0.10	-0.44	0.41	0.09	-0.35	0.46	-0.10
	1	1.4	-0.61	0.14	0.10	-0.46	0.40	0.09	-0.36	0.44	-0.10
	1	1.5	-0.66	0.12	0.10	-0.48	0.39	0.09	-0.37	0.43	-0.10

Table 2: Equilibrium collaboration efforts and elasticities when the EG collaborates with both firms.

Table 2 shows that a one-percent increase in firms' asymmetry produces a 0.44 percent decrease in the EG's collaboration effort with the most efficient firm and 0.22 percent increase in collaboration effort with the inefficient firm. The efficient firm j responds to this reduction in the EG's collaboration effort by increasing its investment in abatement, z_j, but to a small extent, while the inefficient firm i responds by significantly decreasing its abatement, z_i.

Overall aggregate abatement is then decreased when firms are more asymmetric, which induces the regulator to increase the emission fee. Specifically, a one-percent increase in firms' asymmetry leads to a 0.43 percent increase in the emission fee. In this setting, the efficient firm j decreases its emissions when firms become more asymmetric, while firm i increases its own emissions. However, the latter effect dominates, yielding an overall increase in aggregate emissions and ultimately reducing social welfare.

4 Welfare effects across regulatory settings

As shown in the last column of Table 1, when firms become more asymmetric in their initial abatement cost, welfare decreases. This occurs, importantly, in all regulatory settings (with and without EG, and with and without environmental policy), as aggregate abatement weakly decreases when firms become more asymmetric.[7] We next investigate under which regulatory context this welfare loss is the smallest.

	Introducing regulation		Introducing EG	
$\gamma_i - \gamma_j$	when EG is absent	when EG is present	when reg. is absent	when reg. is present
0	0.235	0.232	0.007	0.003
0.1	0.232	0.234	0.006	0.008
0.2	0.228	0.236	0.005	0.013
0.3	0.223	0.237	0.004	0.018
0.4	0.219	0.238	0.004	0.022
0.5	0.215	0.238	0.004	0.027

Table 3: Welfare gains from regulation and from EG.

Table 3 shows that introducing one agent (regulator or EG) when none is present (see first and third columns) yields a welfare gain that decreases as firms become more asymmetric. Intuitively, the regulator alone (first column) or the EG alone (third column) cannot induce a sufficient shift in abatement levels across firms in response to asymmetric costs, ultimately entailing smaller welfare gains from this agent's presence. However, when one agent is already present, the introduction of another (see the second and fourth column in Table 3) produces a welfare gain that increases in firm asymmetry. In this case, emission fees and collaboration effort shift abatement levels between the two firms, yielding a larger welfare gain when firms become more asymmetric. The introduction of the second agent complements the incentives to abate of the first agent, especially for the inefficient firm, which closes the abatement difference between the two firms, increasing social welfare.[8]

[7] Firms continue to invest in abatement without the regulator or EG present because of the increase in demand abatement provides through parameter λ. Appendices A4-A6 examine how our equilibrium results are affected if only the EG is present, only the regulator is present, or if neither of them is present.

[8] Tables analogous to tables 3-8 which evaluates the elasticity of the welfare gains or losses with respect to marginal increases in firm asymmetry are available upon request. In the baseline case, percentage changes in the welfare gains from introducing environmental regulation or EGs diminish as firms become more asymmetric in their cost of investing in abatement, and the welfare losses become more severe.

4.1 Comparative Statics

We next turn our attention to how the welfare gains from the EG and/or regulator change at different levels of relevant parameters.

	Introducing regulation		Introducing EG	
$\gamma_i - \gamma_j$	when EG is absent	when EG is present	when reg. is absent	when reg. is present
0	0.000	-0.024	0.029	0.006
0.1	0.000	-0.018	0.023	0.006
0.2	0.000	-0.017	0.022	0.005
0.3	0.000	-0.016	0.021	0.005
0.4	0.000	-0.016	0.020	0.005
0.5	0.000	-0.016	0.020	0.004

Table 4: Change in welfare gains from regulation and from EG when θ increases to 0.45.

Table 4 shows that an increase in the effectiveness of the collaboration effort at reducing abatement costs, θ, produces the same welfare gain from introducing regulation when no EG is present, as expected (see first column).[9] However, it yields a smaller welfare gain from regulation when the EG is already present. Similarly, introducing the EG yields a larger welfare gain, which holds both when regulation is present and absent.

	Introducing regulation		Introducing EG	
$\gamma_i - \gamma_j$	when EG is absent	when EG is present	when reg. is absent	when reg. is present
0	0.000	-0.003	0.003	0.000
0.1	0.000	-0.002	0.002	0.000
0.2	0.000	-0.002	0.002	0.000
0.3	0.000	-0.002	0.002	0.000
0.4	0.000	-0.002	0.002	0.000
0.5	0.000	-0.002	0.001	0.000

Table 5: Change in welfare gains from regulation and from EG when β increases to 0.2.

Table 5 examines how welfare gains are affected by an increase in the value that the EG assigns to emission reductions, β, showing that it produces the same welfare gains of introducing regulation when the EG is absent (first column), but unambiguously smaller gains when the EG is already present. However, the introduction of the EG yields smaller (same) welfare gains when regulation is absent (present). An increase in β increases the EG's collaboration effort with both firms as it increases the marginal benefit of collaboration, which holds both when firms are symmetric and asymmetric. In this case, the introduction of regulation, when firms are already collaborating with the EG has a smaller impact on welfare as some of the welfare gains now come from the EG's increased collaboration effort. In short, an EG with more environmental concerns makes regulation less necessary.

Table 6 shows that an increase in the environmental damage, d, produces larger welfare gains when either EG or regulator is introduced. The increase in environmental damage leads

[9] This is the case for each of the parameters that only impact the EG's decision (θ, β, and c_{EG}).

to larger increases in social welfare as emissions are abated, thus the impact of introducing each agent is amplified.

	Introducing regulation		Introducing EG	
$\gamma_i - \gamma_j$	when EG is absent	when EG is present	when reg. is absent	when reg. is present
0	0.080	0.076	0.003	0.001
0.1	0.080	0.078	0.002	0.001
0.2	0.080	0.079	0.002	0.001
0.3	0.082	0.080	0.002	0.001
0.4	0.082	0.080	0.002	0.002
0.5	0.082	0.080	0.002	0.002

Table 6: Change in welfare gains from regulation and from EG when d increases to 1.25.

	Introducing regulation		Introducing EG	
$\gamma_i - \gamma_j$	when EG is absent	when EG is present	when reg. is absent	when reg. is present
0	0.000	0.005	-0.008	-0.003
0.1	0.000	0.004	-0.007	-0.003
0.2	0.000	0.003	-0.006	-0.003
0.3	0.000	0.003	-0.005	-0.003
0.4	0.000	0.003	-0.005	-0.002
0.5	0.000	0.003	-0.005	-0.002

Table 7: Change in welfare gains from regulation and from EG when c_{EG} increases to 0.1.

Table 7 shows that an increase in the EG's collaboration cost, c_{EG}, still yields the same welfare gain of introducing regulation when the EG is absent, but entails larger welfare gains of introducing regulation when the EG was already present. Introducing the EG when regulation is absent, however, now generates a welfare loss, rather than a gain, since the EG reduces its collaboration effort under all parameter conditions. Similarly, introducing the EG when regulation is already present yields a smaller welfare gain than when the EG faces lower collaboration costs, making the EG less beneficial.

	Introducing regulation		Introducing EG	
$\gamma_i - \gamma_j$	when EG is absent	when EG is present	when reg. is absent	when reg. is present
0	-0.074	-0.081	0.007	0.001
0.1	-0.073	-0.077	0.006	0.002
0.2	-0.072	-0.074	0.006	0.003
0.3	-0.069	-0.071	0.005	0.004
0.4	-0.069	-0.070	0.005	0.005
0.5	-0.068	-0.068	0.005	0.005

Table 8: Change in welfare gains from regulation and from EG when λ increases to 0.2.

An increase in the public image parameter, λ, shown in table 8, induces firms to increase their investment in abatement, which boosts their demands, making regulation less necessary. In particular, the welfare gain from introducing regulation decreases, both when the EG is present and absent. However, introducing the EG yields larger welfare gains, which holds both when regulation is present and absent. Intuitively, firms are more sensitive to the EG's collaboration when λ increases, making the EG's presence more beneficial with and without environmental regulation.

A Appendix

A.1 Equilibrium behavior in the fourth and third stages

In the fourth stage, firms observe the emission fee $t > 0$, their own abatement efforts in the second stage, z_i and z_j, and the EG's collaboration effort. Every firm i then solves

$$\max_{q_i \geq 0} \; (1 + \lambda z_i - Q)q_i - t(q_i - z_i). \tag{1}$$

where the last term, $q_i - z_i$, denotes emissions. The next lemma identifies equilibrium output and profits. The proof of Lemma A1 is omitted, for compactness, but it is analogous to lemma 1 in Espinola-Arredondo et al. (2021).

Lemma A1. *In the fourth stage, every firm i chooses output $q_i(t) = \frac{1}{3}(a - t + \lambda(2z_i - z_j))$, and earns profits $\pi_i(t) = (q_i(t))^2 + tz_i$. Output $q_i(t)$ is positive if and only if $z_i > \frac{1}{2}z_j - \frac{a-t}{2\lambda}$. In addition, profits are increasing in firm i's abatement effort z_i, and in public image λ, but decreasing in firm j's abatement effort z_j, and in the emission fee t if abatement effort is sufficiently low such that $z_i < \frac{2(a-t-\lambda z_j)}{9-4\lambda}$.*

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

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

The next lemma identifies the equilibrium emission fee. Lemma A2 is analogous to lemma 2 in Espinola-Arredondo et al. (2021) and its proof is omitted.

Lemma A2. *In the third stage, the regulator sets an optimal emission fee of*

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

which is positive if and only if $Z < \frac{2a(4d-1)}{\lambda+4d(3-\lambda)} \equiv \tilde{Z}$. The emission fee $t(Z)$ is decreasing in the aggregate abatement Z, and increasing in public image λ. The emission fee is increasing in the environmental damage d if and only if $Z < \frac{2a}{2-\lambda} \equiv \bar{Z}$, where cutoff $\bar{Z} > \tilde{Z}$ under all parameter conditions.

In the second stage, we first evaluate realized equilibrium profits in the fourth stage $\pi_k(z_i, z_j) = \pi_k(t(Z))$, where $t(Z)$ is from Lemma A2. Inserting this into each firm i's problem in the second stage, we have that

$$\max_{z_i \geq 0} \pi_i(z_i, z_j) - \frac{1}{2}(\gamma_i - \theta b_i)(z_i)^2,$$

and differentiating with respect to z_i we find

$$\frac{a(8d-2) + (4d(\lambda-3) - \lambda)(z_i + z_j)}{8d+4} + \frac{(4d(\lambda+1) + 3\lambda)(2a + 4d((1+\lambda)z_i + (1-\lambda)z_j) + \lambda(3z_i - z_j))}{8(2d+1)^2}$$
$$+ z_i(b_i\theta_i - \gamma_i) + \frac{z_i(4d(\lambda-3) - \lambda)}{8d+4} = 0$$

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

$$z_i(z_j) = \frac{8ad(4d+\lambda+2)+6a\lambda-4a-\left[2\lambda+(4d+3)\left(\lambda^2+4d(2+\lambda(\lambda-1))\right)\right]z_j}{16d(5d+3+2(d+1)(\gamma_i-b_i\theta))+8(\gamma_i-b_i\theta)-(4d+3)^2\lambda^2-32d(2d+1)\lambda+4\lambda}.$$

Firm j has a symmetric best response function. This best response function has the following properties:

1. when $b_i = 0$ and $\lambda = 0$, the best response function is

$$z_i(z_j) = \frac{a\left(8d^2+4d-1\right)-2d(4d+3)z_j}{2\gamma_i+4d(2\gamma_i(d+1)+5d+3)},$$

   which is unambiguously decreasing in z_j;

2. when $b_i = 0$ and $\lambda > 0$, the best response function is

$$z_i(z_j) = \frac{8ad(4d+\lambda+2)+a(6\lambda-4)-z_j\left[(4d+3)\left(4d((\lambda-1)\lambda+2)+\lambda^2\right)-2\lambda\right]}{8\gamma_i+16d(2\gamma_i(d+1)+5d+3)-(4d+3)^2\lambda^2-32d(2d+1)\lambda+4\lambda},$$

   and is decreasing in z_j if and only if $\gamma_i < \bar{\gamma}_i$;

3. when b_i, $\lambda > 0$, $z_i(z_j)$ is decreasing in z_j if and only if $\gamma_i > \bar{\gamma}_i + \theta b_i$,

where $\bar{\gamma}_i \equiv \frac{\lambda(9\lambda-4)+8d[\lambda(3\lambda+4)-6]-16d^2(1-\lambda)(5+\lambda)}{8(1+2d)^2}$. This cutoff decreases in d, and increases in λ as follows:

$$\frac{\partial\bar{\gamma}_i}{\partial d} = \frac{(4d+3)(\lambda-2)^2}{2(2d+1)^3} < 0,$$
$$\frac{\partial\bar{\gamma}_i}{\partial\lambda} = \frac{8d(2d(\lambda+2)+3\lambda+2)+9\lambda-2}{4(2d+1)^2} > 0.$$

A.2 Proof of Proposition 1

Simultaneously solving for z_i and z_j in the best response function $z_i(z_j)$, and $z_j(z_i)$ yields the equilibrium abatement

$$z_i(b_i,b_j) = \frac{1}{B}\left[a(4d(4d+\lambda+2)+3\lambda-2)\left(4d(3+2(\gamma_j-b_j\theta)-\lambda(2\lambda+3))+4(\gamma_j-b_j\theta)-6\lambda^2+\lambda\right)\right]$$

for each firm i, where the term B is defined as

$$\begin{aligned}
B \equiv\ & 3\lambda^2(6\theta(b_i+b_j)-6(\gamma_i+\gamma_j)+1)+8\lambda(-\theta(b_i+b_j)+\gamma_i+\gamma_j)+16(\gamma_i-b_i\theta)(\gamma_j-b_j\theta)\\
&+32d^3\left[\lambda^2(2\theta(b_i+b_j)-2(\gamma_i+\gamma_j+1)-8\lambda(-\theta(b_i+b_j)+\gamma_i+\gamma_j)+4b_i\theta b_j\theta-\gamma_j)-10\theta b_i+b_j)\right.\\
&\left.+2\gamma_i(2(\gamma_j-b_j\theta)+5)+10\gamma_j+10\lambda^3-36\lambda+21\right]+16d^2\left[-4\lambda^2(-2\theta(b_i+b_j)+2(\gamma_i+\gamma_j)+7)-\right.\\
&16\lambda(-\theta(b_i+b_j)+\gamma_i+\gamma_j)+2(6b_i\theta(b_j\theta-\gamma_j)+\gamma_i(6(\gamma_j-b_j\theta)+11))-22\theta(b_i+b_j)+22\gamma_j+2\lambda^4\\
&\left.+29\lambda^3-40\lambda+27\right]+2d\left[48\left(-\theta(b_i\gamma_j+b_i+b_j\gamma_i+b_j)+b_ib_j\theta^2+\gamma_i\gamma_j+\gamma_i+\gamma_j\right)\right.\\
&\left.+\lambda^2(42\theta(b_i+b_j)-42\gamma_i-42\gamma_j-155)+12\lambda(2\theta(b_i+b_j)-2\gamma_i-2\gamma_j+3)+24\lambda^4+70\lambda^3\right]\\
&+18\lambda^4-21\lambda^3.
\end{aligned}$$

When the EG is absent, $b_i = b_j = 0$, each firm i's equilibrium abatement is

$$z_i(0,0) = \frac{1}{C}\left[a(4d(4d+\lambda+2)+3\lambda-2)\left(4\gamma_j+4d(2\gamma_j-\lambda(2\lambda+3)+3)-6\lambda^2+\lambda\right)\right]$$

where the term C is defined as

$$\begin{aligned}C \equiv & -\lambda^2(3(6\gamma_i+6\gamma_j-1)+2d(42\gamma_i+42\gamma_j+16d(4\gamma_i+4\gamma_j+d(2\gamma_i+2\gamma_j-1)+14)+155)) \\ & +8\lambda(\gamma_i+\gamma_j-d(6\gamma_i+6\gamma_j+16d(2\gamma_i+2\gamma_j+d(2\gamma_i+2\gamma_j+9)+5)-9)) \\ & +16(\gamma_j(2d+1)(\gamma_i+2d(2\gamma_i(d+1)+5d+3))+d(6\gamma_i+d(22\gamma_i+(20\gamma_i+42)d+27))) \\ & +2(4d+3)^2\lambda^4+(4d+3)(8d(10d+7)-7)\lambda^3\end{aligned}$$

A.3 Proof of Proposition 2

The EG's marginal benefit is

$$\begin{aligned}MB_i &\equiv \frac{1}{2}\beta(ER_i)^{-\frac{1}{2}}\left[\frac{\partial ER_i}{\partial b_i}\right]+\frac{1}{2}\beta(ER_j)^{-\frac{1}{2}}\left[\frac{\partial ER_j}{\partial b_i}\right] \\ &= \frac{1}{2}\beta(ER_i)^{-\frac{1}{2}}\left[\frac{\partial e_i^{NoEG}}{\partial b_i}-\frac{\partial e_i^{EG}}{\partial b_i}\right]+\frac{1}{2}\beta(ER_j)^{-\frac{1}{2}}\left[\frac{\partial e_j^{NoEG}}{\partial b_i}-\frac{\partial e_j^{EG}}{\partial b_i}\right]\end{aligned}$$

We can simplify this further since $\frac{\partial e_i^{NoEG}}{\partial b_i} = \frac{\partial e_j^{NoEG}}{\partial b_i} = 0$ and $\frac{\partial e_i^{EG}}{\partial b_i} = \frac{\partial q}{\partial b_i} - \frac{\partial z_i}{\partial b_i}$, where $q(t(z_i(b_i,b_j), z_j(b_i,b_j)))$. Therefore,

$$\frac{\partial q}{\partial b_i} = \frac{\partial q}{\partial t}\frac{\partial t}{\partial z_i}\frac{\partial z_i}{\partial b_i} + \frac{\partial q}{\partial t}\frac{\partial t}{\partial z_i}\frac{\partial z_j}{\partial b_i},$$

which simplifies further to $\frac{\partial q}{\partial b_i} = \frac{\partial q}{\partial t}\frac{\partial t}{\partial z_i}\left(\frac{\partial z_i}{\partial b_i}+\frac{\partial z_j}{\partial b_i}\right)$. We also know that since $t(Z) = t(z_i+z_j)$, then $\frac{\partial t}{\partial z_i} = \frac{\partial t}{\partial z_j}$. Substituting this into MB_i, we obtain

$$MB_i \equiv \frac{1}{2}\beta(ER_i)^{-\frac{1}{2}}\left[\frac{\partial z_i}{\partial b_i}-\frac{\partial q}{\partial t}\frac{\partial t}{\partial z_i}\left(\frac{\partial z_i}{\partial b_i}+\frac{\partial z_j}{\partial b_i}\right)\right]+\frac{1}{2}\beta(ER_j)^{-\frac{1}{2}}\left[\frac{\partial z_j}{\partial b_i}-\frac{\partial q}{\partial t}\frac{\partial t}{\partial z_i}\left(\frac{\partial z_i}{\partial b_i}+\frac{\partial z_j}{\partial b_i}\right)\right].$$

A.4 No EG, regulation present

In this case, there is no actor in the first stage and the results from the fourth stage (Lemma A1) and the third stage (Lemma A2) are unchanged.

Second Stage. We can use the result from Proposition 1 where $z_i(b_i, b_j)$ is evaluated at $b_i = b_j = 0$ to obtain each firm i's equilibrium investment in abatement in the absence of the EG,

$$z_i^{NoEG} = \frac{1}{C}\left[a(4d(4d+\lambda+2)+3\lambda-2)\left(4\gamma_j+4d(2\gamma_j-\lambda(2\lambda+3)+3)-6\lambda^2+\lambda\right)\right].$$

Social welfare in this case is

$$SW = \frac{1}{2}[q_i+q_j]^2+\pi_i+\pi_j+t[q_i+q_j-z_i-z_j]-d[q_i+q_j-z_i-z_j]^2.$$

A.5 No regulation, EG present

Fourth stage. In this case, the fourth stage remains unchanged except now we treat $t = 0$, and the results from Lemma A1 become,

$$q_i(z_i, z_j) = \frac{1}{3}\left(a + \lambda(2z_i - z_j)\right),$$
$$\pi_i(z_i, z_j) = \left(q_i(z_i, z_j)\right)^2.$$

Second Stage. In the absence of the regulator, there is no player in the third stage, so we proceed to the second stage of the game where each firm i solves

$$\max_{z_i \geq 0} \pi_i(z_i, z_j) - \frac{1}{2}(\gamma_i - \theta b_i)(z_i)^2.$$

The first-order condition is

$$\frac{4}{9}\lambda(a + \lambda(2z_i - z_j) - (\gamma_i - \theta b_i)z_i = 0,$$

and firm i's best response function is

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

Firm j has a symmetric best response function. Simultaneously solving for z_i and z_j, we find

$$z_i^{NoReg} = \frac{4a\lambda\left(3(\gamma_j - \theta b_j) - 4\lambda^2\right)}{27(\gamma_i - \theta b_i)(\gamma_j - \theta b_j) - 24\lambda^2((\gamma_i - \theta b_i) + (\gamma_j - \theta b_j)) + 16\lambda^4}.$$

First stage. The EG's problem remains

$$\max_{b_i, b_j \geq 0} \underbrace{[\beta(ER_i)^{\frac{1}{2}} - c_{EG}(b_i)^2]}_{\text{Firm } i} + \underbrace{[\beta(ER_j)^{\frac{1}{2}} - c_{EG}(b_j)^2]}_{\text{Firm } j}.$$

In the absence of the regulator, the firm's abatement is not impacted by an emissions fee (as $t = 0$) and solely incentivized by how abatement impacts demand, λ. The EG anticipates this when choosing its collaboration efforts b_i and b_j.

Social welfare in this case is

$$SW = \frac{1}{2}[q_i + q_j]^2 + \pi_i + \pi_j - d[q_i + q_j - z_i - z_j]^2 - c_{EG}(b_i^2 + b_j^2).$$

A.6 No regulation, no EG

In the absence of both the EG and the regulator, the game only includes stages two and four.

Fourth stage. We again use our result from Lemma A1 where $t = 0$, which yields

$$q_i(z_i, z_j) = \frac{1}{3}\left(a + \lambda(2z_i - z_j)\right),$$
$$\pi_i(z_i, z_j) = \left(q_i(z_i, z_j)\right)^2.$$

Second stage. Each firm i's problem in the second stage is

$$\max_{z_i \geq 0} \frac{1}{9}(a + \lambda(2z_i - z_j))^2 - \frac{1}{2}\gamma_i(z_i)^2,$$

with first-order condition

$$\frac{4}{9}\lambda(a + (\lambda z_i - z_j) - \gamma_i z_i = 0,$$

and best response function

$$z_i(z_j) = \frac{4a\lambda - 4\lambda^2 z_j}{9\gamma_i - 8\lambda^2}.$$

Firm j has a symmetric best response function. Simultaneously solving for z_i and z_j, we obtain

$$z_i^{NoEG,NoReg} = \frac{4a\lambda\left(3\gamma_j - 4\lambda^2\right)}{27\gamma_i\gamma_j - 24\lambda^2(\gamma_i + \gamma_j) + 16\lambda^4},$$

which coincides with z_i^{NoReg} when evaluated at $b_i = b_j = 0$ (see Appendix A.5). Social welfare in this case is

$$SW = \frac{1}{2}[q_i + q_j]^2 + \pi_i + \pi_j - d[q_i + q_j - z_i - z_j]^2,$$

which, when evaluated at the equilibrium is

$$\begin{aligned} SW =& \frac{1}{\left(27\gamma_i\gamma_j - 24\lambda^2(\gamma_i + \gamma_j) + 16\lambda^4\right)^2} 4a^2[-6\lambda^4\left(-9\gamma_i^2 - 22\gamma_i\gamma_j - 9\gamma_j^2 + 2d(\gamma_i + \gamma_j)(3\gamma_i + 3\gamma_j - 16)\right) \\ & - 72d\lambda^3\left(\gamma_i^2 + 6\gamma_i\gamma_j + \gamma_j^2\right) - 81\gamma_i^2\gamma_j^2(d-1) - 32\lambda^6(\gamma_i + \gamma_j + 8d) + 192d\lambda^5(\gamma_i + \gamma_j) \\ & + 18\lambda^2(\gamma_i + \gamma_j)(-7\gamma_i\gamma_j + \gamma_i(6\gamma_j - 2)d - 2\gamma_j d) + 108\gamma_i\gamma_j d\lambda(\gamma_i + \gamma_j)]. \end{aligned}$$

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