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Profit-Enhancing Environmental Policy:
Uninformed Regulation in an Entry-Deterrence Model[*]

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Abstract

This paper considers a polluting firm, subject to environmental policy, who seeks to deter the entry of potential competitors. We investigate under which conditions firm profits are enhanced by regulation. We show that, contrary to common belief, inefficient firms may lobby in favor of environmental regulation when their production is especially polluting. In addition, we evaluate how this result is affected by the regulator's information accuracy and the environmental damage from pollution.

KEYWORDS: Entry deterrence; Signaling; Environmental policy; Informational advantage; Profits.

JEL CLASSIFICATION: D82, H23, L12, Q5

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1 Introduction

Environmental regulation is often deemed as detrimental for firm profits. While this result holds under complete information, we show that, under incomplete information, regulation can facilitate firms' information transmission, and thus have a positive effect on profits.

We consider a setting in which an incumbent monopolist faces entry threats from a potential newcomer, which is uninformed about the incumbent's production costs (efficient or inefficient). The incumbent's output generates an environmental externality that the regulator seeks to correct with the use of pollution taxes. For completeness, our model allows the regulator to have different degrees of information about the incumbent's costs (i.e., perfectly informed, partially informed, or completely uninformed). In this incomplete information setting, the regulator must set a first-period emission fee on the incumbent, who responds by choosing an output level. Both fee and output are subsequently observed by the entrant, as signals it uses to infer the incumbent's efficiency level before deciding whether to join the industry. Our model is, therefore, useful to analyze industries where firms develop new products whose costs are difficult to assess by regulators and potential entrants.

In our study, we first show that the efficient firm increases its output relative to complete information in order to reveal its type to potential entrants and thus deter entry. That is, the efficient incumbent exerts a "separating effort" that cannot be profitably mimicked by the inefficient type of firm. We demonstrate that such effort is ameliorated by regulation. Hence, emission fees give rise to two opposite effects on profits: a negative effect, as firms are forced to decrease their output; and a positive effect, as fees reduce the incumbent's separating effort. We show that the positive effect dominates when pollution is sufficiently damaging, and thus fees are strict enough. In this context, the inefficient type of firm finds it unprofitable to mimic the output level of the efficient incumbent, thus allowing the latter to reveal its type exerting a small separating effort. As a consequence, stringent regulation can become profit enhancing under incomplete information settings. In summary, environmental policy helps the efficient firm more easily convey its type potential rivals.

Second, we explore whether the profit-enhancing effect of emission fees is sensitive to the regulator's information accuracy. In particular, a poorly informed regulator would assign a large probability on the incumbent's costs being high when they are actually low, thus setting a lax fee on this firm. Such inaccurate information produces two effects on profits: a positive effect (from the less stringent fee), and a negative effect (as the incumbent is now forced to increase its separating effort in order to convey its type to potential entrants). We identify under which conditions the positive effect dominates and, hence, profits monotonically increase as the regulator becomes more poorly informed. In particular, we show that such monotonicity arises when the environmental damage from pollution is relatively large. In this context, emission fees become stricter, hindering the ability of the inefficient firm to mimic the output decision of the efficient firm, which ultimately reduces the separating effort that the latter needs to exert to convey its type.

Finally, we study the equilibrium in which the inefficient type of incumbent deters entry by concealing its costs from potential rivals. We demonstrate that emission fees lower the firm's costs of concealing information, thus providing more incentives to practice entry deterrence than when regulation is absent. Hence, regulators can expect support from the most unexpected ally: inefficient firms which, in addition, are especially polluting. Our findings, therefore, help to explain the recent lobbying for stringent environmental regulation by relatively polluting companies, such as the mining company Rio Tinto, and the oil company BP, as part of the Pew Center on Global Climate Change.[1]

Several papers analyze settings in which environmental regulation affects profits under contexts of complete information, such as Porter (1991), Porter and van der Linde (1995a,b), Farzin (2003) and Schoonbeek and de Vries (2009). Our paper shows that, under incomplete information, firms can still favor regulation. Specifically, a firm favors emission fees when they facilitate its signaling ability, i.e., conveying or concealing information from potential rivals.

Our study also contributes to the literature on entry-deterring models with signaling; see Milgrom and Roberts (1982), Harrington (1986), and Ridley (2008). This literature, however, abstracts from the regulatory contexts in which firms operate. We demonstrate that considering such regulatory setting is crucial to understand firms' incentives to support or oppose environmental policies. That is, our results would provide an additional motive for firms to favor emission fees, even in the absence of the standard arguments provided by the literature, such as innovation and corporate social responsibility.

As described above, our paper builds on signaling models in which the uninformed entrant observes several signals, each of them originating from different agents. In particular, Schultz (1999) analyzes the ability of different incumbents to use their output decisions to deter entry, and shows that a pooling equilibrium can be sustained if the incentives of these firms are relatively aligned. Similarly, Espinola-Arredondo and Munoz-Garcia EM (2013, 2015) examine entry decisions when the potential entrant observes one signal originating from the incumbent firm (output) and another from the regulator (emission fee), demonstrating that a pooling equilibrium exists in which entry is deterred if the incumbent's and regulator's preferences are aligned, i.e., when entry is damaging for the incumbent and it can be deterred without generating large welfare losses.[2] While EM (2015) describes under which conditions the incumbent firm seeks to deter entry in a given information and regulatory context (incomplete information and emission fees), it does not evaluate firms' interests towards regulation and information; our main investigation in this paper. Therefore, our results help understand in which settings firms would actually support the introduction of environmental regulation while practicing entry deterrence, and if a more accurately informed regulation can become profit enhancing.[3] This result is relevant for policymakers who evaluate the implementation

[1] Maloney and McCormick (1982) empirically analyze which firms support environmental regulation in different U.S. industries, such as textile mills and smelting plants for cooper, lead and zinc. Their study shows that, while these firms are subject to a costly regulation, their market share increases, potentially indicating larger profits.

[2] Denicolò (2008) also examines a signaling model, in which a firm decides whether to acquire advanced technology in order to convey its costs of regulatory compliance to an uninformed regulator. However, firms are always active in the industry, and thus entry deterrence cannot arise. In addition, Denicolò (2008) does not allow for the regulator to sustain different degrees of information.

[3] EM (2013) considers a signaling model in which the regulator perfectly observes the incumbent's costs and, as a

of environmental policy on polluting industries facing entry threats.

The following section describes the model. Section 3 (4) analyzes the separating (pooling) equilibrium, while section 5 discusses our results.

2 Model

Consider an incomplete information model whereby an incumbent firm, facing an inverse demand $P(q) = 1 - q$, privately observes its production costs, c_K, either high or low, i.e., $K = \{H, L\}$, where $1 > c_H > c_L > 0$. A potential entrant does not observe the incumbent's costs, but knows that they are high with probability $p \in (0, 1)$ and low otherwise. The costs of the entrant are high, c_H, and under complete information it would only enter when the incumbent's costs are also high.[4] The production of all firms generates pollution that the regulator addresses setting emission fees in both periods. The social welfare function considers consumer and producer surplus, tax revenues, and environmental damage from pollution, $ED(q) \equiv dq^2$, where $d > 1/2$ guarantees that emission fees are positive under all information contexts. (Emission fees are, hence, revenue neutral.)

The regulator can be perfectly informed about the incumbent's costs, as poorly informed as the entrant is, or partially informed. In particular, the regulator assigns a belief p^β to the incumbent's costs being high, where parameter $\beta \in [0, +\infty)$ reflects the regulator's degree of information accuracy.[5] This allows for cases in which $\beta = 0$, and thus the regulator is certain about facing a high-cost incumbent, i.e., $p^\beta = 1$; that where $\beta = 1$, implying that he is as poorly uninformed as the entrant is; and that in which $\beta \to \infty$, entailing that he is sure about facing a low-cost incumbent, i.e., $p^\beta = 0$. In the second stage of the game, firms compete a la Cournot if entry occurs; otherwise, the incumbent maintains its monopolistic position.

The time structure of the game is as follows: (1) the incumbent privately observes its production costs, c_K, where $K = \{H, L\}$; (2) the regulator sets an emission fee t_1 on the incumbent's output; (3) the K-type incumbent responds to fee t_1 by choosing an output level $q^K(t_1)$; (4) the entrant observes two signals (emission fee and output level), updates its prior beliefs about the incumbent's type, and decides whether to enter; (5) the regulator sets emission fees either on the incumbent alone (under no entry) or on both firms (under entry); and (6) firm/s respond by selecting their output level.[6]

consequence, the only uninformed agent is the potential entrant. In contrast, EM (2015) extends that model to allow for the regulator to have access to different degrees of information (e.g., being as poorly informed as the entrant, or having access to better information about the incumbent's real costs). Such extended model shows that the regulator may actually be willing to facilitate the incumbent's entry-deterring practices under larger conditions when he is poorly informed than when his information is more accurate.

[4] This is a common assumption in the literature of entry-deterrence without regulation, often justified by the lack of experience of the potential entrant in the industry. When environmental regulation is present, this assumption can be rationalized on the basis of the newcomer's inexperience in complying with the administrative and legal details of the policy.

[5] For instance, the regulator could receive a non-public report from other government agencies, such as the IRS, helping him assess the incumbent's costs.

[6] The potential entrant does not observe the value of β at the beginning of the game, but sustains a prior that assigns full probability to $\beta = 1$, i.e., $p^\beta = p$. After observing the regulator's emission fee and the incumbent's output

Under complete information, the K–type incumbent solves

$$\max_{q\geq 0}\ (1-q)q-(c_K+t_1)\,q$$

which yields an output function $q^K(t_1)=\frac{1-c_K-t_1}{2}$. The regulator seeks to induce the socially optimal output that maximizes social welfare, $q_K^{SO}=\frac{1-c_K}{1+2d}$. In particular, anticipating the incumbent's output function $q^K(t_1)$, the regulator sets an emission fee $t_1^K=(2d-1)\frac{1-c_K}{1+2d}$ which solves $\frac{1-c_K-t_1}{2}=\frac{1-c_L}{1+2d}$. In the second period, a similar analysis applies if no entry ensues, where the same fee is still optimal. If, instead, firms compete a la Cournot, every firm i produces $q_i^K(t_2)=\frac{1-2c_i+c_j-t_2}{3}$ where $j\neq i$. In this context, the regulator induces q_K^{SO} by setting a fee that solves $q_i^K(t_2)+q_j^K(t_2)=q_K^{SO}$. For more details on complete information strategies, see EM (2013).

The next sections analyze the separating equilibrium (SE) and pooling equilibrium (PE). In the SE (PE), we examine the output and profits for the low-cost (high-cost) incumbent since the high-cost (low-cost, respectively) firm behaves as under complete information.

3 Separating equilibrium

In a context in which regulation is absent, as in standard entry-deterrence games, the low-cost firm increases its output (relative to complete information) in order to convey its type to the potential entrant and thus deter entry; see Milgrom and Roberts (1982). When regulation is present, the incumbent similarly increases its production in order to signal its efficient cost structure to potential rivals, but such additional production generates more pollution. In this context, the regulator sets more stringent emission fees in order to curb such additional externality. In particular, as shown in EM (2013, 2015), a separating equilibrium can be sustained where the low-cost firm increases its output function, from $q^L(t_1)=\frac{1-c_L-t_1}{2}$ under complete information to $q^A(t_1)=\frac{(1-c_H)(1+2d)-\sqrt{3\delta}}{2}-\frac{1+2d}{2}t_1$, where δ denotes the discount factor. The regulator, anticipating output function $q^A(t_1)$, sets an emission fee

$$t_1^*=\frac{2d-1+(1+2d)(1-p^\beta)+\left[p^\beta(3+2d)-\sqrt{3\delta}-(1+2d)\right]c_H+2(1-p^\beta)c_L}{\sqrt{3\delta}}$$

which yields an output level $q^A(t_1^*)=\frac{2+p^\beta\sqrt{3\delta}-p^\beta\left(2+\sqrt{3\delta}\right)c_H-2\left(1-p^\beta\right)c_L}{2(1+2d)}$ in equilibrium. Hence, the output difference $q^A(t_1^*)-q^L(t_1^L)$ can be interpreted as the low-cost firm's separating effort. The next lemma examines how such effort is affected by the regulator's information accuracy, β.

Lemma 1. *Separating effort* $q^A(t_1^*)-q^L(t_1^L)=\frac{p^\beta\left[\sqrt{3\delta}(1-c_H)-2(c_H-c_L)\right]}{2(1+2d)}$ *is decreasing in* β*, and*

level, the entrant's beliefs are updated. In the separating equilibrium, the two signals help the entrant assign full probability on the incumbent's costs being low and thus $\beta\to\infty$. In contrast, in the pooling equilibrium, the two signals leave the entrant's prior beliefs of the incumbents' costs and of the value of β unaffected. For a more detailed discussion of belief updating when the potential entrant observes two signals, see EM (2015).

becomes nil when $\beta \to \infty$ (i.e., $p^{\beta} \to 0$).

The separating effort, depicted in figure 1, is nil when the regulator is perfectly informed.[7] When his information becomes less accurate, however, he assigns a positive probability to the incumbent's costs being high, thus setting a less stringent fee. Such a fee makes the output decision of the low-cost firm easier to mimic by the high-cost type and, hence, forces the former to increase its output in order to signal its type. This result is illustrated by leftward movements in figure 1 (lower β) for a given damage d. Figure 1 also depicts the effect of more polluting output on the separating effort of the efficient firm. In particular, as d increases emission fees become more stringent, thus hindering the ability of the inefficient incumbent to imitate its production decision. As a consequence, the efficient firm does not need to exert such a large separating effort when pollution is damaging, e.g., $d = 1.5$, than when it is not, e.g., $d = 0.51$, which shrinks the difference between output levels $q^A(t_1^A)$ and $q^L(t_1^L)$. (Recall that emission fees become zero for all $d < 1/2$, implying that the separating effort when $d = 0.51$ closely resembles that in standard entry-deterrence models in which the regulator is absent.)

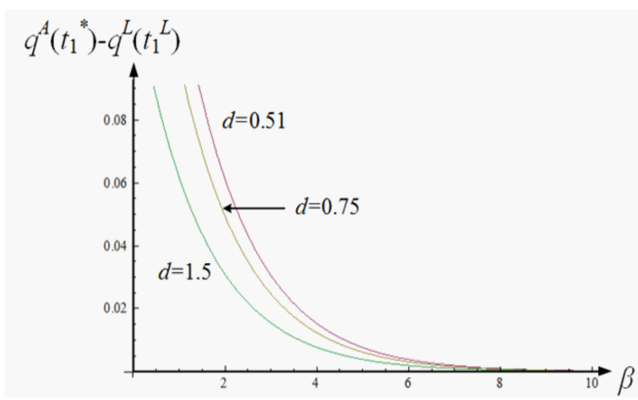

Fig 1. Separating effort as a function of β and d.

The above results suggest that a less informed regulator gives rise to two opposite effects on profits: a positive effect, as he sets less stringent fees; and a negative effect, since such a fee forces the firm to increase its separating effort. The next lemma compares these two effects.

Lemma 2. *The equilibrium profits of the low-cost incumbent in the SE, $\pi_{SE}^{L,R}(\beta)$, increase in β for all $\beta < \beta_1$, but decrease otherwise; where cutoff $\beta_1 \equiv \frac{1}{\ln p} \ln \frac{(1-2d)(1-c_L)}{4-\sqrt{3\delta}(1-c_L)-2c_L}$. In addition, $\beta_1 > 0$ for all $d < d_1 \equiv \frac{1-\sqrt{3\delta}(1-c_L)-2c_H+c_L}{2(1-c_L)}$, and β_1 decreases in d.*

Figure 2a depicts equilibrium profits of the low-cost incumbent as a function of the regulator's

[7] For simplicity, figure 1 considers costs $c_H = 1/3$, $c_L = 1/4$, and no discounting. These cost parameters allow for the separating equilibrium to arise, i.e., $c_H < \frac{\sqrt{3\delta}+(1+2d)c_L}{\sqrt{3\delta}+(1+2d)}$. For our numerical example such inequality becomes $\frac{1}{3} < \frac{4\sqrt{3}+(1+2d)}{4\sqrt{3}+4(1+2d)}$, which holds for all $d > \frac{1}{2}$. Other parameter combinations yield similar results and can be provided by the authors upon request.

information accuracy, β, illustrating their non-monotonicity.[8] In words, the incumbent obtains a larger profit with a regulator who is partially informed about its type ($\beta = \beta_1$ in figure 2a) than with a perfectly informed ($\beta \to \infty$) or a completely uninformed ($\beta = 0$) regulator. When $\beta > \beta_1$, the regulator sets stringent fees, and thus a partially informed regulator entails an overall positive effect on profits. In contrast, when $\beta < \beta_1$, fees become lax, and further reductions in β help the high-cost firm to easily mimic the low-cost incumbent, reducing the profits of the latter.

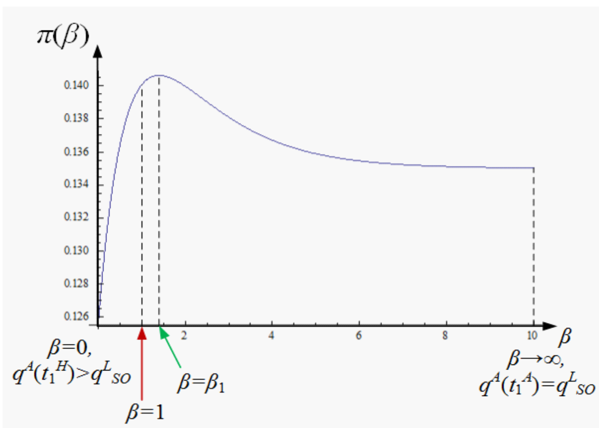

Fig 2a. Profits in the SE when $d = 0.75$.

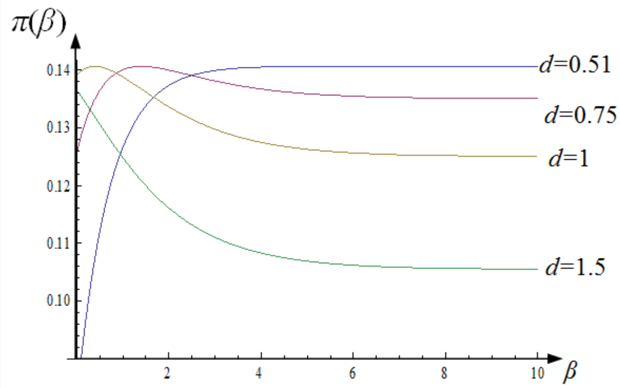

Fig 2b. Profits in the SE for different values of d.

Figure 2b depicts the effect of environmental damage on profits. When d is low (e.g., $d = 0.51$), the emission fee is lax and attracts the high-cost firm to mimic, ultimately requiring a large separating effort from the low-cost incumbent; a behavior that is emphasized when the regulator becomes more uninformed (leftward movement in figure 2b). Hence, in this case equilibrium profits monotonically decrease. The opposite argument applies when d is high ($d = 1.5$), and thus emission fees are stringent. In this context, the output level of the low-cost firm is more difficult to mimic, helping it obtain larger profits as the regulator becomes more uninformed.

We next examine whether regulation leads efficient firms to obtain higher profits under the SE than in complete information (CI).

Proposition 1. *Profits satisfy* $\pi_{SE}^{L,R}(\beta) \geq \pi_{CI}^{L,R}$ *if and only if* $\beta \geq \beta_2$, *where* $\beta_2 \equiv \frac{1}{\ln p} \ln \frac{2(1-2d)}{2-\frac{4-3\delta(1-c_H)}{2-\sqrt{3\delta}(1-c_L)}}$, *and* $\beta_2 \geq 0$ *for all* $d \geq d_2 \equiv \frac{(2+\sqrt{3\delta})(1-c_H)}{4(1-c_L)}$.

Figure 3 depicts the difference between the profits in the SE and CI, $\pi_{SE}^{L,R}(\beta) - \pi_{CI}^{L,R}$. Let us first consider this difference when $d = 0.75$. Starting from $\beta \to \infty$ where $\pi_{SE}^{L,R}(\beta) = \pi_{CI}^{L,R}$, a marginal decrease in β entails a positive effect on profits (laxer fees) that dominates its negative effect (easier

[8] In order to facilitate comparisons, figure 2a (and all subsequent figures) use the same parameter values as in figure 1.

to mimic output), thus yielding $\pi_{SE}^{L,R}(\beta) > \pi_{CI}^{L,R}$. Further reductions in β, however, entail a less stringent emission fee, and a easier to mimic production, ultimately generating the opposite profit ranking.

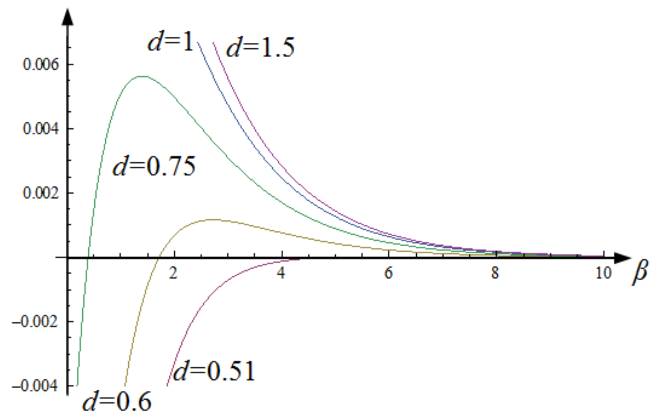

Fig 3. Profit difference $\pi_{SE}^{L,R}(\beta) - \pi_{CI}^{L,R}$.

Figure 3 also shows that, as the environmental damage increases, the profit ranking $\pi_{SE}^{L,R}(\beta) \geq \pi_{CI}^{L,R}$ holds under a wider range of β. Intuitively, when pollution is very damaging the regulator sets stringent emission fees, which the high-cost firm cannot profitably mimic. Hence, when regulation is present the efficient firm can be better off under incomplete than complete information; a result contrasting that when regulation is absent; see Milgrom and Roberts (1982).[9]

4 Pooling equilibrium

EM (2015) show that a pooling equilibrium (PE) can be sustained in which the high-cost incumbent mimics the output function of the low-cost firm. If the regulator supports such concealing strategy, he increases the emission fee from t_1^H under CI to t_1^L under the PE. As a consequence, this firm's output level increases from $q^H(t_1^H) = \frac{1-c_H}{1+2d}$ to $q^L(t_1^L) = \frac{1-c_L}{1+2d}$, and its mimicking effort is given by the difference $q^L(t_1^L) - q^H(t_1^H) = \frac{c_H-c_L}{1+2d}$.[10] Let us next evaluate the equilibrium profits of the high-cost firm.

Lemma 3. *The equilibrium profit of the high-cost incumbent in the PE, $\pi_{PE}^{H,R}$, is constant in β. In addition, $\pi_{PE}^{H,R}$ increases in d if and only if $d < d_4$; where $d_4 \equiv \frac{1+\delta(1+c_H^2)+c_H(1-2\delta-c_L)+c_L(2c_L-3)}{2(1-c_H)(1+\delta-\delta c_H-c_L)}$.*

First, the profits of the high-cost incumbent do not depend on β, since in the PE the regulator

[9] When $d = 0.51$ emission fees are close to zero. Figure 3 shows that our results predict that $\pi_{SE}^{L,R}(\beta) < \pi_{CI}^{L,R}$ for all values of β, resembling that in standard entry-deterring models without regulation.

[10] In particular, for the PE to arise: (1) the high-cost incumbent must be sufficiently symmetric to the low-cost firm, since otherwise its mimicking effort would be too costly; and (2) the efficiency loss that the regulator generates by "overtaxing" the high-cost incumbent must be small.

mimics the emission fee he would set on the efficient firm, t_1^L, and the incumbent responds by mimicking its output function, $q^L(t_1)$, thus yielding an output level $q^L(t_1^L)$ which is independent on β.[11] In addition, lemma 3 identifies that profits are non-monotonic in d. This property arises because an increase in d yields two opposite effects on profits: a negative effect from a more stringent fee; and a positive effect, since such strict fee reduces the mimicking output $q^L(t_1^L)$. In particular, the mimicking effort $q^L(t_1^L) - q^H(t_1^H) = \frac{c_H - c_L}{1+2d}$ decreases in d at a decreasing rate. Hence, the positive effect of an increase in d on profits is large when $d < d_4$, thus dominating its negative effect, but it becomes small otherwise; as illustrated in figure 4.

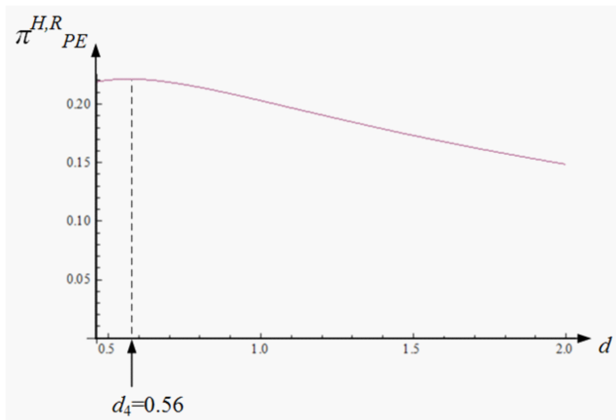

Fig 4. Profits $\pi^{H,R}_{PE}$ as a function of d.

While profits under the PE are positive, we still need to determine whether they are larger than under CI, as evaluated in Proposition 2.

Proposition 2. *Profits satisfy* $\pi^{H,R}_{PE} \geq \pi^{H,R}_{CI}$. *In addition,* $\pi^{H,R}_{PE} - \pi^{H,R}_{CI}$ *increases in* d *if and only if* $d < d_5$; *where* $d_5 \equiv \frac{(2-\delta)c_H^2 - \delta + 6c_L - 4c_L^2 - 2c_H(3-\delta-c_L)}{2(1-c_H)[(\delta-2)c_H + 2c_L - \delta]}$.

Our results, hence, go in line with those in standard entry-deterrence models without regulation, which predict that profits are larger in the PE than in CI. The profit difference $BDE^R \equiv \pi^{H,R}_{PE} - \pi^{H,R}_{CI}$ can then be interpreted as the benefit from deterring entry (BDE). Such a benefit is increasing in d if $d < d_5$, since the positive effect of more stringent regulation (easier to mimic production) outweighs its negative effect. We next analyze whether the benefit of deterring entry is affected by regulation.

Corollary 1. $BDE^R \geq BDE^{NR}$ *for all* $d \in (d_6, d_6^{'})$. *(See appendix for cutoffs* d_6 and $d_6^{'}$.*)*

As depicted in figure 5, BDE is larger without than with regulation when environmental damages

[11] The regulator's information accuracy, β, affects however his willingness to support the high-cost incumbent in its concealing strategy. In particular, the regulator behaves as prescribed in this PE if the savings in entry costs arising from deterring entry exceed the (expected) inefficiencies from setting a stringent fee t_1^L on a firm which could possibly have high production costs.

are small, $d < d_6$. Intuitively, emission fees are less stringent, implying that the high-cost incumbent must exert a large mimicking effort. Hence, the positive effect of regulation is offset by its negative effect. However, when pollution is more damaging, $d > d_6$, emission fees become stringent, thus reducing the incumbent's mimicking effort. In this case, BDE is larger with than without regulation.

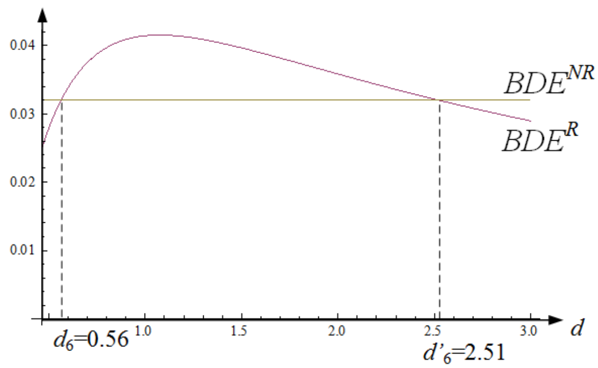

Fig 5. BDE^R and BDE^{NR}.

5 Discussion and Conclusions

Is pollution good for profits? We demonstrate that profits are not necessarily decreasing in d; a result that holds both in the SE and PE. Under the SE, if the regulator is partially informed, the profits of the low-cost firm are larger when pollution becomes more damaging. Intuitively, regulation hinders the mimicking ability of the high-cost firm. Hence, an incumbent facing an uninformed regulator and operating in polluting (not-so-polluting) industries would favor (oppose) regulation since it facilitates (hinders) its entry-deterring practices.

Firms do not necessarily prefer uninformed regulators. At first glance, one may suspect that an uninformed regulator is beneficial for a low-cost incumbent, since he assigns a large probability on its costs being high, setting less stringent emission fees. Such a result undoubtedly holds when the incumbent faces no entry threats. However, under entry threats, the profits of the low-cost firm are not necessarily monotonic in the regulator's information, since laxer emission fees facilitate the mimicking effort of the high-cost firm, thus hindering its profits.

Inefficient firms favoring stringent emission fees? We also show that, when damages are significant, the benefits from deterring entry are actually larger when regulation is present than absent; see Corollary 1. This yields a rather unexpected prediction: the high-cost firm would actually favor environmental regulation when pollution is damaging, since such a regulation ameliorates its mimicking effort.

Further research. Our model considers a single incumbent facing the threat of entry. However, in some industries several firms face such a threat. When regulation is absent, Harrington (1987) shows that, in a context of homogeneous products, firms' behavior under the separating equilibrium coincides with that under complete information, and that the pooling equilibrium cannot be sustained. However, when product differentiation is allowed, Schultz (1999) demonstrates that such equilibrium can be supported whereby incumbents coordinate their production decisions to deter entry. The literature has, nonetheless, overlooked the effect of regulation on these equilibrium results, i.e., whether it facilitates entry-deterring practices (as shown in our model) or, instead, hinders them. In addition, our setting can be extended in several other dimensions: first, considering that firms' environmental damage is a function of their production costs; and second, allowing for emission fees to affect firms' abatement decisions, where abatement costs are type-dependent.

6 Appendix

6.1 *Proof of Lemma 1*

The output difference $q^A(t_1^*) - q^L(t_1^L)$ is positive if $c_H < \frac{\sqrt{3\delta}+2c_L}{\sqrt{3\delta}+2} \equiv \alpha_A$, a cutoff that originates at $c_H = \frac{\sqrt{3\delta}}{\sqrt{3\delta}+2}$ when $c_L = 0$ and reaches $c_H = 1$ when $c_L = 1$. In addition, cutoff α_A satisfies $\alpha_A > \alpha_1 \equiv \frac{\sqrt{3\delta}+(1+2d)c_L}{\sqrt{3\delta}+(1+2d)}$ since α_1 originates at $c_H = \frac{\sqrt{3\delta}}{\sqrt{3\delta}+(1+2d)}$ and reaches $c_H = 1$ when $c_L = 1$, and their vertical intercepts satisfy $\frac{\sqrt{3\delta}}{\sqrt{3\delta}+(1+2d)} < \frac{\sqrt{3\delta}}{\sqrt{3\delta}+2}$ since $d > 1/2$. Hence, for all parameter values in which the SE exists, $\alpha < \alpha_1$, the output difference $q^A(t_1^*) - q^L(t_1^L)$ is positive. Finally, the output difference decreases in β, reaches its highest value, $\frac{\sqrt{3\delta}(1-c_H)-2(c_H-c_L)}{2(1+2d)}$, when $\beta = 0$; and collapses to zero when $\beta \to \infty$. ■

6.2 *Proof of Lemma 2*

First-period profits in the SE are $\left(1 - q^A(t_1^*)\right) q^A(t_1^*) - c_L \cdot q^A(t_1^*)$, and rearranging yields

$$\frac{8d(1-c_L)^2 - 2p^\beta\lambda(2d-1)(1-c_L) + -p^{2\beta}\lambda^2}{4(1+2d)^2}$$

where $\lambda \equiv 2(c_H - c_L) - \sqrt{3\delta}(1-c_H)$. Differentiating with respect to β, yields $\frac{p^\beta \lambda \ln p\left[(2d-1)(c_L-1)-p^\beta\lambda\right]}{2(1+2d)^2}$ which is zero if $\beta = \frac{1}{\ln p} \ln \frac{(1-2d)(1-c_L)}{4-\sqrt{3\delta}(1-c_L)-2c_L} \equiv \beta_1$. In addition, cutoff β_1 satisfies $\beta_1 > 0$ for all $d < d_1 \equiv \frac{1-\sqrt{3\delta}(1-c_L)-2c_H+c_L}{2(1-c_L)}$, and β_1 decreases in d since $\frac{\partial \beta_1}{\partial d} = -\frac{2}{\ln p(1-2d)} < 0$. ■

6.3 *Proof of Proposition 1*

Profits in the SE, $\pi_{SE}^{L,R}(\beta)$, are

$$\pi_{SE}^{L,R}(\beta) \equiv \left(1 - q^A(t_1^*)\right) q^A(t_1^*) - c_L \cdot q^A(t_1^*) + \delta\left[\left(1 - x_{inc}^L(t_1^L)\right) x_{inc}^L(t_1^L) - c_L \cdot x_{inc}^L(t_1^L)\right],$$

since $x_{inc}^L(t_1^L) = \frac{1-c_L}{1+2d}$, $\pi_{SE}^{L,R}(\beta)$ simplifies

$$\frac{8d(1+\delta)(1-c_L)^2 - p^{2\beta}\left[3\delta(1-c_H)^2 + 4(c_H-c_L)\left((c_H-c_L)-\sqrt{3\delta}(1-c_H)\right)\right] - 2p^{\beta}\lambda(2d-1)(1-c_L)}{4(1+2d)^2}$$

Under CI, profits $\pi_{CI}^{L,R} = (1+\delta)\frac{2d(1-c_L)^2}{(1+2d)^2}$. Hence, the profit difference $\pi_{SE}^{L,R}(\beta) - \pi_{CI}^{L,R}$ is

$$\frac{p^{\beta}\left[-p^{\beta}\left[3\delta(1-c_H)^2 + 4(c_H-c_L)\left(\sqrt{3\delta}(c_H-1)+(c_H-c_L)\right)\right] + 2\lambda(2d-1)(c_L-1)\right]}{4(1+2d)^2}$$

which becomes zero for all $\beta \geq \beta_2$, where $\beta_2 \equiv \frac{1}{\ln p}\ln\frac{2(1-2d)}{2-\frac{4-3\delta(1-c_H)}{2-\sqrt{3\delta}(1-c_L)}}$. In addition, cutoff β_2 is positive for all $d \geq d_2 \equiv \frac{\left(2+\sqrt{3\delta}\right)(1-c_H)}{4(1-c_L)}$. ■

6.4 *Proof of Lemma 3*

Profits in the PE are

$$\begin{aligned}\pi_{PE}^{H,R} &= \left(1-q^L(t_1^L)\right)q^L(t_1^L) - c_H\cdot q^L(t_1^L) \\ &+\delta\left[\left(1-q^H(t_1^H)\right)q^H(t_1^H) - c_H\cdot q^H(t_1^H)\right]\end{aligned}$$

Plugging output levels $q^L(t_1^L)$ and $q^H(t_1^H)$ into $\pi_{PE}^{H,R}$ yields

$$\pi_{PE}^{H,R} = \frac{2d(1+\delta) + 2d\delta c_H^2 - c_L(c_L+2d-1) + c_H\left[(1-2d)c_L - 1 - 2d(1+2\delta)\right]}{(1+2d)^2}$$

Differentiating $\pi_{PE}^{H,R}$ with respect to d, and solving for d, we obtain

$$d_4 \equiv \frac{1+\delta(1+c_H^2) - c_H(-1+2\delta+c_L) + c_L(2c_L-3)}{2(-1+c_H)(-1-\delta+\delta c_H+c_L)}.$$

6.5 *Proof of Proposition 2*

Profit $\pi_{PE}^{H,R}$ is in the proof of Lemma 3, and

$$\pi_{CI}^{L,R} = (2+\delta)\frac{d(1-c_H)^2}{(1+2d)^2}.$$

Hence, $\pi_{PE}^{H,R} \geq \pi_{CI}^{H,R}$ for all $d < d_5$; where $d_5 \equiv \frac{(c_H-c_L)(1-c_L)}{(1-c_H)[\delta+(2-\delta)c_H-2c_L]}$. In addition,

$$\pi_{PE}^{H,R} - \pi_{CI}^{H,R} = \frac{d\delta - d(2-\delta)c_H^2 - c_L\left(2d-1+c_L\right) + c_H(2d(1-\delta) - 1 + (1+2d)c_L)}{(1+2d)^2}$$

Differentiating with respect to d, and solving for d yields

$$d = \frac{(2-\delta)c_H^2 - \delta + 6c_L - 4c_L^2 - 2c_H(3-\delta-c_L)}{2(1-c_H)\left[(\delta-2)c_H + 2c_L - \delta\right]} \equiv d_5.$$

6.6 *Proof of Corollary 1*

Profit difference $\pi_{PE}^{H,R} - \pi_{CI}^{H,R}$ is given in the proof of Proposition 2. Since

$$\begin{aligned}\pi_{PE}^{H,NR} &\equiv \left(1-q^L\right)q^L - c_H \cdot q^L + \delta\frac{(1-c_H)^2}{4} \\ &= \frac{1+\delta(1+c_H^2 - 2c_H(1+\delta-c_L) - c_L^2)}{4}\end{aligned}$$

and $\pi_{CI}^{H,NR} = \frac{(1-c_H)^2}{4} + \delta\frac{(1-c_H)^2}{9}$, then

$$\pi_{PE}^{H,NR} - \pi_{CI}^{H,NR} = \left[\frac{1+\delta(1+c_H^2 - 2c_H(1+\delta-c_L) - c_L^2)}{4}\right] - \left[\frac{(1-c_H)^2}{4} + \delta\frac{(1-c_H)^2}{9}\right]$$

Hence, $\pi_{PE}^{H,R} - \pi_{CI}^{H,R} \geq \pi_{PE}^{H,NR} - \pi_{CI}^{H,NR}$ for all $d \in [d_6, d_6']$, where

$$d_6 \equiv \frac{D}{\varphi-\psi} + \frac{1}{\varphi-\psi}\left[4\delta + (4\delta-9)(c_H-2)c_H + 9(c_L-2)c_L)^2 - (\varphi-\psi)E\right]^{1/2}$$

and

$$d_6' \equiv \frac{-D}{\varphi-\psi} + \frac{1}{\varphi-\psi}\left[4\delta + (4\delta-9)(c_H-2)c_H + 9(c_L-2)c_L)^2 - (\varphi-\psi)E\right]^{1/2}$$

where $\varphi = 5\delta + (5\delta-9)c_H^2$, $\psi = 2c_H(5\delta-9c_L) + 9c_L^2$, $D \equiv 9(c_H-c_L)(c_H+c_L-2) - 4\delta(1-c_H)^2$, and $E \equiv \varphi + 9c_L(3c_L-4) - 2c_H(9c_L+5\delta-18)$. ■

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