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 actually larger when regulation is present than absent. We show that, contrary to common belief, inefficient firms may lobby in favor of environmental regulation. This result arises if production is especially polluting, implying that firms are subject to stringent policies. In particular, regulation can help firms reduce their mimicking effort, more easily concealing their relative inefficiency from potential rivals and deter entry. We also examine whether these results are affected by the information accuracy of regulators, demonstrating that firms may obtain larger profits when a regulator are well, rather than poorly, informed about their production costs.

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

JEL classification: D82, H23, L12, Q5
1 Introduction

Media often provide countless environmental reports raising awareness of the damaging effects of pollution, its future impact, and suggesting the need to set more stringent environmental policies to curb pollution. These policy recommendations, however, face the concern from large groups of citizens, who fear that stricter regulations could hinder profits, ultimately affecting employment. Our paper shows that, while such a concern is granted under settings of complete information, it is not necessarily valid under incomplete information contexts. In particular, we demonstrate that profits can actually increase when pollution becomes more severe and, as a consequence, regulatory authorities react setting a more stringent environmental policy. Therefore, under certain conditions pollution and regulation can become profit enhancing.

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. The incumbent’s output generates an environmental externality that the regulator seeks to correct with the use of emission fees. While the regulator does not perfectly observe the incumbent’s costs, he has access to more accurate information than the potential entrant does, as regulator and incumbent have interacted in previous periods. In this incomplete information setting, the regulator must set a first-period emission fee on the incumbent, who responds 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.

In this context, Espinola-Arredondo and Munoz-Garcia (2014) show the existence of a separating (pooling) equilibrium where the incumbent and regulator cooperate in order to convey (conceal, respectively) the incumbent’s type to the potential entrant, thus deterring entry. While the authors examine under which conditions these equilibria can be sustained, and in which contexts incomplete information becomes welfare improving, their analysis is silent about firms’ incentives along several dimensions: Are firms’ profits larger when environmental regulation is present or absent? Is this answer sensitive to the information context in which firms operate? And, are firms better off when the regulator has access to more accurate information about their production costs?

In our study, we first analyze the efficient firm’s output decision in the separating equilibrium of the game. In particular, this 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 sufficiently large “separating effort” that cannot be profitably mimicked by the inefficient type of firm. While such effort can be large in models where regulation is absent, we show that environmental policy can help in reducing it. Hence, the introduction of environmental regulation gives rise to two opposite effects on profits: on one hand, it yields a negative effect, as firms are forced to reduce their output level; an effect that emerges under all information contexts. However, it also produces a positive effect when firms operate under incomplete information, as fees facilitate the incumbent’s information transmission (reducing its separating effort). Comparing the relative size of both effects, we show that the positive effect dominates when pollution is sufficiently damaging, and thus fees are strict enough. As a consequence, stringent regulation can become profit enhancing.
under incomplete information settings.¹

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. The opposite argument applies when pollution is relatively small. If, instead, the environmental damage of pollution is intermediate, profits are non-monotonic in the regulator’s information accuracy. In this context, firms would prefer regulators that have some information about its production costs, rather than being fully informed or uninformed.

Third, we examine whether the presence of regulation affects the incentives of the inefficient incumbent to mimic the output decision of the efficient type of firm. In particular, this firm overproduces relative to complete information in order to conceal its type from the potential entrant and thus deter entry. A natural question is then whether environmental regulation helps the incumbent reduce its overproduction effort. 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, regulatory agencies can expect support for environmental policies from the most unexpected ally: inefficient firms which, in addition, are especially polluting. Intuitively, stringent regulation would facilitate the mimicking effort that they must exert in order to conceal their costs from potential competitors. 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; and by firms developing new products whose costs are difficult to assess by regulators and potential entrants, such as the chemical company DuPont and the injection modeling systems company Husky. For instance, during 2009 alone, DuPont filed more than 2,000 U.S. patents affecting both its products and production processes. As a consequence, a new rival considering joining one of the industries in which DuPont operates would face a significant uncertainty about DuPont’s real production costs. A similar argument applies to Husky, which filed 65 U.S. patents in the 2012-13 period.²

¹An analog argument applies to the pooling equilibrium, where emission fees lower the output level that the inefficient firm seeks to imitate, thus facilitating its mimicking effort.
²Maloney 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.
1.1 Related literature

*Porter hypothesis.* Previous literature analyzed settings in which environmental regulation produces a positive effect on profits under contexts of complete information, a research question often referred to as the “Porter hypothesis,” after Porter (1991) and Porter and van der Linde (1995a,b) who examine under which conditions environmental policies can trigger innovation and ultimately increase profits. In a similar study, Farzin (2003) analyzes firms’ incentives to improve product quality as a response to more stringent environmental policies, which boosts demand, and ultimately profits. Still under a complete information model, Schoonbeek and de Vries (2009) examine the role of environmental regulation in deterring entry, identifying settings in which the incumbent firm favors emission fees that would deter entry of potential rivals under the same or larger conditions than the regulator does. Our paper shows that, in a context of incomplete information, firms can still support regulation when the motives analyzed by the literature are absent, i.e., even when product quality or innovation are unaffected by regulation. Specifically, a firm favors emission fees when they facilitate its signaling ability, i.e., conveying or concealing information from potential rivals.

*Entry deterrence and regulation.* 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.

As described in the introduction, our paper builds on signaling models in which the uninformed entrant observes several signals, each of them originating from different agents, infers the production costs of the incumbent firm, and then decides whether to join the industry. 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, i.e., when they sell complementary products. Similarly, EM (2013, 2014), 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.\(^3\) While EM (2014) 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

\(^3\) 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.
informed regulation can become profit enhancing.\textsuperscript{4}

The following section describes the model. Section 3 examines a setting under which only the
separating equilibrium arises in the incomplete information game, and compares profits in this
context against two benchmarks: complete information and no regulation. Section 4 then provides
a similar profit comparison but in the case in which only a pooling equilibrium emerges under
incomplete information. Section 5 discusses the implications of our results and concludes.

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 potential entrant
are high, \( c_H \), and under complete information would only enter the industry when the incumbent’s
costs are also high, but stay out otherwise.\textsuperscript{5} The production of all firms generates an environmental externality that the regulator addresses by setting emission fees, i.e., he imposes a fee \( t_1 \) per unit of output in order to maximize the social welfare function

\[
SW(q) = CS(q) + PS(q) + T_1 - ED(q)
\]

where \( CS(q) \) and \( PS(q) \) denote consumer and producer surplus, respectively; \( T_1 \equiv t_1 q \) represents
tax revenue; and \( ED(q) \) is the environmental damage from pollution, \( ED(q) \equiv dq^2 \) where \( d > 1/2 \)
which guarantees that emission fees are positive under all information contexts. (Emission fees are,
therefore, revenue neutral.)

The regulator can be perfectly informed about the incumbent’s costs, as poorly informed as
the potential entrant is, or partially informed. In particular, the regulator assigns a belief \( p^\beta \) to
the incumbent’s costs being high, where parameter \( \beta \in [0, +\infty) \) reflects the degree of information
accuracy that the regulator enjoys relative to the entrant. In particular, if the regulator initially
believes that the incumbent’s costs are high, \( p > 1/2 \), then the information provided in the report
(and captured in parameter \( \beta \) ) can give rise to three cases: (1) the regulator emphasizes his initial
prior about the incumbent’s costs being high, i.e., \( p^\beta > p > 1/2 \), which occurs when \( \beta \in [0,1] \);
(2) the regulator moderates his initial belief, i.e., \( p > p^\beta \geq 1/2 \);\textsuperscript{6} or (3) the regulator believes

\textsuperscript{4}EM (2013) considers a signaling model in which the regulator perfectly observes the incumbent’s costs and, as a
consequence, the only uninformed agent is the potential entrant. In contrast, EM (2014) 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.

\textsuperscript{5}This is a common assumption in the literature analyzing entry-deterring practices when regulation is absent,
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 environmental policy.

\textsuperscript{6}This case emerges when parameter \( \beta \) satisfies \( \beta \in \left( 1, \frac{\ln 1/2}{\ln p} \right) \), where the upper bound of this interval, \( \beta = \frac{\ln 1/2}{\ln p} \),
that the incumbent’s costs are actually low, i.e., \( p > 1/2 > p^3 \), which arises when \( \beta \) is sufficiently large, i.e., \( \beta > \frac{\ln 1/2}{\ln p} \). The above cases include extreme settings such as that in which \( \beta = 0 \), and thus the regulator is certain about facing a high-cost incumbent, i.e., \( p^3 = 1 \); that where \( \beta = 1 \), implying that he is as poorly uninformed about the incumbent’s type as the potential entrant is; and that in which \( \beta \to \infty \), entailing that the regulator is sure about facing a low-cost incumbent, i.e., \( p^3 = 0 \). (A similar argument applies to the case in which the regulator initially believes that the incumbent’s costs are low, i.e., \( p < 1/2 \).) In the second stage of the game, firms compete a la Cournot if entry occurs, and the incumbent maintains its monopolistic position if entry is deterred. Production is still polluting, and thus the regulator sets emission fees in order to maximize social welfare.

Summarizing, the time structure of the game is as follows: (1) the incumbent firm 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, potentially operating under incomplete information about this firm’s costs since \( p^3 \) can be strictly different from 0 and 1; (3) the \( K \)-type incumbent responds to the fee \( t_1 \) by choosing an output level \( q^K(t_1) \) that maximizes its monopoly profits; (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 the industry; (5) the regulator sets emission fees either on the incumbent alone (if entry did not occur) or on both firms (if entry ensued); and (6) firm/s respond by simultaneously and independently selecting their output level.\(^7\)

**Complete information.** 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 \( SW(q) \), i.e., \( q_{SO}^K = \frac{1-c_K}{1+2d} \). Anticipating the incumbent’s output function \( q^K(t_1) \), the regulator sets an emission fee \( t_1^K = (2d - 1)\frac{c_K}{1+2d} \) which induces \( q_{SO}^K \), i.e., \( t_1^K \) solves \( \frac{1-c_K-t_1^K}{2} = \frac{1-c_K}{1+2d} \). A similar analysis applies if no entry ensues in the second period, where the same fee is still optimal. If, instead, two firms compete a la Cournot in the second period, every firm \( i \) produces according to output function \( q_i^K(t_2) = \frac{1-2c_i+c_j-t_2}{3} \) where \( j \neq i \). In this context, the regulator induces the aggregate socially optimal output \( q_{SO}^K \), by setting a fee that solves \( q_i^K(t_2) + q_j^K(t_2) = q_{SO}^K \).

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\(^7\)The potential entrant does not observe the value of \( \beta \) at the beginning of the game, but sustains a prior that assigns full probability to \( \beta = 1 \), i.e., \( p^3 = p \). After observing the regulator’s emission fee and the incumbent’s output 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 \( \beta \) unaffected. For a more detailed discussion of belief updating when the potential entrant observes two signals, see EM (2014).
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; a result demonstrated by 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 pollution. In particular, as shown in EM (2013, 2014), a separating equilibrium can be sustained when the entrant’s priors are sufficiently high and when the low-cost incumbent anticipates that competition in the post-entry game would be tough, i.e., \( c_H < \frac{\sqrt{3d+1/(2d)}c_L}{\sqrt{3d+1/(2d)}} \). In such an equilibrium, the low-cost firm increases its output function, from \( q^L(t_1) = \frac{1-c_L-t_1}{2} \) under complete information to \( q^A(t_1) = \frac{(1-c_H)(1+2d)-\sqrt{3d} - 1+2d}{2} t_1 \), where \( \delta \) denotes the discount factor. The regulator, anticipating output function \( q^A(t_1) \), sets an emission fee

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

which yields an output level \( q^A(t_1^*) = \frac{2 + p^3 \sqrt{3d} - p^3(2 + \sqrt{3d}) c_H - 2(1 - p^3) c_L}{2(1 + 2d)} \) in equilibrium. Hence, the firm increases its output level from \( q^L(t_1^L) = \frac{1-c_H}{1+2d} \) to \( q^A(t_1^*) \), where the 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, \( \beta \). (Since the high-cost incumbent and the regulator behave as under complete information, we focus on examining output and profits for the low-cost incumbent as well as the regulation that this firm faces.)

Lemma 1. The low-cost firm’s separating effort, \( q^A(t_1^*) - q^L(t_1^L) = \frac{p^3 \sqrt{3d(1-c_H) - 2(c_H-c_L)}}{2(1 + 2d)} \), is nil when the regulator is perfectly informed about the incumbent’s costs being low, \( \beta \to \infty \) (i.e., \( p^3 \to 0 \)), but positive otherwise.

Hence, the low-cost firm increases its output function from \( q^L(t_1) = \frac{1-c_L-t_1}{2} \) to \( q^A(t_1) \) in order to convey its type to the potential entrant. When the regulator is perfectly informed about the incumbent’s costs being low, i.e., \( \beta \to \infty \), he anticipates an increase in output (and pollution), and sets a more stringent fee than under complete information, \( t_1^A > t_1^L \), in order to curb the additional pollution. In this setting, the regulator can still induce the socially optimal output \( q^L(t_1^L) = q^{SO}_L \). In particular, the separating effort measuring the increase in output levels from complete information to the separating equilibrium, i.e., \( q^A(t_1^*) - q^L(t_1^L) \), depicted in figure 1, is nil when the regulator is perfectly informed about the incumbent’s low costs.\(^8\) When his information becomes less accurate,\(^8\) For simplicity, figure 1 considers costs \( c_H = 1/3, c_L = 1/4 \), and no discounting of future payoffs. These cost parameters allow for the separating equilibrium to arise, i.e., \( c_H < \frac{\sqrt{3d+1/(2d)}c_L}{\sqrt{3d+1/(2d)}} \). For our numerical example such inequality becomes \( \frac{1}{\delta} < \frac{4\sqrt{3d+1/(2d)}}{4\sqrt{3d+1/(2d)}} \), which holds for all \( d > \frac{1}{2} \). Other parameter combinations yield similar results and can be provided by the authors upon request.
however, the regulator assigns a positive probability to the incumbent’s costs being high, thus setting a less stringent fee. Such a laxer fee makes the output decision of the low-cost firm easier to mimic by the high-cost type and, as a consequence, forces the former to increase its output in order to more effectively signal its type to potential entrants. In summary, a less accurately informed regulation and, hence, a less stringent fee, leads to an increase in the low-cost firm’s separating effort; as illustrated by leftward movements in figure 1 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 $q^A(t^A_1)$ and $q^L(t^L_1)$. (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.)

Therefore, a less informed regulator (lower $\beta$) entails a less stringent environmental policy (positive effect on profits) but it also gives rise to a negative effect since such lax fee forces the low-cost firm to exert a more intense separating effort if it seeks to convey its type. The next lemma identifies under which parameter conditions the positive effect on profits dominates its negative effect.

**Lemma 2.** The equilibrium profits of the low-cost incumbent in the separating equilibrium, $\pi^{L,R}_{SE}(\beta)$, increase in $\beta$ for all $\beta < \beta_1$, but decrease otherwise; where cutoff $\beta_1 \equiv \frac{1}{\ln p} \ln \frac{(1-2d)(1-c_L)}{4-\sqrt{3}(1-c_L)^2}$. In addition, the degree of information accuracy at which the profits of the low-cost firm reach its maximum, cutoff $\beta_1$, satisfies $\beta_1 > 0$ for all $d < d_1 \equiv \frac{1-\sqrt{3}(1-c_L)-2c_H+c_L}{2(1-c_L)}$, and decreases in $d$.

Figure 2a depicts the equilibrium profits that the low-cost incumbent obtains in the separating
equilibrium (SE) as a function of the regulator’s information accuracy, β. In particular, the figure illustrates the non-monotonicity of profits with respect to β; namely, the incumbent obtains a higher profit with a regulator who is not perfectly informed about its type (e.g., β = 2 in figure 2a) than with a perfectly informed regulator (β → ∞). In this setting, a regulator with less accurate information (small decrease in β) entails a positive effect on profits (namely, less stringent regulation) which dominates its negative effect, since the emission fee is still sufficiently strict to deter the high-cost incumbent from mimicking the output decision of the low-cost firm. As a consequence, profits of the low-cost incumbent increase. Further reductions in information accuracy do not necessarily increase profits but, instead, lower them. Specifically, when β < β₁ (for instance β = 1), a decrease in β helps the high-cost firm to easily mimic the low-cost incumbent’s output. As a result of the large separating effort that the low-cost incumbent must exert, relative to complete information, its overall profits are actually damaged by a less informed regulator who sets a laxer regulation.

![Fig 2a. Profits in the SE when d = 0.75.](image1)

![Fig 2b. Profits in the SE under different values of d.](image2)

Figure 2b depicts how the previous results are affected by variations in the environmental damage, d. Specifically, when d is relatively low, e.g., d = 0.6, a regulator with less accurate information (leftward movement in the figure) produces a monotonic decrease in the incumbent’s profits for all values of β; as opposed to the setting in figure 2a in which profits are non-monotonic in β. Indeed, when d = 0.6 in figure 2b, the emission fee that the regulator would set even if he was perfectly informed about the incumbent’s low costs (when β → ∞) would be relatively lax. Hence, further reductions in such emission fee attract the high-cost firm to mimic, ultimately requiring a large separating effort from the low-cost incumbent which, consequently, reduces its profits. In contrast, when pollution becomes more damaging, e.g., d = 1.5, emission fees are more stringent.

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9In order to facilitate comparisons, figure 2a (and all subsequent figures) use the same parameter values as in figure 1, i.e., \( c_H = 1/3 \), \( c_L = 1/4 \), and no discounting.
In this context, a regulator with access to less accurate information entails a reduction in emission fees which cannot be easily mimicked by the high-cost firm, thus yielding a positive effect on the incumbent’s profits which dominate its small negative effect (i.e., profits are now monotonically increasing as $\beta$ decreases).\footnote{In particular, for the parameter values considered in figure 2b, cutoff $d_3$ from Lemma 2 becomes $d_3 = 1.15$; thus implying that the peak of the incumbent’s profit function, $\beta_1$, occurs in the negative quadrant for all $d > 1.15$.}

In summary, efficient firms would prefer environmental agencies having access to less reliable information about its costs when pollution is damaging, e.g., $d = 1.5$; but would favor agencies as accurately informed as possible when pollution generates a small environmental deterioration, e.g., $d = 0.6$. Otherwise, in the last context, the incumbent would need to exert a larger separating effort to convey its type and deter entry. Hence, a well-informed regulator facilitates the incumbent’s entry-deterring strategy. Finally, when the damage associated to pollution is intermediate, efficient firms would prefer relatively uninformed regulators, rather than a regulator who assigns full probability to the firm’s costs being either low (perfectly informed regulator) or high (totally uninformed regulator).

Let us next compare the incumbent’s profits in the separating equilibrium against those in complete information.

**Proposition 1.** Under a context of environmental regulation, the profits of the low-cost incumbent are weakly higher under the separating equilibrium (SE) than under complete information (CI), i.e., $\pi_{SE}^{L,R}(\beta) \geq \pi_{CI}^{L,R}$, if and only if $\beta \geq \beta_2$, where $\beta_2 \equiv \frac{1}{\ln p} \ln \frac{2(1-2d)}{4-d(1-c_H)}$. In addition, cutoff $\beta_2$ is positive for all $d \geq d_2 \equiv \frac{2+\sqrt{3\beta}}{4(1-c_L)}$.

The difference between the profits in the SE and CI contexts, measured as the benefit of operating under incomplete information $BII_{L,R}(\beta) \equiv \pi_{SE}^{L,R}(\beta) - \pi_{CI}^{L,R}$, is depicted in figure 3. Let us first consider this benefit under the same environmental damage as in figure 2a, $d = 0.75$. Our results indicate that, while the incumbent prefers to operate under CI when the regulator is poorly informed ($\beta < \beta_2$), it would prefer to interact in the SE when the regulator’s information becomes more accurate ($\beta \geq \beta_2$).\footnote{Cutoff $\beta_2$ in this parametric example becomes $\beta_2 = 0.39$ since $d = 3/4$.} Alternatively, starting from $\beta \to \infty$ where $\pi_{SE}^{L,R}(\beta) = \pi_{CI}^{L,R}$, a marginal decrease in $\beta$ entails a positive effect on profits that dominates its negative effect, thus yielding $\pi_{SE}^{L,R}(\beta) > \pi_{CI}^{L,R}$. Further reductions in $\beta$, however, entail a less stringent emission fee, and a easier to mimic production, ultimately generating a large negative effect that offsets its positive effect, i.e., $\pi_{SE}^{L,R}(\beta) < \pi_{CI}^{L,R}$, when $\beta < \beta_2$. 
In addition, figure 3 plots the benefit of operating under incomplete information contexts for different values of $d$, indicating that, as the environmental damage increases, $\pi_{SE}^{L,R} (\beta) \geq \pi_{CI}^{L,R}$ holds under a wider range of $\beta$, i.e., for a more varied degree of information accuracy. Intuitively, when pollution is extremely damaging the regulator sets stringent emission fees, entailing that the first (positive) effect of a regulator with less accurate information, i.e., laxer emissions, dominates the second (negative) effect, as the high-cost firm cannot profitably mimic the production decision of the efficient type of incumbent.\textsuperscript{12} Our findings hence show that, when regulation is present, the efficient firm can be better off under incomplete than complete information settings. Importantly, this result contrasts with that when regulation is absent, whereby the efficient firm is unambiguously worse off in the SE than in CI; see Milgrom and Roberts (1982).\textsuperscript{13}

### 3.1 Profit comparisons in the separating equilibrium

In the remainder of this section, we explore two types of profit comparisons: first, for a given regulatory setting, we evaluate whether the incumbent’s profits are larger when operating under incomplete or complete information (a comparison started above), and whether such profit difference is larger when regulation is present or absent. Table I summarizes our profit comparisons where, fixing the regulatory setting (in rows), we compare profits across different information contexts (in columns). Second, for a given information structure, we analyze whether the incumbent’s profits are larger with than without regulation (row $A$), thus driving the firm to actually favor the introduction of emission fees; and then investigate whether such profit difference is larger when

\textsuperscript{12}Specifically, for our numerical example, the profit gain from the SE is positive for all information accuracies $\beta$, i.e., $\pi_{SE}^{L,R} (\beta) \geq \pi_{CI}^{L,R}$ for all $\beta$, if $d \geq d_2$, where $d_2$ is 0.82.

\textsuperscript{13}When environmental regulation is almost negligible, $d = 0.51$ whereby 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 $\beta$, i.e., $BII_{R,L}^{SE} (\beta) < 0$, resembling that in standard entry-deterring models where regulation is absent.
firms operate in a complete or incomplete information context.

<table>
<thead>
<tr>
<th>Regulatory setting</th>
<th>Regulation</th>
<th>No regulation</th>
<th>(A) Benefits from regulation, BR</th>
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<tr>
<td></td>
<td>$\pi_{SE}^{L,R}$</td>
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<td>$\pi_{CI}^{L,R}$</td>
<td>$\pi_{CI}^{L,NR}$</td>
<td>$\pi_{CI}^{L,R} - \pi_{CI}^{L,NR}$</td>
</tr>
</tbody>
</table>

Table I. Profit comparisons under high priors

The next corollary identifies under which conditions incomplete information yields a profit gain for the low-cost incumbent, as described in the first type of comparisons in column B, and whether such profit gain is larger when regulation is present than absent.

**Corollary 1 (Complete vs. Incomplete information).** When environmental regulation is absent, the low-cost incumbent obtains a lower profit under incomplete than complete information, i.e., $BII_{L,NR} < 0$, for all parameter values. When regulation is present, the benefit of operating under an incomplete information context, $BII_{L,R}(\beta)$, is larger than that when regulation is absent, $BII_{L,NR}$, if and only if the regulator’s accuracy of information satisfies, $\beta > \beta_3$. (See appendix for the expression of cutoff $\beta_3$.)

Figure 4 depicts cutoff $\beta_2$ from Proposition 1, and cutoff $\beta_3$ from Corollary 1. In particular, the region of $(\beta, d)$-pairs above $\beta_2$ indicate settings in which incomplete information is beneficial for the low-cost firm, i.e., $\pi_{SE}^{L,R}(\beta) \geq \pi_{CI}^{L,R}$; as illustrated in region A. For parameter values below cutoff $\beta_2$, by contrast, incomplete information lowers profits. In addition, the area above $\beta_3$ represents $(\beta, d)$-pairs for which $BII_{L,R}(\beta)$ is larger than $BII_{L,NR}$. In words, when regulation is present, the profit gain that the efficient firm experiences from operating under incomplete rather than complete information, $BII_{L,R}(\beta)$, is larger than that under no regulation, $BII_{L,NR}$, for all $\beta > \beta_3$, which thus arises for most $(\beta, d)$-pairs (regions A and B), as depicted in figure 4.
Finally, let us examine the incentives of the efficient firm to favor or oppose the introduction of environmental regulation under different information contexts (see row A of Table I).

**Corollary 2 (Benefits from regulation).** *Introducing environmental policy under CI entails an unambiguous reduction in profits for the low-cost firm, i.e., \( BR_{CI}^L \equiv \pi_{CI}^{L,R} - \pi_{CI}^{L,NR} < 0 \). In contrast, regulation has a positive effect on profits in the SE, i.e., \( BR_{SE}^L(\beta) \equiv \pi_{SE}^{L,R}(\beta) - \pi_{SE}^{L,NR}(\beta) > 0 \), as long as the regulator’s accuracy of information satisfies \( \beta > \beta_4 \). (See appendix for the expression of cutoff \( \beta_4 \)).*

Hence, under CI the efficient firm is negatively affected by the introduction of regulation, i.e., \( BR_{CI}^L(\beta) < 0 \), for all parameter values. However, under the SE, regulation can become profit enhancing if the regulator’s information is sufficiently accurate, \( \beta > \beta_4 \). Intuitively, while under CI the introduction of emission fees only entails a negative effect on profits, under SE they also give rise to a positive effect. In particular, in the SE the low-cost firm needs to exert a smaller separating effort when the regulator is present than absent (i.e., emission fees hinder the high-cost incumbent’s ability to mimic). When the regulator’s information is relatively accurate, i.e., \( \beta > \beta_4 \), emission fees become sufficiently stringent to deter the high-cost firm from imitating the low-cost incumbent, ultimately facilitating the former’s entry-deterring strategy relative to settings without regulation.

**4 Pooling equilibrium**

When priors are sufficiently low, EM (2014) show that a pooling equilibrium (PE) can be sustained in which the high-cost incumbent mimics the output function of the low-cost firm, thus increasing
it from $q^H(t_1)$ under CI to $q^L(t_1)$ under the PE. In this setting, the regulator supports such concealing strategy of the high-cost incumbent increasing its emission fee from $t^H_1$ under CI to $t^L_1$ under the PE. As a consequence, this firm’s output level increases from $q^H(t^H_1)$ to $q^L(t^L_1)$, where $q^L(t^L_1) = \frac{1-c_L}{1+2d} > \frac{1-c_H}{1+2d} = q^H(t^H_1)$ since $c_L < c_H$ by assumption, and thus its mimicking effort is given by the output difference $q^L(t^L_1) - q^H(t^H_1) = \frac{c_H - c_L}{1+2d}$. In particular, for the pooling equilibrium 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 in order to deter entry must be small. Let us next evaluate the equilibrium profits that, under a context of environmental regulation, the high-cost firm obtains in the PE. (Since the low-cost incumbent and the regulator select the same strategies under PE and CI, our subsequent analysis focuses on the high-cost firm and the regulation it faces.)

**Lemma 3.** The profits that the high-cost incumbent obtains under the pooling equilibrium (PE) with regulation, $\pi^{H,R}_{PE}$, are independent on the regulator’s degree of information accuracy, $\beta$. In addition, $\pi^{H,R}_{PE}$ are increasing in environmental damages, $d$, for all $d < d^4$, but decreasing otherwise; where $d^4 = \frac{1+\delta(1-c_h^2)+c_h(1-2\delta-c_l)+c_l(2c_l-3)}{2(1-c_h)(1+\delta-\beta c_h-c_l)}$.

First, note that the profits of the high-cost incumbent do not depend on $\beta$, since in the PE the regulator mimics the emission fee he would set on the efficient firm, $t^L_1$, and the incumbent responds by also mimicking its output function, $q^L(t^L_1)$, thus yielding an output level $q^L(t^L_1)$ which is independent on $\beta$. In addition, lemma 3 identifies that profits under PE, $\pi^{H,R}_{PE}$, are non-monotonic with respect to the environmental damage of pollution, $d$, which arises because an increase in $d$ yields two opposite effects on profits: a negative effect, arising from a more stringent fee; and a positive effect, since such strict fee reduces the output level that the high-cost firm seeks to mimic, $q^L(t^L_1)$, thus becoming easier to imitate. Since the mimicking effort is $q^L(t^L_1) - q^H(t^H_1) = \frac{c_H - c_L}{1+2d}$, the positive effect of regulation is captured by the fact that such output difference shrinks as $d$ increases, and at a decreasing rate; as depicted in figure 5a. As a consequence, the positive effect of an increase in $d$ (i.e., the reduction in the inefficient firm’s mimicking effort) is initially large, thus dominating its negative effect; see region where overall profits increase for all $d < d^4$ in figure 5b. Such positive effect, however, decreases as $d$ is further augmented, thus being offset by the negative effect, ultimately reducing profits for all $d \geq d^4$; as illustrated in the right-hand side of figure 5b.

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14 The regulator’s information accuracy, $\beta$, affects however his willingness to help the high-cost incumbent in its concealing strategy. In particular, as shown in EM (2014), 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 $t^L_1$ on a firm which could possibly have high production costs.
Proposition 2. The profits of the high-cost incumbent under the PE are larger than under CI, i.e., \( \pi_{PE}^{H,R} \geq \pi_{CI}^{H,R} \), for all parameter values under which the PE can be sustained. In addition, the profit difference \( \pi_{PE}^{H,R} - \pi_{CI}^{H,R} \) is increasing in environmental damages, \( d \), for all \( d < d_6 \), but decreasing otherwise; where \( d_6 = \frac{(2-\delta)c_H^2-\delta+6c_L-4c_L^2-2c_H(3-\delta-c_L)}{2(1-c_H)(\delta-2)c_H+2c_L-\delta} \).

Our results when regulation is present, hence, go in line with those in standard entry-deterrence models where regulation is absent, which predicts that the high-cost firm has incentives to behave as prescribed in the PE if its profits from concealing information (and thus deter entry) are larger than its profits under CI; whereby the firm chooses output level \( q^H = \frac{1-c_H}{2} \) and entry ensues. Our findings in Proposition 2 also examine the profit difference \( \pi_{PE}^{H,R} - \pi_{CI}^{H,R} \), which measures the benefit from operating under incomplete, rather than complete, information. Alternatively, this difference can be interpreted as the gain in profits that the high-cost firm obtains from deterring entry under the PE (which is not observed in CI). In particular, such profit gain is increasing in the environmental damage for low values of \( d \); as depicted in figure 6 for \( d < d_6 \). In particular, as described above, the positive effect of more stringent regulation (i.e., easier to mimic production) outweighs its negative effect, but only when \( d \) is sufficiently low. Otherwise, its negative effect dominates and the profit difference shrinks.
4.1 Profit comparisons in the pooling equilibrium

A natural question is hence: Does the introduction of environmental regulation provide firms with further incentives to deter entry or, instead, reduce such entry-deterrence motive? The following corollary compares these incentives in the PE, measured by the $BII$ expression with and without regulation. (The remainder of this section thus follows a similar profit comparison as Table I, but applied to the PE.)

**Corollary 3 (Complete vs. Incomplete information).** The benefits from operating under incomplete information for the high-cost incumbent when environmental regulation is present, $BII_{H,R} = \pi_{PE}^{H,R} - \pi_{CI}^{H,R}$, are larger than when regulation is absent, $BII_{H,NR} = \pi_{PE}^{H,NR} - \pi_{CI}^{H,NR}$, for all $d \in (d_7, d_0)$. (See appendix for the expression of cutoffs $d_7$ and $d_0$.)

As depicted in figure 7a, the benefits from deterring entry are larger without than with regulation when environmental damages are relatively low, i.e., $BII_{H,NR} > BII_{H,R}$ for all $d < d_7$. Intuitively, emission fees are less stringent under low values of $d$, which implies that the high-cost incumbent must significantly increase its output in order to mimic the production decision of the low-cost firm; a similar increase in output to that in models where regulation is absent. As a consequence, the positive effect of regulation (i.e., facilitating the incumbent’s mimicking effort) is small, and it is offset by the negative effect of emission fees on profits; ultimately yielding a larger benefit from deterring entry when regulation is absent than when he is present.
However, when pollution is more damaging, $d > d_7$, emission fees become stringent, thus reducing the output level that the incumbent seeks to imitate. In this case, regulation facilitates the incumbent’s mimicking effort, thus yielding a larger benefit from deterring entry when regulation is present, i.e., $BII^{H,R} > BII^{H, NR}$ for $d > d_7$. Nonetheless, when environmental damages are further increased, $d > d_7$, emission fees become so stringent that the high-cost incumbent would prefer exerting the standard mimicking effort in the absence of regulation than be subject to such a strict policy, i.e., $BII^{H, NR} > BII^{H,R}$.

Figure 7b examines how the previous ranking in the $BII$s are affected by a decrease in the incumbent’s costs, from $c_H = 0.45$ in figure 7a to $c_H = 0.33$ in figure 7b. In particular, a more efficient incumbent would exert a smaller mimicking effort since its cost differential with respect to the low-cost firm shrunk. The positive effect of regulation (i.e., reduction in the inefficient firm’s mimicking effort) is thus now smaller, implying that the negative effect dominates. As a consequence, in this setting the benefit from deterring entry is larger when regulation is absent, i.e., $BII^{H, NR} > BII^{H,R}$ for all values of $d$.

Finally, we evaluate whether the introduction of environmental regulation is more beneficial for the incumbent when operating under complete or incomplete information settings.

**Corollary 4 (Benefits from regulation).** Under CI, environmental regulation increases the profits of the high-cost incumbent, i.e., $BR_{CI}^{H} \equiv \pi_{CI}^{H,R} - \pi_{CI}^{H, NR} > 0$, if and only if $d > d_8$, where $d_8 \equiv \frac{9+5\delta+3(\delta(2+\delta))^{1/2}}{18+8\delta}$. Under PE, regulation increases the incumbent’s profits, i.e., $BR_{PE}^{H} \equiv \pi_{PE}^{H,R} - \pi_{PE}^{H, NR} > 0$, as long as environmental damages satisfy $d > d_9$, where $d_9 \equiv \frac{1+\delta(1+c_H^2) + 2c_H(1-\delta-c_L) - c_L(4-3c_L)}{2[1+\delta(1+c_H^2) - 2c_H(1-\delta-c_L) - c_L^2]}$.

Hence, the firm’s profits are larger when regulation is present if pollution is not very damaging, i.e., $BR_{CI}^{H} > 0$ for all $d \leq d_8$ as depicted in figure 8. Intuitively, the introduction of emission fees would produce a unambiguous reduction in the incumbent’s profits if it remained a monopolist...
during all time periods. The incumbent, however, experiences entry of a competitor in the second period in the case of CI. In this setting, a small emission fee (such as those when $d < d_8$) entails a reduction in aggregate duopoly output, ultimately increasing the incumbent’s overall profits above those when the regulator is absent. In contrast, when environmental damages are sufficiently large, $d > d_8$, and thus emission fees are stringent, the high-cost incumbent obtains higher profits if regulation is absent, i.e., $BR^H_{CI} < 0$.

![Fig 8. Benefits from regulation under CI and PE.](image)

Under an incomplete information context, a similar argument applies. In particular, when $d < d_9$ environmental regulation is relatively lax, and helps the incumbent decrease the output level $q^L(t_1^L)$ that it must produce in the PE, thus facilitating its mimicking effort. In this case, the firm is better off with than without regulation, i.e., the high-cost firm would actually favor the introduction of environmental policy. In contrast, when environmental damages are large, $d > d_9$, the emission fee becomes more stringent, ultimately producing an overall decrease in profits.

5 Discussion and Conclusions

Is pollution good for profits? Our paper demonstrates that profits are not necessarily decreasing in the environmental damage of pollution, $d$. In addition, this result holds both under low and high priors; as depicted in figures 2b for the SE and 5b for the PE. For instance, under a SE, if the regulator is relatively uninformed about the incumbent’s costs, the profits of the low-cost firm are larger when pollution becomes more damaging.\footnote{In the context of figure 2b and for a given $\beta = 0.1$, the incumbent’s profits are larger when $d = 1.5$ than when $d = 0.6$.} Intuitively, a damaging pollution induces a more stringent regulation, which hinders the ability of the high-cost firm to mimic the low-cost incumbent,
thus facilitating its separating effort and increasing profits. Therefore, our results suggest that incumbent monopolists facing an uninformed regulator and operating in very polluting industries would not oppose environmental regulation but, actually, favor it. Such a policy can facilitate their entry-deterring practices, ultimately increasing profits. By contrast, when incumbents operate in not-so-polluting industries they would oppose environmental policies. In particular, emission fees are now lax, thus attracting the high-cost firm to mimic its output level and, as a consequence, produce a negative overall effect on profits.

**Firms do not necessarily prefer uninformed regulators.** At first glance, one may suspect that a regulator with less accurate information is beneficial for a low-cost incumbent, since in this setting the regulator assigns a large probability on the incumbent’s costs being high, and thus sets less stringent emission fees, ultimately increasing its profits. Such a result undoubtedly holds when the incumbent faces no entry threats. However, when entry threats are present, the profits of the low-cost firm are not necessarily monotonic in the accuracy of the regulator’s information. While less precise information still yields laxer emission fees and thus a positive effect on profits, they also give rise to a negative effect: specifically, less stringent fees facilitate the ability of the high-cost firm to mimic the output level of the low-cost incumbent, ultimately forcing the latter to exert a larger separating effort in order to convey its type and deter entry. Comparing the relative size of both effects, we demonstrate that less accurate information produces an overall decrease in the incumbent’s profits when pollution is not very damaging, since in this setting emission fees are lax and output easy to mimic by the high-cost firm. In contrast, when pollution is extremely damaging, profits increase as the regulator becomes less accurately informed, thus following a similar pattern as under no entry threats.

**Supporting emission fees, but only under incomplete information.** Under low priors, we show that firms support environmental regulation (e.g., actively lobbying in their favor) when they interact in incomplete information settings whereby they are threatened by the entry of potential competitors. However, they would unambiguously oppose such fees if, despite facing entry threats, potential entrants are perfectly informed about their relative efficiency. This result can be especially attractive for regulatory agencies seeking support for new emission fees among industry participants: while it is difficult to originate from firms operating in mature industries in which technology and production costs are easily observable by potential entrants, support is likely to emerge from firms developing new products whose costs are more difficult to observe by newcomers.

**Inefficient firms favoring stringent emission fees?** Our findings also illustrate that, when environmental damages are significant, the benefits that inefficient firms obtain from deterring entry are actually larger when regulation is present than absent; see Corollary 3. This yields a rather unexpected prediction: the high-cost firm would actually favor the presence of environmental regulation, but only when pollution is damaging and thus emission fees become sufficiently stringent. In this context, the stringency of environmental regulation helps the inefficient firm reduce the mimicking

\[\]16 However, when the regulator becomes better informed (high values of $\beta$), pollution induces a more significant increase in emission fees, and thus a negative effect on profits which can dominate its positive effect.
effort it must exert to deter entry. In contrast, when pollution is less damaging, emission fees do not significantly affect the mimicking effort, and yield an overall reduction in profits.

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 $q_A(t_1^*) - q_L(t_1^*)$ is positive as long as $c_H < \frac{\sqrt{33} + 2c_L}{\frac{\sqrt{33} + 2}{\sqrt{33} + 2}} \equiv \alpha_A$, a cutoff that originates at $c_H = \frac{\sqrt{33}}{\sqrt{33} + 2}$ when $c_L = 0$ and reaches $c_H = 1$ when $c_L = 1$. Let us now compare cutoff $\alpha_A$ with the set of parameter values under which the separating equilibrium can be sustained, i.e., $c_H < \frac{\sqrt{33} + (1+2d)c_L}{\sqrt{33} + (1+2d)} \equiv \alpha_1$. In particular, cutoff $\alpha_1$ originates at $c_H = \frac{\sqrt{33}}{\sqrt{33} + (1+2d)}$ when $c_L = 0$ and reaches $c_H = 1$ when $c_L = 1$; where the vertical intercepts of these two cutoffs satisfy $\frac{\sqrt{33}}{\sqrt{33} + (1+2d)} < \frac{\sqrt{33}}{\sqrt{33} + 2}$ since $d > 1/2$ by definition. Hence, $\alpha_A > \alpha_1$ implying that, for all parameter values in which the separating equilibrium exists, the output difference $q_A(t_1^*) - q_L(t_1^*)$ is positive, i.e., $q_A(t_1^*) > q_L(t_1^*)$.

Finally, note that such output difference reaches its highest value, $\frac{\sqrt{33}(1-c_H)-2(c_H-c_L)}{2(1+2d)}$, when the regulator believes the incumbent’s costs are high, $\beta = 0$; and collapses to zero when the regulator believes that the incumbent’s costs are low, $\beta \to \infty$. ♦

6.2 Proof of Lemma 2

First-period profits in the SE are

$$ (1 - q_A(t_1^*)) q_A(t_1^*) - c_L \cdot q_A(t_1^*) $$
where output function \( q^A(t_1) \) is \( q^A(t_1) = \frac{(1-c_H)(1+2d)-\sqrt{3d}}{2} - \frac{1+2d}{2} t_1 \), while fee \( t_1^* \) is

\[
t_1^* = \frac{2d - 1 + \sqrt{3}(1 - p^\beta) + \left[ p^\beta (2 + \sqrt{3}) - (1 + 2d) - \sqrt{3} \delta \right] c_H + 2(1 - p^\beta) c_L}{1 + 2d},
\]
as shown in Proposition 1 of EM (2014). Hence, the output level that arises when output function \( q^A(t_1) \) is evaluated at the emission fee \( t_1^* \) is

\[
q^A(t_1^*) = \frac{2 + p^\beta \sqrt{3} - p^\beta (2 + \sqrt{3}) c_H - 2(1 - p^\beta) c_L}{2(1 + 2d)}.
\]

Therefore, first-period profits simplify to

\[
8d(1 - c_L)^2 - 2p^\beta \lambda (2d - 1)(1 - c_L) + p^2 \lambda^2,
\]
where \( \lambda = 2(c_H - c_L) - \sqrt{3}(1 - c_H) \). Differentiating these profits with respect to \( \beta \), yields

\[
\frac{\partial}{\partial d} \ln \left[ (2d - 1)(c_L - 1) - p^\beta \lambda \right] = 0.
\]

Under a CI context, profits \( \pi_{CI}^{L,R} (\beta) \) are

\[
\pi_{CI}^{L,R} (\beta) = \left( 1 - q^L(t_1^*) \right) q^L(t_1^*) - c_L \cdot q^L(t_1^*) - \delta \left[ (1 - x^L_{inc}(t_1^*)) x^L_{inc}(t_1^*) - c_L \cdot x^L_{inc}(t_1^*) \right]
\]
where \( x^L_{inc}(t_1^*) = \frac{1-c_L}{1+2d} \). In particular, the incumbent chooses an output level \( q^L(t_1^*) \) in the first period which deters entry, and then selects the standard monopoly output level \( x^L_{inc}(t_1^*) \) in the second-period game. Hence, \( \pi_{CI}^{L,R} (\beta) \) simplifies to

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

Under a CI context, profits \( \pi_{CI}^{L,R} \) are

\[
\pi_{CI}^{L,R} = \left[ (1 - q^L(t_1^*)) q^L(t_1^*) - c_L \cdot q^L(t_1^*) \right] + \delta \left[ (1 - x^L_{inc}(t_1^*)) x^L_{inc}(t_1^*) - c_L \cdot x^L_{inc}(t_1^*) \right]
\]
whereby the low-cost firm is not subject to entry threats (as potential entrants observe its low costs and do not join the industry). In addition, \( q^L(t_1^*) = x^L_{inc}(t_1^*) = \frac{1-c_L}{1+2d} \). Therefore, profits \( \pi_{CI}^{L,R} \)
simplify to

\[
\pi_{CI}^{LR} = (1 + \delta) \frac{2d(1 - c_L)^2}{(1 + 2d)^2}
\]

Hence, the profit difference \(BII^{LR}(\beta) = \pi_{SE}^{LR}(\beta) - \pi_{CI}^{LR}\) is

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

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

### 6.4 Proof of Corollary 1

The profit gain when regulation is present, \(BII^{LR}(\beta)\), was defined in the proof of Proposition 1. When regulation is absent, the profit gain is \(BII^{LR, NR} = \pi_{SE, NR}^{LR} - \pi_{CI, NR}^{LR}\). Let us separately find the profit of this firm under SE and CI, and then we will analyze its difference.

**Profit under no regulation and CI.** The profit that the low-cost incumbent obtains under a CI context, \(\pi_{CI, NR}^{LR}\), is

\[
\pi_{CI, NR}^{LR} \equiv (1 - q^L) q^L - c_L \cdot q^L + \delta \left[ (1 - x_{inc})^L x_{inc}^L - c_L \cdot x_{inc}^L \right]
\]

where output level \(q^L = x_{inc}^L = \frac{1-c_L}{2}\). Hence, \(\pi_{CI, NR}^{LR} = (1 + \delta) \frac{(1-c_L)^2}{4}\).

**Profit under no regulation and SE.** The profit that the low-cost incumbent obtains under a SE, \(\pi_{SE, NR}^{LR}\), is

\[
\pi_{SE, NR}^{LR} \equiv (1 - q^{SE}) q^{SE} - c_L \cdot q^{SE} + \delta \left[ (1 - x_{inc})^L x_{inc}^L - c_L \cdot x_{inc}^L \right]
\]

where \(x_{inc}^L = \frac{1-c_L}{2}\) in the second period (once the incumbent has successfully deterred entry), whereas \(q^{SE}\) is the least-costly separating output level that cannot be profitably mimicked by the high-cost firm, that is, \(q^{SE}\) solves

\[
\frac{(1 - c_H)^2}{4} + \delta \frac{(1 - c_H)^2}{9} \geq [(1 - q^{SE}) q^{SE} - c_H \cdot q^{SE}] + \delta \frac{(1 - c_H)^2}{4}
\]

which equality, i.e., \(q^{SE} = \frac{5\delta - 9c_H - 3\sqrt{3\delta}(1-c_L)}{3\delta - 9}\). Plugging \(q^{SE}\) and \(x_{inc}^L = \frac{1-c_L}{2}\) into the expression of \(\pi_{SE, NR}^{LR}\) yields

\[
3 \frac{[5\delta - 3\kappa - 9c_L][\kappa + 3c_L - 3] - (9 - 5\delta)(3\kappa - 9c_L - 5\delta)c_L}{(9 - 5\delta)^2} + \delta \frac{(1 - c_L)^2}{4}
\]

where \(\kappa = \sqrt{3\delta}(1-c_L)\).

**Profit gain under no regulation.** Therefore, the profit gain when regulation is absent, \(BII^{LR, NR} \equiv \)
which is negative, $BII^{L,NR} < 0$, under all parameter values.

Comparing the BII expressions, we obtain that $BII^{L,R}(\beta) \geq BII^{L,NR}$ if and only if $\beta \geq \beta_3$, where $\beta_3 \equiv \frac{1}{\ln H} \ln \frac{1}{A}$ and

$$A \equiv x \left[ 3\delta^2 \sqrt{3} \alpha (1 - c_H)^2 \omega \right] + 6\delta \gamma (1 - c_H)$$
$$-4\gamma \sqrt{3} \alpha (c_H - c_L) - 8\mu \alpha (c_H - c_L)^2 + \sqrt{2} B^{-1/2}$$

$$x \equiv (3\delta + c_H^2 (3\delta - 4) - 4c_L^2 + c_H (8c_L - 6\delta))^2, \ a \equiv 2d - 1, \ \omega \equiv (1 - c_H) (1 - c_L), \ \gamma \equiv (1 - c_H) (c_H - c_L) (1 - c_L),$$
$$\mu \equiv (c_H - c_L) (1 - c_L),$$

$$B \equiv (9 - 5\delta)^2 (3\delta (1 - c_H)^2 + 4\sqrt{3} \delta \eta + 4 (c_H - c_L)^2 (81 + 720 d\delta + 4d^2 (9 + 5\delta)^2 + 5\delta (18 + 5\delta) - 54 \kappa - 6\kappa (5\delta + 4d (1 + d) (9 + 5\delta)) - 2 (4d (81 + 5\delta (36 - 5\delta + 3\kappa) - 81 \kappa + 3y + 12d^2 y c_L$$
$$+ (1296d + (5 (81 + \delta (5\delta - 18))) + 20d^2 (81 + 5\delta (5\delta - 18))) c_L^2 x),$$

$$y \equiv 54 + 5\delta (6 + \kappa) - 27 \kappa, \ \text{and} \ \eta \equiv (c_H - c_L) (1 - c_H).$$

### 6.5 Proof of Corollary 2

The benefits from regulation under a CI context are $BR^{L}_{CI} \equiv \pi^{L,R}_{CI} - \pi^{L,NR}_{CI}$, where $\pi^{L,R}_{CI} = (1 + \delta)^{2d (1 - c_H)^2}$ was found in the proof of Proposition 1, whereas $\pi^{L,NR}_{CI} = (1 + \delta) \frac{(1 - c_L)^2}{4}$ was found in the proof of Corollary 1. Hence, the profit difference $BR^{L}_{CI} \equiv \pi^{L,R}_{CI} - \pi^{L,NR}_{CI}$ is

$$- \frac{(1 - 2d)^2 (1 + \delta) (1 - c_L)^2}{4 (1 + 2d)^2}$$

which is negative for all parameter values.

The benefits from regulation under the SE are $BR^{L}_{SE} \equiv \pi^{L,R}_{SE} (\beta) - \pi^{L,NR}_{SE}$, where the expression of $\pi^{L,R}_{SE} (\beta)$ was found in the proof of Proposition 1, while $\pi^{L,NR}_{SE}$ were found in the proof of Corollary 1. Thus, the profit difference $BR^{L}_{SE} \equiv \pi^{L,R}_{SE} (\beta) - \pi^{L,NR}_{SE}$ is

$$-p^{2\beta} (3\delta (1 - c_H)^2 + 4\delta \sqrt{3} \delta + 4 (c_H - c_L)^2) + 2p^{\beta} a (\omega \sqrt{3} \delta - \mu) + 8d (1 + \delta) (1 - c_L)^2$$

$$+ \frac{1}{4} \delta (1 - c_L)^2 - \frac{(5\delta - 3\kappa - 9c_L)c_L}{9 - 5\delta} + \frac{3 (3c_L + \kappa - 3) (9c_L + 3\kappa - 5\delta)}{(9 - 5\delta)^2}$$

which is positive for all $\beta > \beta_4$, where
\[
\beta_4 \equiv \frac{1}{\ln p} \ln \left( \frac{1}{x} \right) (3 \omega \delta^2 \sqrt{3} a (1 - c_H)^2 - 6 \gamma (2d - 1) (1 - c_H) - 4 \gamma \sqrt{3} a (c_H - c_L) - 8 \mu a (c_H - c_L)^2 \\
+ \frac{1}{(9 - 5 \delta)^2} (3 \delta (1 - c_H)^2 + 4 \eta \sqrt{3} \delta + 4 (c_H - c_L)^2) (-81 (1 + 2d)^2 \\
- 27 (7 + 4d (13 + 7d)) \delta - z + 25 \delta^2 a^2 + 108 \kappa + 12 \kappa (5 \delta + 4d (1 + d) (9 + 5 \delta)) + 2 (4d^2 (81 (3 - 2 \kappa) \\
+ \delta m + 4d (81 (3 - 2 \kappa) + \delta (351 + 5 \delta (5 \delta - 23) + 30 \kappa)) + 81 (3 - 2 \kappa) + \delta m) c_L \\\n+ (9 (19 - 4d + 76d^2) \delta - 729 (1 + 2d)^2 - z + 25 a^2 \delta^2 c_L^2) x \right)^{1/2}
\]

where \( z \equiv 5 (23 - 52d + 92d^2) \delta^2 \), and \( m \equiv 189 + 5 (13 - 5 \delta) \delta + 30 \kappa \).

### 6.6 Proof of Lemma 3

The profits that the high-cost incumbent obtains in the PE with regulation are

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

whereby the incumbent mimics the output level of the low-cost firm during the first-period game, \( q^L(t_1^L) = \frac{1 - c_H}{1 + 2d} \), in order to conceal its type and deter entry, but reverts to its standard monopoly output \( q^H(t_1^H) = \frac{1 - c_H}{1 + 2d} \) in the second period. Plugging \( q^L(t_1^L) \) and \( q^H(t_1^H) \) yields overall profits of

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

Taking first-order conditions with respect to \( d \) yields

\[
\frac{2((1 - 2d)(1 + \delta) + (1 - 2d) \delta c_H^2 + c_L (2c_L + 2d - 3) + c_H ((1 - 2d) c_L + 1 + 2d (1 + 2 \delta) - 2 \delta)}{(1 + 2d)^3}
\]

setting them equal to zero, and solving for \( d \) yields

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

### 6.7 Proof of Proposition 2

On one hand, the profits that the high-cost incumbent obtains in the PE with regulation, \( \pi_{PE}^{H,R} \), were found in the proof of Lemma 3. On the other hand, its profits under a CI setting with regulation, \( \pi_{CI}^{H,R} \), are

\[
\pi_{CI}^{H,R} \equiv (1 - q^H(t_1^H)) q^H(t_1^H) - c_L \cdot q^H(t_1^H) \\
+ \delta \left[ (1 - x_{inc}^H(t_2^H) - x_{ent}^H(t_2^H)) x_{inc}^H(t_2^H) - c_L \cdot x_{inc}^H(t_2^H) \right]
\]

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whereby the high-cost firm is a monopolist in the first-period game, but entry ensues in the second-period game since the potential entrant observes the incumbent’s inefficiency. In particular, monopoly output is \( q_H(t_H^1) = \frac{1-c_H}{1+2d} \) in the first period, whereas in the second period duopoly output functions are \( x_{inc}(t_2) = x_{ent}(t_2) = \frac{1-c_H - t_2}{3} \) and the emission fee is \( t_2^H = (4d - 1) \frac{1-c_H}{2(1+2d)} \). Therefore, profits \( \pi_{CI}^{H,R} \) simplify to

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

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

\[
d\delta - d(2 - \delta)c_H^2 - c_L(2d - 1 + c_L) + c_H(2d(1 - \delta) - 1 + (1 + 2d)c_L)
\]

\[
(1+2d)^2
\]

Differentiating the profit difference \( \pi_{PE}^{H,R} - \pi_{CI}^{H,R} \) with respect to \( d \), setting it equal to zero, and solving for \( d \) yields \( d = d_6 \), where \( d_6 \equiv \frac{(2-\delta)c_H^2 + 6c_L - 4c_H^2 - 2c_H(3-\delta - c_L)}{2(1-c_H)(\delta - 2)c_H + 2c_L - \delta} \).

6.8 Proof of Corollary 3

On one hand, the profit difference \( BII^{H,R} \equiv \pi_{PE}^{H,R} - \pi_{CI}^{H,R} \) when regulation is present was defined in the proof of Proposition 2. On the other hand, this profit difference when regulation is absent is \( BII^{H,NR} \equiv \pi_{PE}^{H,NR} - \pi_{CI}^{H,NR} \). Let us separately find each term in this expression. First, in the pooling equilibrium under no regulation, Milgrom and Roberts (1982) show that profits \( \pi_{PE}^{H,NR} \) become

\[
\pi_{PE}^{H,NR} = (1 - q^L) q^L - c_H \cdot q^L + \delta \frac{(1-c_H)^2}{4}
\]

whereby the high-cost incumbent mimics the output level of the low-cost firm in the first-period game in order to deter entry, \( q^L = \frac{1-c_L}{2} \), but chooses its standard monopoly output once entry has been deterred, \( q^H = \frac{1-c_H}{2} \). Hence, pooling profits under no regulation are

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

Second, the profits under CI when regulation is absent, \( \pi_{CI}^{H,NR} \), are

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

since the high-cost firm enjoys monopoly profits in the first period but suffers entry in the second period.

Therefore, the profit difference \( BII^{H,R} \equiv \pi_{PE}^{H,R} - \pi_{CI}^{H,R} \) becomes
\[
\left[1 + \delta (1 + c_H^2 - 2c_H (1 + \delta - c_L) - c_L^2) \right] - \left[\frac{(1 - c_H)^2}{4} + \frac{\delta (1 - c_H)^2}{9}\right]
\]

Hence, \( BII_{H,R} > BII_{H,NR} R \) for all \( d \in [d_7, d_7'] \), where

\[
d_7 \equiv \frac{D}{\varphi - \psi} + \frac{1}{\varphi - \psi} \left[ 4\delta + (4\delta - 9) (c_H - 2)c_H + 9(c_L - 2)c_L \right] - (\varphi - \psi)E \]

and

\[
d_7' \equiv \frac{-D}{\varphi - \psi} + \frac{1}{\varphi - \psi} \left[ 4\delta + (4\delta - 9) (c_H - 2)c_H + 9(c_L - 2)c_L \right] - (\varphi - \psi)E \]

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 \( E \equiv \varphi + 9c_L(3c_L - 4) - 2c_H(9c_L + 5\delta - 18) \).

### 6.9 Proof of Corollary 4

On one hand, the profit gain that the high-cost incumbent obtains from the introduction of regulation under a CI setting is \( BR_{CI}^H = \pi_{CI}^{H,R} - \pi_{CI}^{H,NR} \), where \( \pi_{CI}^{H,R} \) was found in the proof of Proposition 2, while \( \pi_{CI}^{H,NR} \) was identified in the proof of Corollary 3. Hence, the benefit from regulation under CI, \( BR_{CI}^H = \pi_{CI}^{H,R} - \pi_{CI}^{H,NR} \), is

\[
\left(2 + \delta\right) \left[\frac{d(1 - c_H)^2}{4} + \frac{\delta (1 - c_H)^2}{9}\right]
\]

which, solving for \( d \), is positive for all \( d > d_8 \), where \( d_8 \equiv \frac{9 + 5\delta + 3[\delta(2+\delta)]^{1/2}}{18 + 8\delta} \).

On the other hand, under a PE, the profit gain that the high-cost incumbent obtains from the introduction of regulation is \( BR_{PE}^H = \pi_{PE}^{H,R} - \pi_{PE}^{H,NR} \), where \( \pi_{PE}^{H,R} \) was found in the proof of Lemma 3, whereas \( \pi_{PE}^{H,NR} \) was described in the proof of Corollary 3. Hence, the benefit from regulation under a PE, \( BR_{PE}^H = \pi_{PE}^{H,R} - \pi_{PE}^{H,NR} \), is

\[
\frac{2d(1 + \delta) + 2d\delta c_H^2 - c_L(2d - 1 + c_L) - c_H [2d(1 + \delta) - 1 - (1 + 2d)c_L]}{(1 + 2d)^2}
\]

which, solving for \( d \), is positive for all \( d > d_9 \), where \( d_9 \equiv \frac{1 + \delta (1 + c_H^2) + 2c_H (1 - \delta - c_L) - c_L(4 - 3c_L)}{2 [1 + \delta (1 + c_H^2) - 2c_H (1 - \delta - c_L) - c_L^2]} \).

### References


