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Commitment in Environmental Policy as an Entry-Deterrence Tool

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Abstract

This paper investigates under which conditions governments strategically commit to stringent environmental policies in order to balance market power and the damages emerging from the externality. We compare social welfare under two policy regimes: a flexible and inflexible environmental policy. Our results show that an inflexible policy becomes socially optimal when its associated welfare loss, due to a stringent fee across time, is smaller than its welfare gain, which arises from an improved environmental quality since only one firm operates in the market. Otherwise, the regulator optimally chooses a flexible environmental policy which cannot credibly deter entry. In addition, we demonstrate that the incentives of the social planner and incumbent are not necessarily aligned regarding policy regimes. In particular, under certain conditions the regulator finds socially optimal to commit to an inflexible policy, which deters entry, whereas the incumbent would actually prefer a flexible policy that attracts entry.

Keywords: Entry deterrence; Emission fees; Perfect commitment.

JEL classification: L12, L5, Q5, H23.

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1 Introduction

Recent studies have stressed the potential effects that environmental policy has on market structure and competition. These studies can be grouped according to the primitive reason that explains why environmental regulation hinders entry and/or limits competition upon entry. On one hand, Ryan (2011) and OECD (2006) show that certain types of environmental regulation increase the initial investment that entrants must incur in order to start operating in an industry, thus reducing entry.[1] On the other hand, similar studies demonstrate that environmental policies impose cost differentials among firms. Specifically, these papers identify the presence of strong economies of scale in the compliance of environmental policy, entailing a cost differential between incumbents and entrants if their scale of operations differs.[2] Furthermore, such cost differential can be further augmented since environmental policy often places a heavier burden on new pollutant sources than on the incumbents'.[3]

This paper investigates the effect of environmental policy on market entry, showing that environmental regulation may be detrimental for competition, *even in the absence* of the above arguments. Our results therefore emphasize that the potential adverse effects of environmental regulation are not restricted to industries with particular production processes, or to markets where environmental policy exhibits administrative economies of scale, or settings where incumbent and entrant firms are differently affected by regulation. Instead, our findings highlight the fact that such entry-deterrence effects can be extended to industries where firms are symmetric in costs and they are similarly affected by environmental policy.

In particular, our study considers a social planner who imposes emission fees on an industry, initially monopolized by an incumbent firm, and where an entrant may decide to enter afterwards. For generality, we allow the regulator to choose among two policy regimes: a flexible policy, where authorities adapt the stringency of the emission fee if the number of polluting firms operating in the industry changes, and an inflexible policy, whereby the regulator does not have the ability to rapidly revise his environmental policy if the market structure changes. Since under an inflexible policy initial fees are still enforced in the post-entry game, this policy can attract or deter entry when the regulator commits to a relatively low or high fee, respectively. In contrast, flexible policy cannot credibly deter entry, since the regulator has incentives to revise emission fees if entry ensues.

We first show that, under a flexible policy, the regulator imposes more stringent fees to duopolists than to the incumbent monopolist; as in Buchanan (1969). Under an inflexible policy, by contrast, the social planner must commit to a single emission fee, thereby producing inefficiencies in either one or both periods. Under certain conditions, however, the regulator can improve social welfare

[1] In particular, Ryan (2011) found that the Clean Air Act Amendments of 1990 increased the sunk entry cost by 35% in the market of Portland cement. He argues that, despite the increased profitability in this sector, few entrants chose to enter the industry.

[2] See, for instance, Ungson et al. (1985), Brock and Evans (1985), Dean et al. (2000) and Helland and Matsuno (2003). In this line of work, Monty (1991) and Dean and Brown (1995) report learning-by-doing effects in the compliance of environmental regulation, emphasizing the cost advantage of incumbent firms who are already familiarized with the administrative details of the policy.

[3] Stavins (2005) provides a comprehensive survey on the impact of vintage-differentiation regulation.

by strategically committing to a significantly high fee that deters entry. In particular, relative to a flexible policy, the imposition of a stringent inflexible fee produces two opposite effects: first, it reduces monopoly output during both periods, but second, it improves environmental quality by limiting pollution. When the latter effect dominates the former, overall welfare increases, and therefore entry-deterrence becomes socially optimal. This occurs when entry costs are high, since in this setting entry can easily be deterred by setting a relatively low fee which does not entail significant welfare losses. Entry deterrence is further facilitated when the environmental damage from pollution is relatively high. Indeed, entry-deterrence reduces output, which entails an environmental benefit from a lower level of pollution that is further emphasized as it becomes more damaging. Otherwise, entry deterrence becomes extremely costly and/or does not entail significant environmental benefits. Attracting entry is thus socially optimal and the regulator selects a flexible environmental policy.

Our results hence identify under which conditions the regulator might strategically commit to a relatively stringent environmental policy that, despite hindering the entry of additional firms in subsequent periods, can ultimately lead to welfare improvements. Such equilibrium outcome, however, assumes that regulatory authorities can directly modify the flexibility of their environmental policies. If such degree of flexibility is given by the country's institutional context, our results suggest that countries where environmental regulation slowly adapts to changes in the regulated industry could be unintentionally hindering entry. The use of inflexible policy, however, would not be necessarily suboptimal if, specifically, entry costs and the environmental damage from pollution are relatively high.[4]

Finally, we investigate whether the incumbent's profits are positively affected by emission fees that deter entry. An inflexible policy allows the incumbent to maintain its monopoly power, but reduces profits across time. We show that, when entry is deterred by setting a low inflexible emission fee (i.e., entry costs are large), the incumbent's benefits from monopolizing the industry outweigh the costs from bearing a stringent regulation, and hence the incumbent prefers an inflexible policy. In contrast, when entry-deterrence is more difficult (small entry costs), emission fees become more substantial; implying that the incumbent prefers a flexible policy even if it attracts entry. We furthermore demonstrate that the regulator's and incumbent's interests are not necessarily aligned. In particular, when the regulator finds entry-deterrence socially optimal, the incumbent also favors such policy if the emission fee it bears is relatively small, but opposes it otherwise. Our results hence provide an important distinction often overlooked by critics of environmental policy, who regard it as a tool governments use to protect domestic monopolies from entry and competition. Indeed, our predictions show that the interests of regulatory agencies and incumbent firms might be aligned, but only when entry is relatively easy to deter. Otherwise, the incumbent may actually prefer that the regulator practices *less* entry deterrence.

[4] That is, even if the regulator had the ability to choose a policy regime (flexible or inflexible policies), he would prefer an inflexible policy. Note that if, in contrast, countries' given institutional setting is relatively flexible, our results predict that such regulation would attract additional firms in the industry, yielding optimal social welfare if entry costs and the environmental damage from pollution are sufficiently low.

Related literature. Our paper contributes to three main areas of the literature: that analyzing the effects of environmental policy on entry and competition; that considering the optimal use of commitment in contexts where regulators face time-inconsistency problems; and the literature that examines entry-deterrence in industrial economics. As suggested above, our paper offers a new setting where environmental regulation can serve as an entry-deterrence device, even in the absence of any of the arguments commonly used in the literature: economies of scale or learning-by-doing effects in the compliance of regulation, cost-differentials emerging from environmental policy, etc.

Moreover, the paper contributes to the literature comparing flexible and inflexible policies. Since the initial work by Kydland and Prescott (1977) and Barro and Gordon (1983), several papers examined perfect commitment in monetary policy, Chang (1998) and Alvarez et al. (2004), in capital tax policy, Chamley (1986) and Benhabib et al. (2001), or in both, Dixit and Lambertini (2003). These papers consider a context where inflexible policies can be welfare improving under certain conditions. Commitment in monetary policy, for instance, affects agents' expectations of inflation thereby changing their current economic decisions. This paper similarly identifies how commitment in environmental policy can be used to affect the entrant's expectations about its future profitability, deterring entry in certain contexts and increasing overall welfare.[5]

Finally, our paper relates to the literature on entry-deterrence games initiated by Bain (1956) and Sylos-Labini (1962) for one incumbent and extended by Gilbert and Vives (1986) to several incumbents, by Waldman (1987) to settings of incomplete information, and by Kovenoch and Roy (2005) to product-differentiated markets.[6] A common assumption in these models is that the incumbent firm commits to a particular level of output which, if sufficiently large, may deter entry from potential entrants. In our paper, the incumbent firm cannot commit its future production decision, whereas the regulator can set a constant emission fee across periods, thereby using environmental policy as an entry-deterrence tool in certain contexts. An important difference of our model is that the regulator deters entry in settings where the incumbent would have preferred entry to ensue. Because the literature on entry-deterrence often abstracts from the regulatory context in which firms operate, entry is only deterred if the incumbent seeks to discourage the newcomer. Our results, in contrast, predict settings where entry deterrence is favored by the incumbent, but also contexts where it is actually opposed by the incumbent firm.

The next section describes the model and time structure of the game. Section 3 examines the second-period game, while section 4 investigates the first-period game both with flexible and inflexible policies. Section 5 compares the overall social welfare ensuing from the selection of different environmental policies. At the end of section 5 we evaluate the incumbent's profits under

[5] Ko et al. (1992) compare flexible and inflexible environmental policies under a complete information context where a single incumbent produces stock externalities, i.e., pollution that does not fully dissipate across periods, without allowing for potential entry. Because entry cannot occur in their setting, the optimal policy path across periods mainly depends on the dissipation rate. In our model, in contrast, pollution fully dissipates across periods but entry may occur, thus affecting the social planner's optimal policy path with and without commitment.

[6] In a reinterpretation of the quantity commitments considered in these papers on entry-deterrence, Spence (1977), Dixit (1980), Ware (1984) and Fudenberg and Tirole (1984), assume that incumbent firms commit to an investment in capacity, providing similar results.

flexible and inflexible policies, and section 6 concludes.

2 Model

Consider an entry game with a monopolist incumbent, an entrant who decides whether or not to join the market and a regulator who sets an emission fee per unit of output.[7] The incumbent's constant marginal costs are either high H or low L, i.e., $c_{inc}^{H} > c_{inc}^{L} \geq 0$, where subscript inc denotes the incumbent. In particular, we study a two-stage complete-information game with the following time structure:

1. In the first stage, the regulator chooses between an inflexible environmental policy (setting a constant fee t across time); and a flexible policy, i.e., setting fee t_1 (t_2) in the first (second) period.

2. Given the first-period environmental policy, the incumbent responds selecting an output level, i.e., $q^K(t)$ under an inflexible policy or $q^K(t_1)$ under a flexible policy, where $K = \{H, L\}$ represents the incumbent's type.

3. In the second-period game, the entrant decides whether to enter the industry after observing the regulator's choice of environmental policy and the incumbent's marginal costs.

4. The regulator maintains his environmental policy t if he is committed to a constant fee. Otherwise, he revises the policy from t_1 to t_2. In addition:

   (a) If entry does not occur, the incumbent responds producing a monopoly output $x_{inc}^{K,NE}(t)$ under an inflexible policy and $x_{inc}^{K,NE}(t_2)$ under a flexible policy; where superscript NE denotes no entry.

   (b) Similarly, if entry ensues both firms compete as Cournot duopolists, producing $x_{inc}^{K,E}(t)$ and $x_{ent}^{K,E}(t)$ under an inflexible policy, and $x_{inc}^{K,E}(t_2)$ and $x_{ent}^{K,E}(t_2)$ under a flexible policy; where superscript E represents entry and subscript ent denotes the entrant.

In the following section we examine fees and output levels in the second-period game, as well as the resulting social welfare in equilibrium. Afterwards we analyze the first stage, and finally compare social welfare under flexible and inflexible policies.

3 Second-period game

Flexible policy. Let us next examine the subgame where the regulator selects a flexible environmental policy.

[7] As described below, our model allows for emissions to be a convex function of output, embodying not only cases in which the relationship between output and emissions is proportional, but also cases in which such relationship is increasing.

No entry. If entry does not occur, the incumbent's profits when facing a given fee t_2 are $\pi_{inc}^{K,NE}(x_{inc}) \equiv p(x_{inc})\, x_{inc} - \left(c_{inc}^{K} + t_2\right) x_{inc}$, where $K = \{H, L\}$, and the inverse demand function $p(x_{inc})$ is linear in output and satisfies $p'(x_{inc}) < 0$ and $p(x_{inc}) > c_{inc}^{K}$ for all x_{inc}. The regulator's social welfare function in the second period is

$$SW_2^{K,NE} \equiv \gamma CS(x_{inc}) + \pi_{inc}^{K,NE}(x_{inc}) + T^{K,NE} - d(x_{inc}), \tag{3.1}$$

where $CS(x_{inc}) \equiv \int_0^{x_{inc}} p(x)\, dx - p(x_{inc})x_{inc}$ represents the consumer surplus for a given output x_{inc}. The parameter γ denotes the weight that the social planner assigns to consumer surplus and $\gamma \in [0, 1]$. In addition, $T^{K,NE}$ is the tax revenue under no entry, and function $d(x_{inc})$ represents the strictly convex environmental damage from output, where $d'(x_{inc}) > 0$ and $d''(x_{inc}) > 0$.[8] Furthermore, we assume that the marginal environmental damage satisfies $p(0) - c_{inc}^{K} > d'(0)$, which ensures that it is socially efficient to produce the first unit of output. The regulator seeks to induce the socially optimal output $x_{SO}^{K,NE}$ which solves $MB^{K,NE}(x_{inc}) = MD^{NE}(x_{inc})$, where

$$MB^{K,NE}(x_{inc}) \equiv (1 - \gamma)\, p'(x_{inc})x_{inc} + p(x_{inc}) - c_{inc}^{K} \tag{3.2}$$

represents the marginal benefit of additional output on consumer and producer surplus, whereas $MD^{NE}(x_{inc}) \equiv d'(x_{inc})$ denotes the marginal environmental damage of output. The regulator then imposes an emission fee $t_2^{K,NE} = MP_{inc}^{K,NE}(x_{SO}^{K,NE})$ on monopoly output in order to induce the production level $x_{SO}^{K,NE}$ in the second period, where $MP_{inc}^{K,NE}(x_{inc})$ represents the marginal profits of increasing x_{inc} given no entry.[9]

Entry. If entry occurs, firms compete as Cournot duopolists in the second period. The profit functions for the incumbent and entrant are

$$\pi_{inc}^{K,E}(x_{inc}, x_{ent}) \equiv p(X)\, x_{inc} - \left(c_{inc}^{K} + t_2\right) x_{inc} \quad \text{and} \quad \pi_{ent}^{K,E}(x_{inc}, x_{ent}) \equiv p(X)\, x_{ent} - (c_{ent} + t_2)\, x_{ent} \tag{3.3}$$

where $X = x_{inc} + x_{ent}$ represents the aggregate output level, superscript E denotes entry and c_{ent} is the entrant's marginal cost where $c_{ent} = c_{inc}^{H}$. The regulator's social welfare function is

$$SW_2^{K,E} \equiv \gamma CS(X) + PS(X) + T^{K,E} - d(X). \tag{3.4}$$

where $PS(X) \equiv \pi_{inc}^{K,E}(x_{inc}, x_{ent}) + \pi_{ent}^{K,E}(x_{inc}, x_{ent}) - F$. The regulator aims to induce the aggregate

[8] Note that this damage function allows for aggregate emissions to be a convex function of output, and in turn, overall damage from pollution to be a convex function of aggregate emissions. That is, emissions can be represented as $e_i = f(x_{inc})$, where $f(\cdot)$ is weakly convex in x_{inc}, and environmental damage as $d(x_{inc}) = g(f(x_{inc}))$, where $g(\cdot)$ is also a weakly convex function in emissions.

[9] Appendix 1 shows that such an emission fee exists both under entry and no entry. In addition, note that when social welfare does not include consumer surplus, $\gamma = 0$, the optimal tax leads the incumbent to fully internalize the environmental damage of her output decision. However, when $\gamma > 0$, the relative value of consumption increases, which implies a lower optimal tax $t_2^{K,NE}$. Therefore, the monopolist only internalizes a fraction of her environmental damage.

socially optimal output $X_{SO}^{K,E}$ that solves $MB^{K,E}(X) = MD^{E}(X)$, where

$$MB^{K,E}(X) \equiv (1-\gamma)\, p'(X)X + p(X) - c_{inc}^{K} \tag{3.5}$$

and $MD^{E}(X) \equiv d'(X)$. Hence, the emission fee $t_2^{K,E}$ that induces aggregate output $X_{SO}^{K,E}$ is $t_2^{K,E} = MP_j^{K,E}\left(x_{j,SO}^{K,E} | x_{k,SO}^{K,E}\right)$ for all firm $j = \{inc, ent\}$ and $k \neq j$, where $MP_j^{K,E}\left(x_j | x_{k,SO}^{K,E}\right)$ denotes the marginal profit that firm j obtains by increasing its duopoly output given that its rival k produces the socially optimal output[10] $x_{k,SO}^{K,E}$.

To make entry decision interesting, we consider that when the incumbent's costs are low, entry is unprofitable, i.e., the entrant's duopoly profits, $\pi_{ent}^{L,E}(t)$, lie below his fixed entry cost F, $\pi_{ent}^{L,E}(t) < F$, for any emission fee t. Hence, the entrant stays out even when emission fees are absent, i.e., $\pi_{ent}^{L,E}(0) < F$. In contrast, when the incumbent's costs are high, entry is profitable in equilibrium both under the flexible and inflexible fee. As section 4.2 shows, the flexible fee is more stringent than the inflexible tax, thus implying that entrant's profits are lower when the environmental policy is flexible. Therefore, the entrant joins the market if $\pi_{ent}^{H,E}(t_2^{H,E}) > F$.[11] Entry, however, becomes unprofitable if fees are sufficiently high. That is, $\pi_{ent}^{H,E}(t)$ decreases in t and satisfies $\pi_{ent}^{H,E}(t) \leq F$ for all fees $t \geq \bar{t}$. For compactness, we refer to $\bar{t}$ as the "entry-deterring fee."

Inflexible policy. Under an inflexible policy, firms face the same constant fee t that the regulator selects in the first-period game, producing output $x_{inc}^{K,NE}(t)$ in the case of no entry and $x_j^{K,E}(t)$ for any firm $j = \{inc, ent\}$ in the case of entry. Hence, we analyze the regulator's setting of an optimal inflexible policy in our discussion of the first-period game.

4 First-period game

4.1 Flexible policy

The regulator seeks a first-period output q that maximizes social welfare. Specifically, this occurs when the socially optimal output under monopoly q_{SO}^{K} solves $MB^{K,NE}(q) = MD^{NE}(q)$. Analogous to the no-entry case in the second stage, emission fee $t_1^K = MP_{inc}^{K}\left(q_{SO}^{K}\right)$ induces the monopolist to produce q_{SO}^{K}. Consequently, this fee coincides with that under monopoly in the second period, $t_1^K = t_2^{K,NE}$. Let $SW^{L,NE}\left(t_1^L, t_2^{L,NE}\right)$ denote the overall social welfare across both periods when entry does not ensue since the incumbent's costs are low, and the regulator sets t_1^L and $t_2^{L,NE}$ fees in the first and second period, respectively. Similarly, let $SW^{H,E}\left(t_1^H, t_2^{H,E}\right)$ represent the social welfare when entry occurs given that the incumbent's costs are high, and the regulator sets fees

[10] This implies that, when the incumbent's costs are high, in order to find fee $t_2^{H,E}$ and individual output levels $x_{j,SO}^{H,E}$ and $x_{k,SO}^{H,E}$, the social planner must simultaneously solve $x_{j,SO}^{H,E} + x_{k,SO}^{H,E} = X_{SO}^{H,E}$ and $t_2^{H,E} = MP_j^{H,E}\left(x_{j,SO}^{H,E} | x_{k,SO}^{H,E}\right)$ for both firms $j = \{inc, ent\}$.

[11] Note that these conditions on entry costs, i.e., $\pi_{ent}^{H,E}(t_2^{H,E}) > F > \pi_{ent}^{L,E}(0)$, also satisfy the standard assumption in entry-deterrence models where regulation is absent, in which F satisfies $\pi_{ent}^{H,E}(0) > F > \pi_{ent}^{L,E}(0)$, since $\pi_{ent}^{H,E}(0) > \pi_{ent}^{H,E}(t_2^{H,E})$.

t_1^H and $t_2^{H,E}$. In order to illustrate our results, we develop the following example throughout the paper.

Example. Consider an inverse demand function $p(X) = 1 - X$ and incumbent costs $1 > c_{inc}^H = c_{ent} > c_{inc}^L$. Environmental damage is given by $d(X) = d \times X^2$ where[12] $d \in \left[\frac{\gamma}{2}, \frac{1+\gamma}{2}\right]$. The socially optimal output is $q_{SO}^K = \frac{1-c_{inc}^K}{2+2d-\gamma}$ and $q_{SO}^K = X_{SO}^{K,E}$, where $K = \{H, L\}$. As a consequence, the emission fee that induces q_{SO}^K in the first period is $t_1^K = (2d-\gamma)q_{SO}^K$. The optimal fee in the second period when the incumbent's costs are high is $t_2^{H,E} = (1+4d-2\gamma)\frac{X_{SO}^{H,E}}{2}$ where $t_2^{H,E} > t_1^H$, illustrating that the regulator sets more stringent fees to the duopolists than to the monopolist. If the incumbent's costs are low, the first- and second-period fee is $t_1^L = t_2^{L,NE} = (2d-\gamma)q_{SO}^L$. Hence, overall social welfare in the case that $\gamma = 1$ is $SW^{L,NE}\left(t_1^L, t_2^{L,NE}\right) = \frac{(1-c_{inc}^L)^2}{1+2d}$ when the regulator faces a low-cost incumbent, and $SW^{H,E}\left(t_1^H, t_2^{H,E}\right) = \frac{1-(2-c_{inc}^H)c_{inc}^H}{1+2d} - F$ when he faces a high-cost incumbent.[13]

4.2 Inflexible policy

Let us now consider the subgame where the regulator chooses a constant tax policy. First, in the case of no entry, the regulator seeks to induce the same optimal output in both periods, namely, q_{SO}^K and $x_{SO}^{K,NE}$. This can be achieved by a fee $t^{K,NE} = MP_{inc}^K\left(q_{SO}^K\right)$, which coincides with the optimal fee $t_1^K = t_2^{K,NE}$ under a flexible policy. If entry occurs, however, the regulator needs to set different fees to the first-period monopolist than to the second-period duopolists in order to induce the socially optimal aggregate output. Any fixed fee t therefore produces a deadweight loss in one or both periods. Hence, in this setting the regulator minimizes the discounted sum of the absolute value of deadweight losses across both periods, choosing a fee t that solves

$$\min_t \ |DWL_1(t)| + \delta_R |DWL_2(t)| \tag{4.1}$$

where $\delta_R \in [0, 1]$ denotes the regulator's discount factor. The deadweight loss of tax t in the first period is $DWL_1(t) \equiv \int_{\tilde{q}^{K,NE}(t)}^{q_{SO}^K} \left[MB^{K,NE}(q) - MD^{NE}(q)\right] dq$, where output $\tilde{q}^{K,NE}(t)$ solves $MP_{inc}^{K,NE}(q) = t$, i.e., $\tilde{q}^{K,NE}(t)$ is the monopoly profit-maximizing output for a given fee t. Figure 1a below illustrates the first-period welfare loss of setting a fee t that differs from the socially optimal fee t_1^K. In particular, figure 1a depicts the case where $t > t_1^K$, leading to a monopoly output $\tilde{q}^{K,NE}(t)$ that lies below the socially optimal output q_{SO}^K.[14]

[12] Intuitively, this implies that the importance that the social planner assigns to consumer surplus and environmental damage must be relatively close. If instead, the environmental damage is extremely low (high) and the weight on consumer surplus is high (low), the regulator would choose to not reduce output levels setting a zero fee (reduce output to zero by setting a high fee, respectively).

[13] Since we analyze social welfare across two time periods, the example assumes no discounting of future payoffs.

[14] In order to allow for the case where $t < t_1^K$, expression (6) considers the absolute value of the deadweight loss of fee t.

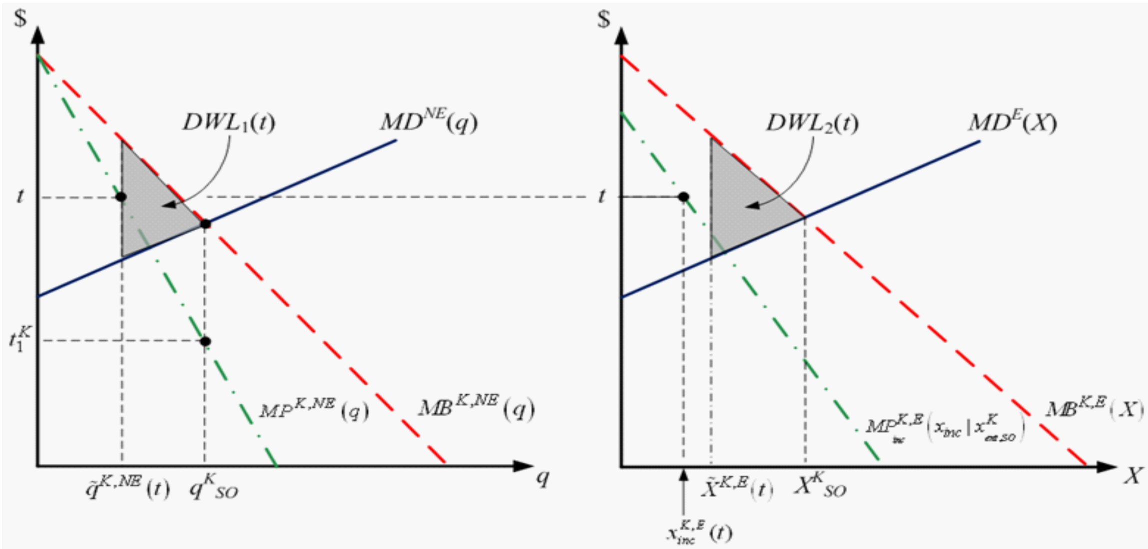

Figure 1a Figure 1b

Similarly, the deadweight loss associated with tax t in the second period is given by $DWL_2(t) \equiv \int_{\widetilde{X}^{K,E}(t)}^{X_{SO}^{K,E}} \left[MB^{K,E}(X) - MD^{E}(X)\right] dX$, where $\widetilde{X}^{K,E}(t) = x_{inc}^{K,E}(t) + x_{ent}^{K,E}(t)$ and output $x_j^{K,E}(t)$ solves $MP_j^{K,E}\left(x_j | x_{k,SO}^{K,E}\right) = t$ for all firm j, i.e., $x_j^{K,E}(t)$ represents firm j's profit-maximizing output for a given fee t after entry. Deadweight loss $DWL_2(t)$ is depicted in figure 1b. Specifically, the constant fee t maps into $MP_{inc}^{K,E}(\cdot)$, inducing the incumbent to produce $x_{inc}^{K,E}(t)$. However, $DWL_2(t)$ is calculated from aggregate duopoly output $\widetilde{X}^{K,E}(t)$.

Entry deterrence. In the context of an inflexible environmental policy, the regulator can commit to a relatively high fee $\bar{t}$ that deters entry, i.e., a fee that lowers the entrant's duopoly profits below his fixed entry cost F. Let $SW^{H,NE}\left(\bar{t}\right)$ denote overall social welfare when the incumbent's costs are high, and the regulator commits to a sufficiently high fee $\bar{t}$ that deters entry.[15] Intuitively, the welfare cost of deterring entry arises from substantially reducing the incumbent's monopoly output across both periods, thereby decreasing consumer surplus and profits, whereas its welfare benefit emerges from the reduction in pollution and the savings in entry costs.

Example. Continuing with our example, and considering $\delta_R = 1$ and $\gamma = 1$, the optimal tax t that the regulator chooses across both periods is $t^{L,NE} = (2d-1)x_{SO}^{K,NE}$ when the incumbent's costs are low and therefore entry does not occur. In this case, the welfare-maximizing emission fee

[15] Note that the use of high fees can only serve to deter entry if environmental policy is inflexible along time. If, in contrast, fees can be modified after the first period, entry cannot be credibly deterred. In addition, when the incumbent's costs are low, entry does not occur, and the regulator does not need to commit to a high emission fee $\bar{t}$ in order to deter entry. We hence restrict our analysis to the regulation of the high-cost incumbent.

coincides with that under a flexible policy, $t^{L,NE} = t_1^L = t_2^{L,NE}$. The regulator has no incentive to revise the environmental policy because a monopoly is regulated at each stage. In contrast, when the incumbent's costs are high, entry occurs and the optimal tax is a weighted average of first- and second-period taxes,[16] $t^{H,E} = \frac{9}{25}t_1^H + \frac{16}{25}t_2^{H,E}$, and thus $t_1^H < t^{H,E} < t_2^{H,E}$. Finally, note that the regulator can deter entry by setting a fee $\bar{t}$ that solves $\pi_{ent}^{H,E}(t) = F$, i.e., $\bar{t} = 1 - c_{inc}^H - 3\sqrt{F}$, which decreases as entry becomes more costly, thus facilitating entry deterrence; and it is positive for all $F < F^* \equiv \frac{(1-c_{inc}^H)^2}{9}$. This fee yields an overall social welfare of $SW^{H,NE}(\bar{t}) = \frac{3\sqrt{F}\left[4-(3+6d)\sqrt{F}-4c_{inc}^H\right]}{4}$, whereas the social welfare from setting an inflexible fee $t^{H,E}$ that attracts entry is $SW^{H,E}\left(t^{H,E}\right) = \frac{49-49(2-c_{inc}^H)c_{inc}^H}{50(1+2d)} - F$.

The following lemma examines the regulator's incentives to set entry-deterring fees where the given institutional setting is inflexible.

Lemma 1. *Under an inflexible policy regime, the social welfare from committing to an entry-deterring fee* $\bar{t}$*,* $SW^{H,NE}(\bar{t})$*, exceeds that from setting a fee* $t^{H,E}$ *that attracts entry,* $SW^{H,E}\left(t^{H,E}\right)$*, if and only if* $F > F^{Inflex}(d)$*. In addition, cutoff* $F^{Inflex}(d)$ *satisfies* $F^{Inflex}(d) < \pi_{ent}^{H,E}\left(t^{H,E}\right)$*.*

The figure below represents cutoff $F^{Inflex}(d)$ for the case where $c_{inc}^H = \frac{1}{4}$. Intuitively, when entry costs are higher than $F^{Inflex}(d)$, entry can be deterred by committing to a low fee $\bar{t}$, thereby incurring a small welfare loss.[17] In addition, as entry becomes more costly (higher F), entry-deterrence can be sustained under a larger set of environmental damages, d. For (F, d)-pairs below $F^{Inflex}(d)$, in contrast, entry deterrence becomes more difficult since fee $\bar{t}$ is high, thereby producing a large welfare loss, without entailing a substantial environmental benefit given that d is small. Hence, allowing entry is socially optimal.

[16] It is straightforward to show that this fee generates strictly positive production levels for both incumbent and entrant across periods. In addition, as the $\delta_R \to 0$, the weight on t_1^H increases and that on $t_2^{H,E}$ decreases. Intuitively, the social planner assigns no value to the future deadweight loss and therefore selects a fee that minimizes deadweight loss in the first-period game.

[17] Note that the entry-deterring fee $\bar{t}$ is strictly positive since cutoff F^* lies above $\pi_{ent}^{H,E}\left(t_2^{H,E}\right)$ for all parameter values; as shown in the proof of Lemma 1.

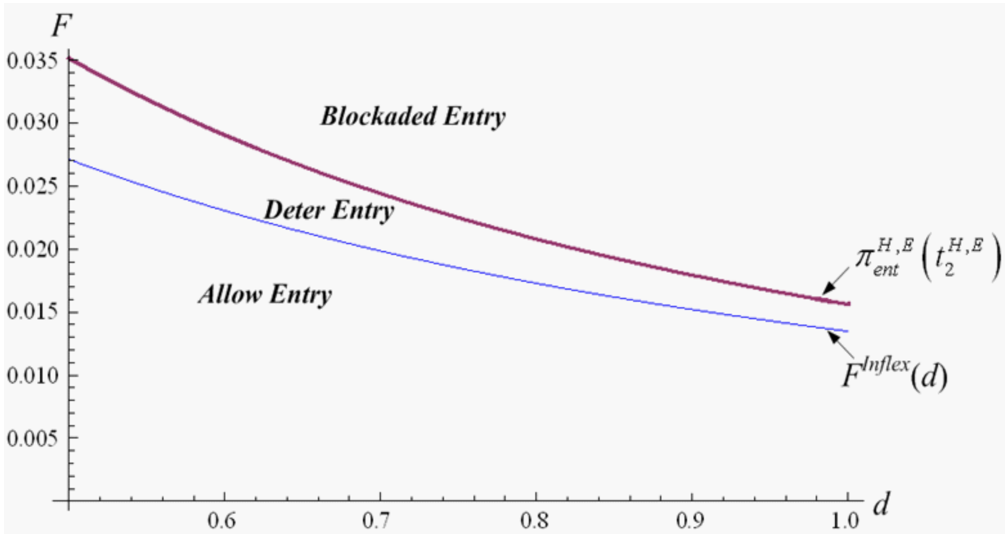

Figure 2. Cutoff $F^{Inflex}(d)$ and $\pi_{ent}^{H,E}\left(t_2^{H,E}\right)$.

Blockaded entry. For comparison purposes, figure 2 also includes the threshold under which entry costs are sufficiently high, making entry unprofitable under a flexible policy $t_2^{H,E}$, i.e., for all $F > \pi_{ent}^{H,E}\left(t_2^{H,E}\right)$ and entry is blockaded. Importantly, note that cutoff $F^{Inflex}(d)$ lies below the threshold for which entry is blockaded, allowing the regulator to practice entry deterrence if entry costs are intermediate. In our parametric example, for instance, the threshold for which entry is blockaded is $F > \pi_{ent}^{H,E}\left(t_2^{H,E}\right) \equiv \frac{\left(1-c_{inc}^H\right)^2}{4(1+2d)^2} > F^{Inflex}(d)$.

5 Welfare comparisons

We can now examine the first period of the game, where the regulator chooses between a flexible and an inflexible policy. Furthermore, if an inflexible policy is selected, the regulator needs to decide whether to set a sufficiently high fee $\bar{t}$ that deters entry. As described above, when the incumbent's costs are low, entry does not occur, and optimal emission fees coincide in both policy regimes, yielding similar welfare. When the incumbent's costs are high, however, emission fees not only differ in both policy settings, but also allow for the use of the emission fee as an entry-deterrence device.

Let us finally introduce additional notation. Let $F^{Flex}(d)$ represent the entry cost that makes the regulator indifferent between selecting an inflexible fee that deters entry, yielding $SW^{H,NE}\left(\bar{t}\right)$, and setting a flexible policy, resulting in an overall welfare of $SW^{H,E}\left(t_1^H, t_2^{H,E}\right)$. In our above parametric example, cutoff $F^{Flex}(d)$ lies above cutoff $F^{Inflex}(d)$ under all feasible values of d; as depicted in figure 3.[18] Intuitively, a regulator is less willing to bear the welfare loss of deterring entry

[18] See proof of Proposition 1 for more details. To facilitate the comparison with figure 2, the figure also considers

when he chooses a flexible policy than when he is already committed to a constant environmental policy. The following proposition summarizes the regulator's policy choice in the subgame-perfect equilibrium of the game. For presentation purposes, let region I represent entry costs where $F < F^{Inflex}(d)$ (see figure 3), region II the case in which $F^{Inflex}(d) < F < F^{Flex}(d)$, region III denote the case where $F^{Flex}(d) < F < \pi_{ent}^{H,E}\left(t_2^{H,E}\right)$, and in region IV entry costs satisfy $F > \pi_{ent}^{H,E}\left(t_2^{H,E}\right)$.

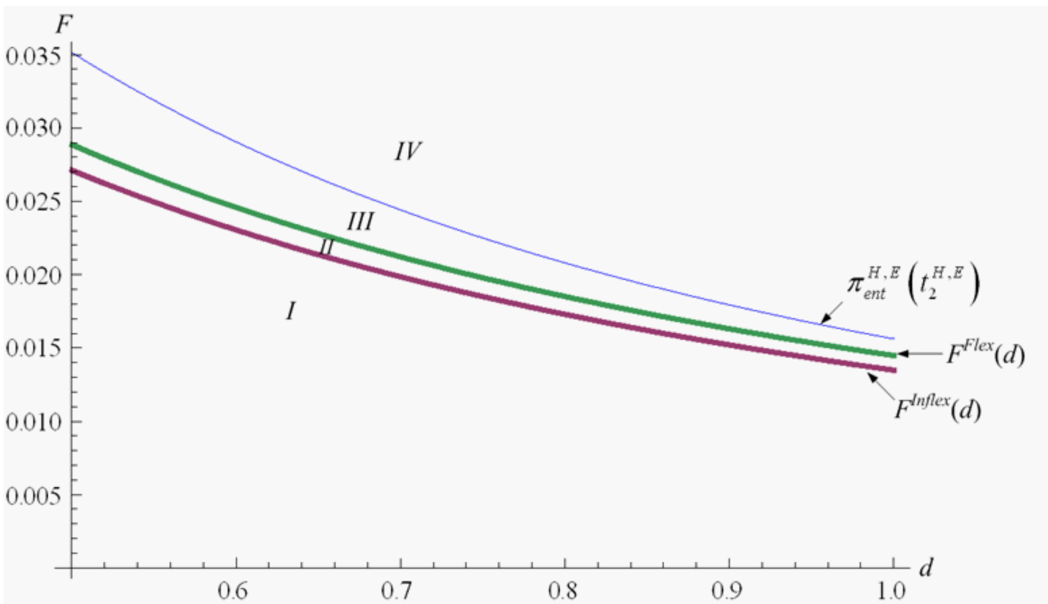

Figure 3. Cutoffs $F^{Flex}(d)$, $F^{Inflex}(d)$ and $\pi_{ent}^{H,E}\left(t_2^{H,E}\right)$.

Proposition 1. *In equilibrium, the regulator selects:*

1. *A flexible policy that attracts entry both in region I and II, since social welfare satisfies* $SW^{H,E}\left(t_1^H, t_2^{H,E}\right) > SW^{H,E}\left(t^{H,E}\right) > SW^{H,NE}\left(\bar{t}\right)$ *and* $SW^{H,E}\left(t_1^H, t_2^{H,E}\right) > SW^{H,NE}\left(\bar{t}\right) > SW^{H,E}\left(t^{H,E}\right)$*, respectively;*

2. *An inflexible policy* $\bar{t}$ *that deters entry in region III, since social welfare satisfies* $SW^{H,NE}\left(\bar{t}\right) > SW^{H,E}\left(t_1^H, t_2^{H,E}\right) > SW^{H,E}\left(t^{H,E}\right)$*; and*

3. *A flexible policy that blockades entry in region IV.*

The regulator's decision can therefore be divided into four regions. When entry costs are sufficiently low, $F < F^{Inflex}(d)$, he prefers to set a flexible policy, since it yields a larger social welfare than an inflexible policy. This case is graphically represented in region I of figure 3. Intuitively,

$c_{inc}^H = \frac{1}{4}$. Different cost parameters yield similar comparisons, and can be provided by the authors upon request.

entry can only be deterred by committing to a relatively stringent fee $\bar{t}$, which reduces the incumbent's monopoly output during both periods, thus significantly decreasing consumer and producer surplus. Furthermore, deterring entry entails a small benefit since the environmental damage from pollution, d, is relatively small in this region. As a consequence, the welfare loss from setting $\bar{t}$ offsets its associated environmental benefits, and a flexible environmental policy is welfare superior. A similar argument holds when entry costs are moderately low, $F^{Inflex}(d) < F < F^{Flex}(d)$ in region II, where flexible policies also yield a larger welfare.[19] When entry costs are relatively high, however, social welfare can be maximized by deterring entry. In region III, entry can be deterred by imposing a relatively low $\bar{t}$, thereby incurring small welfare losses from reducing the incumbent's monopoly output. In addition, such output reduction entails significant environmental benefits, provided that d is relatively high, which ultimately increases overall welfare. Our results hence suggest that governments maintain flexible environmental policies in industries with low entry costs and small environmental damages —which facilitates entry— but commit to relatively high fees otherwise, thus hindering entry.

Finally, the region under which entry deterrence becomes socially optimal (region III) shrinks in the entrant's costs. In particular, an increase in c_{ent} produces a downward shift in the entrant's duopoly profits, $\pi_{ent}^{H,E}\left(t_2^{H,E}\right)$, reducing the distance $\pi_{ent}^{H,E}\left(t_2^{H,E}\right) - F^{Flex}(d)$. Intuitively, when the entrant is more inefficient, its profits upon entry decrease, making him less attracted to the market, and hence the regulator's task of deterring entry becomes less necessary.

Incumbent profits. From a policy perspective, the setting of stringent environmental policies is commonly regarded as a tool governments may use to deter entry and promote the profits of domestic monopolies. The next corollary shows that this is not necessarily true in our model.

Corollary 1. *The profits of the high-cost incumbent are larger when the regulator sets an entry-deterring fee $\bar{t}$ than under any other policy if and only if $F > F^{Profits}(d)$, where $F^{Profits}(d) \equiv \frac{1274(1-c_{inc}^{H})^2}{5625(1+2d)^2}$.*

In particular, fee $\bar{t}$ helps the incumbent maintain her monopoly power, but significantly reduces her output and profits during both periods. As a consequence, the high-cost incumbent prefers that the regulator deters entry only when fee $\bar{t}$, and thus the profit loss that she must bear, is relatively small. This specifically occurs when entry is easy to deter, i.e., entry costs are relatively high. In particular, figure 4 superimposes cutoff $F^{Profits}(d)$ on figure 3, identifying the region where the incumbent prefers to bear a stringent fee $\bar{t}$ in order to deter entry, when $F > F^{Profits}(d)$, or she prefers entry otherwise (shaded area).

[19] The difference with region I arises off-the-equilibrium path since, if the regulator commits to a constant environmental policy, social welfare is now larger by setting an entry-deterrence fee $\bar{t}$ than by commiting to fee $t^{H,E}$.

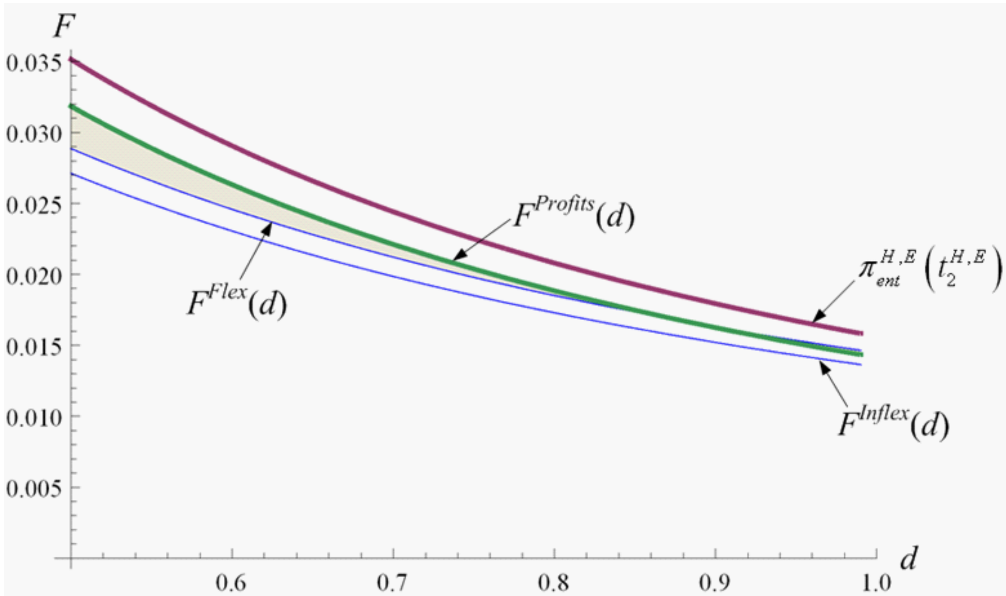

Figure 4. Profits in the entry-deterring equilibrium.

From Proposition 1, the regulator selects an entry-deterring fee $\bar{t}$ when $F^{Flex}(d) < F < \pi_{ent}^{H,E}\left(t_2^{H,E}\right)$. Therefore, the regulator and incumbent's preferences are aligned when entry costs lie in the region above cutoff $F^{Profits}(d)$ and below $\pi_{ent}^{H,E}\left(t_2^{H,E}\right)$ in figure 4. The shaded area represents, in contrast, parameter combinations under which deterring entry is sequentially rational for the regulator, i.e., $F > F^{Flex}(d)$, but such practice imposes a significant profit loss on the incumbent, thereby diminishing her overall profits. In summary, when entry costs are sufficiently high, $F > F^{Profits}(d)$, both the regulator and the high-cost incumbent are willing to bear the cost of a stringent environmental policy in order to deter entry. In contrast, when entry costs are relatively low (in the shaded area), entry-deterrence becomes costly, implying that the incumbent prefers entry rather than bearing the large cost of the strict fee $\bar{t}$ that avoids entry, whereas the regulator still finds entry-deterrence socially optimal.

6 Conclusions

Our paper examines under which conditions governments strategically commit to relatively stringent environmental policies in order to maximize social welfare. We show that entry deterrence becomes socially optimal when its associated welfare loss, due to committing to a stringent fee across time, is smaller than its welfare gain, which arises from an improved environmental quality. Otherwise, the regulator optimally chooses a flexible environmental policy which cannot credibly deter entry. In addition, we demonstrate that the incentives of the social planner and incumbent are not necessarily aligned regarding entry deterrence. In particular, under certain conditions the regulator finds socially optimal to commit to an inflexible policy that deters entry whereas the incumbent would actually prefer a flexible policy that attracts entry.

The paper assumes that the entrant observes the incumbent's costs. In different settings, however, the entrant might not have access to this information, thereby inferring the incumbent's type after observing not only the incumbent's production decision but also the regulator's environmental policy. In such context, environmental regulation can facilitate or hinder the incumbent's information transmission. In addition, we consider a single incumbent, which could be modified to allow for multiple incumbents; as in Gilbert and Vives (1986). Unlike their work, however, free-riding incentives are absent in our model since the incumbents' output choices do not condition entry decisions. Finally, our paper can be extended to the analysis of non-polluting goods. In this case, the regulator would not impose taxes but rather provide subsidies in order to induce firms to produce the socially optimal output.

7 Appendix

7.1 Appendix 1

Let us analyze the existence of socially optimal output and emission fees under complete information.

Second period, No entry. The socially optimal output under monopoly $x_{SO}^{K,NE}$ solves $MB^{K,NE}(x) = MD^{NE}(x)$, where

$$MB^{K,NE}(x) \equiv \frac{\partial[\gamma CS + \pi_{inc}^{K,NE}]}{\partial x} = (1-\gamma)\, p'(x)x + p(x) - c_{inc}^{K}$$

and $MD^{NE}(x) \equiv d'(x)$. Socially optimal output under monopoly $x_{SO}^{K,NE}$ exists if $MB^{K,NE}(0) > MD^{NE}(0)$, which holds since $p(0) - c_{inc}^{K} > d'(0)$. The emission fee that induces the monopolist to produce $x_{SO}^{K,NE}$ is $t_2^{K,NE} = MP_{inc}^{K,NE}\left(x_{SO}^{K,NE}\right)$, where $MP_{inc}^{K,NE}(x_{inc}) \equiv \frac{\partial \pi_{inc}^{K,NE}(x_{inc})}{\partial x_{inc}}$. Note that $t_2^{K,NE}$ is decreasing in costs. In particular, an increase in costs shifts the $MP_{inc}^{K,NE}(x_{inc})$ function downwards, decreasing the value of $x_{SO}^{K,NE}$ that solves $MB^{K,NE}(x) = MD^{NE}(x)$. Given that $MD^{NE}(x)$ is unaffected by the change in costs and it is increasing in x, the optimal value of $t_2^{K,NE}$ decreases.

Second period, Entry. The socially optimal aggregate output under duopoly $X_{SO}^{K,E}$ solves $MB^{K,E}(X) = MD^{E}(X)$, where

$$MB^{K,E}(X) \equiv (1-\gamma)\, p'(X)X + p(X) - c_{inc}^{K}$$

and $MD^{E}(X) \equiv d'(X)$ where $X = x_{inc} + x_{ent}$. In addition, $MB^{K,E}(X)$ is decreasing in X since its slope is $(2-\gamma)\, p'(X)$ given linear demand, which is negative since $\gamma \leq 1$, and $MD^{E}(X)$ is increasing in X since its slope is $d''(X) > 0$. Optimal aggregate output under duopoly $X_{SO}^{K,E}$ exists if $MB^{K,E}(0) > MD^{E}(0)$, which holds since $p(0) - c_{inc}^{K} > d'(0)$. The emission fee $t_2^{K,E}$ that induces the aggregate output $X_{SO}^{K,E}$ is $t_2^{K,E} = MP_j^{K,E}\left(x_{j,SO}^{K,E}|x_{k,SO}^{K,E}\right)$ for all $j = \{inc, ent\}$ and $k \neq j$, where $MP_j^{K,E}\left(x_j|x_{k,SO}^{K,E}\right) \equiv \frac{\partial \pi_j^{K,E}(x_j|x_{k,SO}^{K,E})}{\partial x_j}$ for all firm $j \neq k$. Note that $t_2^{K,E}$ is decreasing in the incumbent's costs, i.e., $t_2^{L,E} > t_2^{H,E}$. In particular, an increase in the incumbent's costs decreases $X_{SO}^{K,E}$ since both firms' best response functions have a slope larger than -1. That is,

$$\frac{\partial x_{ent}(x_{inc})}{\partial x_{inc}} = -\frac{\frac{\partial^2 \pi_{ent}^{K,d}}{\partial x_{ent}\partial x_{inc}}}{\frac{\partial^2 \pi_{ent}^{K,d}}{\partial x_{ent}^2}} = -\frac{p' + p'' x_{ent}}{2p' + p'' x_{ent}} > -1$$

where $p \equiv p(X)$ and $p'' = 0$ given that demand is linear. Given that $MD^{E}(X)$ is unaffected by the change in costs and it is increasing in X, the optimal value of $t_2^{K,E}$ decreases.

First period. The socially optimal output under first-period monopoly q_{SO}^{K} solves $MB^{K,NE}(q) = MD^{NE}(q)$, where

$$MB^{K,NE}(q) \equiv (1-\gamma)\, p'(q) q + p(q) - c_{inc}^{K}$$

and $MD^{NE}(q) \equiv d'(q)$. By a similar argument as for $t_2^{K,E}$ emission fee t_1^{K} exists and is decreasing in costs. ■

7.2 *Proof of Lemma 1*

Under an inflexible policy regime, the social welfare from setting a constant entry-deterring fee $\bar{t} = 1 - c_{inc}^{H} - 3\sqrt{F}$ is

$$SW^{H,NE}(\bar{t}) = \frac{3\sqrt{F}\left[4 - (3+6d)\sqrt{F} - 4c_{inc}^{H}\right]}{4}$$

where the high-cost incumbent produces according to the monopoly output function $q^{H}(t) = \frac{1-c_{inc}^{H}}{2}$ during both periods. If, in contrast, the regulator selects a constant fee $t^{H,E}$, entry ensues, yielding an overall social welfare of

$$SW^{H,E}(t^{H,E}) = \frac{49 - 49(2 - c_{inc}^{H})c_{inc}^{H}}{50(1+2d)} - F$$

Hence, the regulator prefers to deter entry, i.e., $SW^{H,NE}(\bar{t}) > SW^{H,E}(t^{H,E})$, if $F > F^{Inflex}(d)$, where

$$F^{Inflex}(d) \equiv \frac{1310 + 8d(557 + 459d) - 60\sqrt{2}(1 - c_{inc}^{H})^2 G - 2(1+2d)(655 + 918d)(2 - c_{inc}^{H})c_{inc}^{H}}{25(5 + 28d + 36d^2)}$$

and $G \equiv \left[(1+2d)^3(205 + 18d)\right]^{\frac{1}{2}}$. First, note that cutoff $F^{Inflex}(d)$ is decreasing in d for all costs $c_{inc}^{H} \in (0,1)$. Second, cutoff $F^{Inflex}(d)$ lies below $F^{*} \equiv \frac{\left(1-c_{inc}^{H}\right)^2}{9}$ for all admissible values of d, i.e.,

$d \in \left(\frac{1}{2}, 1\right)$. In particular, the highest point of cutoff $F^{Inflex}(d)$, $F^{Inflex}\left(\frac{1}{2}\right)$, is

$$\frac{557 - 30(1 - c_{inc}^H)^2\sqrt{214} - 557(2 - c_{inc}^H)c_{inc}^H}{2450}$$

which is lower than $F^* \equiv \frac{\left(1-c_{inc}^H\right)^2}{9}$, which is constant in d, for all costs $c_{inc}^H \in (0, 1)$. Third, cutoff $F^{Inflex}(d)$ also lies below the entrant's duopoly profits under the flexible fee $t_2^{H,E}$, $\pi_{ent}^{H,E}(t_2^{H,E})$. Specifically, $\pi_{ent}^{H,E}(t_2^{H,E}) = \frac{\left(1-c_{inc}^H\right)^2}{4(1+2d)^2}$ is decreasing in d, reaching its highest value at $d = \frac{1}{2}$, $\frac{\left(1-c_{inc}^H\right)^2}{16}$, which lies above $F^{Inflex}\left(\frac{1}{2}\right)$; and reaches its lowest value at $d = 1$, $\frac{\left(1-c_{inc}^H\right)^2}{36}$, which also lies above $F^{Inflex}(1)$. Fourth, note that the entrant's duopoly profits under the inflexible fee $t^{H,E}$, $\pi_{ent}^{H,E}(t^{H,E}) = \frac{196(1-c_{inc}^H)}{625(1+2d)}$, satisfy $\pi_{ent}^{H,E}(t^{H,E}) > \pi_{ent}^{H,E}(t_2^{H,E})$ since $t^{H,E} < t_2^{H,E}$, i.e., $t^{H,E}$ is less stringent than $t_2^{H,E}$. Therefore, if $F^{Inflex}(d)$ satisfies $F^{Inflex}(d) < \pi_{ent}^{H,E}(t_2^{H,E})$, then

$$F^{Inflex}(d) < \pi_{ent}^{H,E}(t_2^{H,E}) < \pi_{ent}^{H,E}(t^{H,E}).$$

Finally, note that profits $\pi_{ent}^{H,E}(t^{H,E})$ lie below cutoff F^*. Indeed, $\pi_{ent}^{H,E}(t^{H,E})$ reaches its highest point at $d = \frac{1}{2}$, $\frac{49\left(1-c_{inc}^H\right)^2}{625}$, which is lower than cutoff F^*. Since F^* is constant in d, then $F^* > \pi_{ent}^{H,E}(t^{H,E})$ under all parameter values. ■

7.3 *Proof of Proposition 1*

Second period. Under no entry, the K-type incumbent solves

$$\max_{x_{inc}} \; (1 - x_{inc})x_{inc} - \left(c_{inc}^K + t\right)x_{inc}$$

which is maximized at $x_{inc}^{K,NE}(t) = \frac{1-\left(c_{inc}^K+t\right)}{2}$ for any fee t set by the regulator (notice that this allows for flexible and inflexible policies). Similarly, under entry, the incumbent solves

$$\max_{x_{inc}} \; (1 - x_{inc} - x_{ent})x_{inc} - \left(c_{inc}^K + t\right)x_{inc}.$$

whereas the entrant solves a similar problem, where his marginal production costs are high. In this subgame, the K-type incumbent selects a duopoly output of $x_{inc}^{K,E}(t) = \frac{1-2\left(c_{inc}^K+t\right)+(c_{ent}+t)}{3}$ and the entrant chooses $x_{ent}^{K,E}(t) = \frac{1-2(c_{ent}+t)+\left(c_{inc}^K+t\right)}{3}$. In this context, the socially optimal output X_{SO}^K that solves $MB^{K,NE}(x) = MD^{NE}(x)$, which implies $-(1-\gamma)x + (1-x) - c_{inc}^K = 2dx$, is $X_{SO}^K = \frac{1-c_{inc}^K}{2+2d-\gamma}$, which is positive if $d \in \left[\frac{\gamma}{2}, \frac{1+\gamma}{2}\right]$. Under no entry, the regulator can induce X_{SO}^K by setting a second-period fee that satisfies $t_2^{K,NE} = MP_{inc}^{K,NE}(X_{SO}^{K,NE})$, that is $t_2^{K,NE} = (2d-\gamma)X_{SO}^K$. Similarly, under entry, the social planner seeks to induce the same socially optimal output X_{SO}^K. This implies that, in order to find fee $t_2^{K,E}$ and individual output levels $x_{j,SO}^{K,E}$ and $x_{k,SO}^{K,E}$, the social planner must simultaneously solve $x_{j,SO}^{K,E} + x_{k,SO}^{K,E} = X_{SO}^{K,E}$ and $t_2^{K,E} = MP_j^{K,E}\left(x_{j,SO}^{K,E} | x_{k,SO}^{K,E}\right)$ for both firms $j = \{inc, ent\}$. In the context of our example, this implies $t_2^{H,E} = (1 + 4d - 2\gamma)\frac{X_{SO}^{H,E}}{2}$

when the incumbent's costs are high. Note that this yields profits of $\pi_{ent}^{H,E}\left(t_2^{H,E}\right) \equiv \frac{\left(1-c_{inc}^H\right)^2}{4(1+2d)^2}$ for the entrant, implying that entry is blockaded when the fixed entry costs, F, are sufficiently high, i.e., $F > \frac{\left(1-c_{inc}^H\right)^2}{4(1+2d)^2}$. When the incumbent's costs are low, the regulator sets a second-period fee $t_2^{L,E} = \frac{A(1-c_{inc}^H)-B(1-c_{inc}^L)}{2A}$, where $A \equiv 2+2d-\gamma$ and $B \equiv 1-2d+\gamma$. This fee and the resulting duopoly output are positive as long the difference between the incumbent's and entrant's cost is not too large, i.e., $c_{inc}^L < c_{inc}^H < \frac{1+Dc_{inc}^L}{A}$, where $D \equiv 1+2d-\gamma$.

First period. Since the incumbent operates as a monopolist in the first-period game, she chooses output function $q^K(t) = \frac{1-\left(c_{inc}^K+t\right)}{2}$ for any fee t. Given this output function, under a flexible environmental policy the regulator sets a first-period fee t_1^K that solves $t_1^K = MP_{inc}^K(q_{SO}^K)$ where q_{SO}^K denotes the socially optimal output $q_{SO}^K = \frac{1-c_{inc}^K}{2+2d-\gamma}$, i.e., fee $t_1^K = (2d-\gamma)q_{SO}^K$. Under an inflexible policy, the regulator sets a fee $t^{L,NE}$ when the incumbent's costs are low (and thus he anticipates no entry to ensue in the second period) where $t^{L,NE}$ coincides with first- and second-period fees under no entry, i.e., $t^{L,NE} = t_1^L = t_2^{L,NE}$. In contrast, when the incumbent's costs are high, the regulator anticipates entry in the following period, thus setting a fee $t^{H,E}$ that minimizes the deadweight loss as described in expression (6) in the text, i.e., $t^{H,E} = \frac{9}{25}t_1^H + \frac{16}{25}t_2^{H,E}$ where $t_1^H < t^{H,E} < t_2^{H,E}$. In this setting, however, the regulator can choose to commit to an entry-deterring fee $\bar{t}$ such that $\pi_{ent}^{H,E}(t) < F$ for all $t > \bar{t}$. In particular, given that $\pi_{ent}^{H,E}(t) = \frac{1}{9}(1-c_{ent}-t)^2$, the fee $\bar{t}$ that solves $\pi_{ent}^{H,E}(\bar{t}) = F$ is $\bar{t} = 1-c_{inc}^H - 3\sqrt{F}$. This fee $\bar{t}$ is positive for all $F < F^*$, where $F^* \equiv \frac{\left(1-c_{inc}^H\right)^2}{9}$.

Finally, the regulator chooses whether to maintain a flexible policy across periods or to commit to a given emission fee and, if so, whether to allow or deter entry. When the incumbent's costs are low, entry does not occur, and thus the regulator maximizes social welfare by selecting a flexible policy. When the incumbent's costs are high, however, entry ensues as long as the constant fee t does not exceed $\bar{t}$. The overall social welfare that the regulator obtains from setting flexible emission fees t_1^H and $t_2^{H,E}$ is $SW^{H,E}\left(t_1^H, t_2^{H,E}\right) = \frac{1-(2-c_{inc}^H)c_{inc}^H}{1+2d} - F$, that of committing to a constant fee $t^{H,E}$ that allows entry is $SW^{H,E}\left(t^{H,E}\right) = \frac{49-49(2-c_{inc}^H)c_{inc}^H}{50(1+2d)} - F$, and that of committing to an entry-deterring fee $\bar{t}$ is $SW^{H,NE}(\bar{t}) = \frac{3\sqrt{F}\left[4-(3+6d)\sqrt{F}-4c_{inc}^H\right]}{4}$. It is straightforward to show that $SW^{H,E}\left(t_1^H, t_2^{H,E}\right) > SW^{H,E}(\bar{t})$ when $F < F^{Flex}(d)$, where

$$F^{Flex}(d) \equiv \frac{\psi - 48(1-c_{inc}^H)^2(1+2d)^{3/2} - R}{(5+28d+36d^2)^2}$$

and $\psi \equiv 52+16d(11+9d)$ and $R \equiv 4(1+2d)(13+18d)(2-c_{inc}^H)c_{inc}^H$. In addition, $SW^{H,NE}(\bar{t}) > SW^{H,E}\left(t^{H,E}\right)$ when $F > F^{Inflex}(d)$, as described in Lemma 1, and $F^{Inflex}(d) < F^{Flex}(d)$. This implies that when $F < F^{Inflex}(d)$, social welfare satisfies $SW^{H,E}\left(t_1^H, t_2^{H,E}\right) > SW^{H,E}\left(t^{H,E}\right) > SW^{H,NE}(\bar{t})$, and the regulator sets a flexible policy; when $F^{Inflex}(d) < F < F^{Flex}(d)$, social welfare satisfies $SW^{H,E}\left(t_1^H, t_2^{H,E}\right) > SW^{H,NE}(\bar{t}) > SW^{H,E}\left(t^{H,E}\right)$, and the regulator also sets a flexible policy; when $F^{Flex}(d) < F < \pi_{ent}^{H,E}\left(t_2^{H,E}\right)$, social welfare satisfies $SW^{H,NE}(\bar{t}) >$

$SW^{H,E}\left(t_1^H, t_2^{H,E}\right) > SW^{H,E}\left(t^{H,E}\right)$, and the regulator commits to an inflexible fee $\bar{t}$ that deters entry; and when $F > \pi_{ent}^{H,E}\left(t_2^{H,E}\right)$, entry is blockaded and the regulator selects a flexible environmental policy. ■

7.4 *Proof of Corollary 1*

The profits of the high-cost incumbent when the regulator sets an entry-deterring fee $\bar{t} = 1 - c_{inc}^H - 3\sqrt{F}$ are $\frac{9F}{4}$ during both the first and second period, where the high-cost incumbent produces according to the monopoly output function $q^H(t) = \frac{1-c_{inc}^H}{2}$ during both periods, yielding an overall profit of $\frac{18F}{4}$.

If the regulator chooses a flexible policy regime, with equilibrium fees t_1^H and $t_2^{H,E}$ for the first and second-period, respectively, the high-cost incumbent's profits become $\frac{(1-c_{inc}^H)^2}{(1+2d)^2}$ in the first period and $\frac{(1-c_{inc}^H)^2}{4(1+2d)^2}$ in the second period (after entry ensues). Hence, overall profits are $\frac{5(1-c_{inc}^H)^2}{4(1+2d)^2}$. Therefore, profits under the entry-deterring fee $\bar{t}$ are larger than under the flexible fees $\left(t_1^H, t_2^{H,E}\right)$ for all $F > F^{Profits,Flex}(d)$ where $F^{Profits,Flex}(d) \equiv \frac{5(1-c_{inc}^H)^2}{18(1+2d)^2}$.

If the regulator selects an inflexible policy regime, with equilibrium fee $t^{H,E}$, the high-cost incumbent's profits become $\frac{441(1-c_{inc}^H)^2}{625(1+2d)^2}$ in the first period and $\frac{196(1-c_{inc}^H)^2}{625(1+2d)^2}$ in the second period (after entry ensues). Hence, overall profits are $\frac{(9+4\delta)(3+4\delta)^2(1-c_{inc}^H)^2}{(9+16\delta)^2(2+2d-\gamma)^2}$, or $\frac{637(1-c_{inc}^H)^2}{625(1+2d)^2}$ when $\gamma = \delta = 1$. Therefore, profits under the entry-deterring fee $\bar{t}$ are larger than under the inflexible fee $t^{H,E}$ for all $F > F^{Profits,Inflex}(d)$ where $F^{Profits,Inflex}(d) \equiv \frac{1274(1-c_{inc}^H)^2}{5625(1+2d)^2}$.

In addition, note that cutoff $F^{Profits,Inflex}(d) > F^{Profits,Flex}(d)$, since the difference

$$F^{Profits,Inflex}(d) - F^{Profits,Flex}(d) = \frac{98(1-c_{inc}^H)^2}{625(1+2d)^2}$$

is positive under all parameter values. Furthermore, $\pi_{ent}^{H,E}(t^{H,E}) > F^{Profits,Inflex}(d)$ since the difference

$$\pi_{ent}^{H,E}(t^{H,E}) - F^{Profits,Inflex}(d) = \frac{98(1-c_{inc}^H)^2}{1125(1+2d)^2}$$

is positive under all parameter values. Therefore, $\pi_{ent}^{H,E}(t^{H,E}) > F^{Profits,Inflex}(d) > F^{Profits,Flex}(d)$. Hence, the region of parameter values under which the regulator prefers to practice entry deterrence but the high-cost incumbent does not occurs when $F < F^{Profits,Inflex}(d)$. Otherwise, both agents prefer the entry-deterring fee $\bar{t}$. Therefore, only cutoff $F^{Profits,Inflex}(d)$ is binding, and we denote $F^{Profits,Inflex}(d)$ as $F^{Profits}(d)$. ■

References

[1] Alvarez, F., P.J. Kehoe and P.A. Neumeyer. (2004). "The time consistency of optimal monetary and fiscal policies." Econometrica, 72, pp. 541-67.

[2] Bain, J. (1956) *Barriers to New Competition*, Cambridge, Harvard University Press.

[3] Barro, R. and D. Gordon (1983). "A positive theory of monetary policy in a natural rate model." Journal of Political Economy 91, pp. 589-610.

[4] Benhabib, J.,A. Rustichini, and A. Velasco (2001). "Public spending and optimal taxes without commitment." Review of Economic Design 6, pp. 371-396.

[5] Brock, W. and D. Evans (1985) "The Economics of Regulatory Tiering." RAND Journal of Economics, 16(3), pp. 398-409.

[6] Chamley, C. (1986). "Optimal taxation of capital income in general equilibrium with infinite lives." Econometrica 54, pp. 607-22.

[7] Chang, R. (1998). "Credible monetary policy in an infinite horizon model: Recursive approach." Journal of Economic Theory 81, pp. 431-461.

[8] Dean, T. and R. Brown (1995) "Pollution regulation as a barrier to new firm entry: Initial evidence and implications for further research." Academy of Management Journal, 38(1), pp. 288–303.

[9] Dean, T., R. Brown and V. Stango (2000) "Environmental Regulation as a Barrier to the Formation of Small Manufacturing Establishments: A Longitudinal Examination." Journal of Environmental Economics and Management, 40(1), pp. 56-75.

[10] Dixit, A. (1980) "The role of investment in entry-deterrence." Economic Journal 90, pp. 95-106.

[11] Dixit, A. and L. Lambertini (2003) "Interactions of Commitment and Discretion in Monetary and Fiscal Policies." American Economic Review 93(5), pp. 1522-42.

[12] Fudenberg, D. and J. Tirole (1984) "The fat-cat effect, the puppy-dog ploy, and the lean and hungry look." American Economic Review, 74(2), pp. 361–66.

[13] Gilbert, R. and X. Vives (1986) "Entry deterrence and the free-rider problem." Review of Economic Studies 172, pp. 71-83.

[14] Helland, E. and M. Matsuno (2003) "Pollution Abatement as a Barrier to Entry." Journal of Regulatory Economics, 24(2), pp. 243-259.

[15] Ko, I., H.E. Lapan, and T. Sandler (1992) "Controlling stock externalities: Flexible versus inflexible pigouvian corrections." European Economic Review 36. pp. 1263-1276.

[16] Kydland, F. and E. Prescott (1977) "Rules rather than discretion: The inconsistency of optimal plans." Journal of Political Economy 85, pp. 473-492.

[17] Kovenoch, D. and S. Roy (2005) “Free-riding in non-cooperative entry deterrence with differentiated products.” Southern Economic Journal 72, pp. 119-137.

[18] Monty, R. L. (1991) “Beyond environmental compliance: Business strategies for competitive advantage.” Environmental Finance, 11(1), pp. 3–11.

[19] OECD (2006) “Environmental Regulation and Competition.” OECD Competition Policy Rountables. Directorate for Financial and Enterprise Affairs, Competition Committee.

[20] Ryan, S. (2011) “The Costs of Environmental Regulation in a Concentrated Industry.” forthcoming in Econometrica.

[21] Spence, M. (1977) “Entry, capacity, investment and oligopolistic pricing.” Bell Journal of Economics 10, pp. 1-19.

[22] Stavins, R. (2005) “The Effects of Vintage-Differentiation Environmental Regulation.” Discussion paper, Resources for the Future, Washington, D.C.

[23] Sylos-Labini, P. (1962) *Oligopoly and Technical Progress*, Cambridge, Harvard University Press.

[24] Ungson, G., C. James and B. Spicer (1985) “The Effects of Government Regulatory Agencies on Organizations in High Technology and Woods Products Industries.”Academy of Management Journal, 28 (2), pp. 426-445.

[25] Waldman, M. (1987) “Noncooperative entry deterrence, uncertainty and the free-rider problem.” Review of Economic Studies 54, pp. 301-10.

[26] Ware, R. (1984) “Sunk Costs and Strategic Commitment: A Proposed Three-Stage Equilibrium.” The Economic Journal 94, pp. 370-378.