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A Signalling Model of Environmental Overcompliance

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Abstract. I model environmental overcompliance as a signaling device. In the model, a benevolent government may or may not tighten environmental standards. Production costs under the stricter environmental regulation are private information to the firms, and tightening environmental policy is socially desirable only if such costs are sufficiently low. The key assumption of the model is that firms differ in the cost of complying, and so those firms that enjoy a comparative advantage may actually benefit from tighter regulation. In these circumstances, such firms may overcomply in order to signal to the government that compliance costs are low, thus inducing the government to enforce stricter regulation.

1 Introduction

It is not uncommon that firms undertake *unilateral* actions aimed at improving their environmental performance, and overcomply to existing environmental standards. Unlike public voluntary agreements or negotiated agreements, these actions may be undertaken without any explicit bargaining with public authorities.[1] There are two main explanations of this behavior (see Brau and Carraro (1999) for a survey). One explanation ("green consumerism") contends that environmentally concerned consumers reward firms that overcomply by redirecting their demand towards these firms: see Arora and Gangopadhyay (1995). Another explanation ("regulatory threat") is that firms overcomply to reduce the risk of tighter regulation, or to induce the government to choose a form of regulation more favorable to them: see Segerson and Miceli (1999), Maxwell, Lyon and Hackett (2000) and Lutz, Lyon and Maxwell (2000).

However, sometimes firms overcomply in the absence of evident regulatory threats, and the adoption of green technologies is unknown to the general public – especially in the case of "process" rather than "product" overcompliance. This suggests that there may be other reasons why firms enter unilateral voluntary agreements. This paper offers a new explanation of overcompliance, that complements the green-consumerism and the regulatory-threat approaches.

Both approaches share the premise that tightening environmental regulation reduces firms' profits. Obviously, this is what must happen when firms are symmetric, but when firms are asymmetric environmental regulation is not necessarily detrimental to all firms

[1] See Borkey, Glachant and Leveque (1998). In a survey of Voluntary Agreements in the U.S., Mazurek (1999) finds that about one quarter of all agreements were unilateral.

operating in an industry. In oligopoly, particularly if competition is tough, each firm' profit depends on its rivals' costs as well as on own cost, and so firms enjoying a comparative advantage in complying may actually gain from regulation.

To see how this observation may form the basis of a new explanation of environmental overcompliance, suppose that the cost associated with a green technology that meets tighter environmental standards is private information to the firms. Suppose also that it is socially desirable to adopt the green technology if this cost is low, while the social planner wants firms to stick to the dirty technology if the cost is high. Those firms that enjoy a comparative advantage in the adoption of the green technology may then want to induce the government to enforce stricter regulation. Thus, they may wish to signal to the government that the cost of adhering to tighter environmental standards is low. Overcompliance may be a way to send an informative signal. Overcomplying firms bear a cost while their competitors do not comply, but they may gain enough to recoup initial costs when the government regulates and all the other firms are obliged to comply as well. The signal is informative provided that overcomplying is relatively more profitable when the cost associated with the green technology is low.[2]

In the remainder of the paper I formalize the above argument. I present a reduced-form two-period duopoly model with a low-cost firm and a high-cost firm (Section 2). In the first period, the low-cost firm may overcomply to signal to the government that the cost associated with the green technology is not too high. If the government regulates, both firms must adopt

[2] This mechanism is an example of the raising-rivals'-costs tactic (see Krattenmaker and Salop, 1986). This paper shows that raising rivals' costs may be profitable even if own costs raise, provided that the cost gap increases sufficiently, and demonstrates a particular mechanism that leads to an increase in rivals' costs, namely government's regulation triggered by firms' signaling.

the green technology in the second period. Such a model admits separating, semi-separating, and pooling equilibria; overcompliance may emerge in all types of equilibria, although it is more likely in the separating and semi-separating equilibria (Section 3). I then present two examples that fit the assumptions of the reduced-form model for a sizeable set of parameter values: Cournot and Bertrand competition with constant marginal costs (Section 4). I also develop a pre-emption model where the potential entrant can recoup the entry cost only if the government does not regulate and therefore overcompliance is an entry-deterrence device (Section 5). Section 6 offers some concluding remarks.

2 The model

Consider a duopolistic industry in a partial equilibrium framework. Two firms, A and B, produce using either a clean (C) or a dirty (D) technology. There are two periods. At the beginning of each period firms choose whether to adopt the clean or the dirty technology. In the first period, the industry is unregulated. For simplicity, I assume that firm A alone can adopt the clean technology in the first period.[3] Firms' costs with the dirty technology are lower than with the clean technology. The costs associated with the clean technology are uncertain and depend on the realization of a random variable θ. For simplicity, I assume that θ can take on only two values, low ($\theta = \underline{\theta}$) or high ($\theta = \overline{\theta}$). The value of θ is private information to the firms. I denote by p government's prior belief that $\theta = \underline{\theta}$ (so $1 - p$ is the probability that $\theta = \overline{\theta}$). This probability p is common knowledge.

I model environmental policy as an ongoing process, assuming that long-run commitments are not feasible. Thus, at the beginning of the second period, a benevolent government can

[3] This assumption can be relaxed, however: see footnote 7 below.

decide to tighten environmental standards (*regulate*), in which case both firms are forced to adopt the clean technology in the second period. For simplicity, I rule out the possibility that the government can regulate in the first period.[4]

The game unfolds as follows. First, Nature chooses the cost associated with the clean technology, $\underline{\theta}$ (with probability p) or $\overline{\theta}$ (with probability $1 - p$). The outcome is observed by both firms, but not by the government. Then, at the beginning of the first period, firm A chooses whether to adopt the clean or the dirty technology. This choice is observed by firm B. Next, firms compete in the product market and collect first-period profits. First-period prices and outputs are not observed by the government, but the government observes firm A's technology choice in the first period, and may revise its prior beliefs accordingly. Based on these revised beliefs, at the beginning of the second period the government chooses whether or not to regulate, i.e., to force firms to adopt the clean technology. Then, firms choose the second-period technology (they must choose the clean technology if the government has regulated). Finally, firms compete again in the product market and collect second-period profits.

The assumption that first-period prices and output are not observed by the government rules out the possibility that firms signal through their pricing or output strategies. However, firm A can signal through its first-period technology choice. In particular, firm A may adopt the clean technology in the first period, i.e., it may *overcomply*, in order to influence government's policy.

By sequential rationality, equilibrium in later stages of the game is not affected by the

[4] This assumption is restrictive only if the government would regulate in the absence of any further information, given its prior beliefs p. If the government would not regulate given its prior beliefs p, ruling out first-period regulation is an innocent assumption.

choice of first-period prices or output. Thus, at the market competition stages, firms play a standard one-shot game in each period. I do not rely on any specific model of the product market.[5] Any reasonable specification of the market competition stages implies that each firm's profit is weakly decreasing in its own cost and weakly increasing in its rival's cost. In particular, denoting by $\pi_i(T_i, T_j)$ firm i's profit when firm i adopts technology $T_i \in \{D, C\}$ and firm j adopts technology $T_j \in \{D, C\}$, for $i = A, B$ and $i \neq j$, it must be that

$$\pi_i(C, D, \theta) \leq \pi_i(D, D) \text{ and } \pi_i(C, C, \theta) \leq \pi_i(D, C, \theta). \tag{1}$$

This means that adopting the dirty technology would be a dominant strategy in a one-shot game. Consequently, in the second period both firms will adopt the dirty technology if the government has not regulated (they must adopt the clean technology if the government has regulated). Firm i's total discounted profit is:[6]

$$\Pi_i = \pi_i^1 + \delta \pi_i^2. \tag{2}$$

Clearly, firm B is a dummy in the signaling game. The extended game is therefore equivalent to the following reduced game, involving two active players only (firm A and the government):

Stage 0. Nature chooses the low-cost type (i.e. $\theta = \underline{\theta}$, with probability p) or the high-cost type (i.e. $\theta = \overline{\theta}$, with probability $1 - p$).

Stage 1. In the first-period, firm A chooses whether to adopt the clean or the dirty

[5] See Sections 4 and 5 below for some examples.

[6] I do not restrict δ to be lower than 1, in order to allow for the possibility that the second period's duration is longer than that of the first.

technology.

Stage 2. At the beginning of the second period, having observed firm A's first-period choice, the government chooses whether or not to regulate.

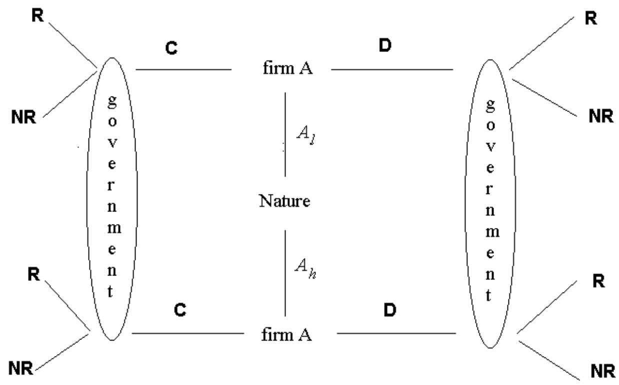

Figure 1: The signaling game

This game is represented in Figure 1. A strategy for firm A in this game is a mapping $\{A_l, A_h\} \rightarrow \{D, C\}$, where A_l and A_h are the low- and high-cost types, and D and C denote adoption of the dirty and clean technology, respectively. A government's strategy is a mapping $\{D, C\} \rightarrow \{R, NR\}$ that specifies whether the government regulates (R) or not (NR) upon observing adoption of the dirty or clean technology.

Since I have assumed that the government can regulate only at the beginning of the second period, its payoff is second-period social welfare, i.e., the sum of consumers' and producers' surpluses minus environmental damages (I drop the time superscripts when there is no possibility of confusion)

$$W = \pi_A + \pi_B + CS \,\square\, D, \tag{3}$$

where CS denotes consumers' surplus and D denotes environmental damages. Environmental damages are lower when output is produced using the clean technology. Thus, in deciding whether or not to regulate, the government must balance the social costs associated with the increase in firms' costs (and the associated decrease in output) and the social benefits due to the decrease in environmental damages. Denote by W^{NR} second-period social welfare if the government does not regulate, so that both firms adopt the dirty technology, by $\underline{W}^R$ social welfare if the government regulates and costs are low ($\theta = \underline{\theta}$), and by $\overline{W}^R$ social welfare if the government regulates and costs are high ($\theta = \overline{\theta}$).

I make the following assumptions, that will be maintained throughout the paper:

Assumption 1. Firm A gains from regulation when the cost associated with the clean technology is low: $\pi_A(C, C, \underline{\theta}) > \pi_A(D, D)$.

Assumption 2. With full information, regulation is welfare increasing if $\theta = \underline{\theta}$, and it is welfare reducing if $\theta = \overline{\theta} : \underline{W}^R > W^{NR} > \overline{W}^R$.

Both assumptions are required for the existence of signaling equilibria. Assumption 2 rules out trivial cases where regulation is always desirable or is never desirable. In these cases, government's policy could not be influenced by firm A's technology adoption in the first period, and so firm A would have no reason to engage in signaling. Assumption 1 tends to be satisfied when firms are asymmetric and firm A has a comparative advantage in complying to tighter environmental standards. As the examples below will show, firm A may then well gain from regulation. In general, the tougher is product market competition, the more likely it is that Assumption 1 is satisfied. Clearly, if firm A did not gain from regulation, it would never wish to signal that the cost of compliance is low.

I shall focus on the sequential equilibria of the game. In a sequential equilibrium, the firms' and government's strategies are sequentially rational, and strategies and beliefs can be regarded as limits of totally mixed strategies and associated beliefs (Kreps and Wilson, 1981). In particular, this means that government's beliefs conform with Bayes' rule whenever it applies.

3 Sequential equilibria

I now proceed to analyze the sequential equilibria of the signaling game described in the previous Section. The game admits separating, semi-separating, and pooling equilibria. In separating equilibria, the low-cost type adopts the clean technology and the high-cost type adopts the dirty technology. The government thus infers from technology choice the true cost of complying. In a pooling equilibrium, both types adopt the same technology in the first period. Finally, in a semi-separating equilibrium the low-cost type always chooses the clean technology and the high-cost type randomizes between adopting the clean and the dirty technology in the first period.

Which kind of equilibrium will emerge depends on two key conditions. First, consider the government's sequentially rational strategy in a pooling equilibrium. In general, denoting by q the government's second period up-dated beliefs that the cost associated with the clean technology is low, expected social welfare under regulation is $W^R(q) = q\underline{W}^R + (1 - q)\overline{W}^R$. By Assumption 2, there exists a critical value $q^* \in (0,1)$, which is implicitly defined as the solution to $W^R(q^*) = W^{NR}$, such that the government regulates if $q > q^*$, and does not regulate if $q < q^*$. In a pooling equilibrium, $q = p$. Then, if $p > q^*$, the government would regulate in a pooling equilibrium, while if this inequality is reversed, the government would not regulate.[7]

The second key condition relates to firm A's incentive to signal in the first period. Assumption 1 guarantees that firm A's second-period profit under regulation is greater than in the absence of regulation, but there is an opportunity cost to overcomplying, which is given by firm A's foregone first-period profit $\pi_A(D,D) - \pi_A(C,D,\theta)$. Thus, firm A may want to overcomply only if $z\delta\,[\pi_A(C,C,\theta) - \pi_A(D,D)] > [\pi_A(D,D) - \pi_A(C,D,\theta)]$, that is, if and only if

$$\Phi(z,\theta) \equiv z\delta\pi_A(C,C,\theta) + \pi_A(C,D,\theta) - (1 + z\delta)\pi_A(D,D) > 0, \tag{4}$$

where z is the probability that the government regulates.

By Assumption 1, $\Phi(z,\underline{\theta})$ is increasing in z. Note that $\pi_A(C,D,\theta)$ must be weakly decreasing in θ. If the parameter θ affects both firms symmetrically, as in the examples below, it seems natural to posit that $\pi_A(C,C,\theta)$ is also decreasing in θ. In what follows, a weaker assumption is however sufficient:

Assumption 3. $\Phi(z,\theta)$ is decreasing in θ.

[7] In the following analysis, I focus on strict inequalities involving parameters. Cases arising when some inequalities are weak are nongeneric and their analysis is left to the interested reader.

Under Assumption 3, firm A has a greater incentive to engage in signaling when the compliance cost is low. Thus, three cases are possible, as inequality (4) may be satisfied at $z = 1$ for both types ($\Phi(1, \overline{\theta}) > 0$), for no type ($\Phi(1, \underline{\theta}) < 0$), or for the low-type only ($\Phi(1, \overline{\theta}) < 0 < \Phi(1, \underline{\theta})$).

I next show in some detail how the type of equilibria that the signaling game admits – separating, semi-separating, and pooling – depend on these conditions.

3.1 Separating equilibria

In this subsection I identify a region of parameter values where the game admits a unique overcompliance equilibrium. At this equilibrium, which is separating, the low-cost type signals its type by overcomplying, thus inducing the government to regulate. This separating equilibrium obtains when $p < q$, so that the government prefers not to regulate in the absence of further information, and only the low-cost type may ever want to overcomply, i.e., $\Phi(1, \underline{\theta}) > 0 > \Phi(1, \overline{\theta})$.

Proposition 1. If $p < q$ and $\Phi(1, \underline{\theta}) > 0 > \Phi(1, \overline{\theta})$, there is a unique, separating equilibrium where the low-cost type adopts the clean technology in the first period, the high-cost type adopts the dirty technology in the first period, and the government regulates if and only if it observes that firm A has adopted the clean technology.

Proof. It is immediate to confirm that the proposed equilibrium is, indeed, an equilibrium.

To show uniqueness, note that inequality $\Phi(1, \overline{\theta}) < 0$ means that the high-cost type would never overcomply in the first period. Thus, upon observing overcompliance, the government must infer that $\theta = \underline{\theta}$ and therefore must regulate with probability 1. But then the low-cost type must necessarily overcomply, since $\Phi(1, \underline{\theta}) > 0$. *Q.E.D.*

Proposition 1 shows that overcompliance may be a used as a signaling device. Since only the low-cost type is willing to overcomply, the signal is informative and from the observation that firm A has adopted the green technology the government infers that the associated cost is low. Thus, the government regulates, and in the second period low-cost type firm A recoups the cost of first-period overcompliance.

3.2 Semi-separating equilibria

The separating equilibrium described in Proposition 1 is destroyed if $\Phi(1, \overline{\theta}) > 0$; in this case, however, there exists a semi-separating overcompliance equilibrium provided that $p < q$.

When $\Phi(1, \overline{\theta}) > 0$, the high-cost type has an incentive to mimic the low-cost type if the government regulates with probability 1 upon observing overcompliance in the first period. Thus, if $p < q$ the government's strategy supporting the equilibrium described in Proposition 1 would no longer be sequentially rational. This means that the government must regulate with probability lower than one, such that the high-cost type is indifferent between mimicking the low-cost type and not. For the government to regulate with probability lower than one, it in turn must be indifferent between regulating and not, i.e., it must be that $q = q$. This is possible provided that the high-cost type randomizes between overcomplying and not appropriately.

Along with this semi-separating equilibrium, the game also admits a pooling equilibrium. However, government's beliefs supporting such a pooling equilibrium are not entirely plausible.

Proposition 2. If $p < \hat{q}$ and $\Phi(1, \overline{\theta}) > 0$, there are two equilibria, one semi-separating and the other pooling. In the semi-separating equilibrium, the low-cost type always adopts the clean technology; the high-cost type adopts the clean technology with probability x^* such that $W^R(q^*) = W^{NR}$; and the government, upon observing overcompliance in the first period, regulates with probability z^* such that $\Phi(z^*, \overline{\theta}) = 0$. In the pooling equilibrium, the government never regulates and both types adopt the dirty technology.

Proof. First of all, let us confirm that the proposed equilibrium is, indeed, an equilibrium. Let x denote the probability that the high-cost type overcomplies in the first period. When the low-cost type always overcomplies, the government revises its first-period belief using Bayes' rule as follows:

$$q = \frac{p}{p + x(1 - p)}. \tag{5}$$

Denote by x^* the solution to equation $q(x) = \hat{q}$.

For the high-cost type to be indifferent between adopting the clean and the dirty technology, the government must randomize between regulating and not regulating with probability z^* such that $\Phi(z^*, \overline{\theta}) = 0$. Since $\Phi(z, \theta)$ is decreasing in θ, clearly $\Phi(z^*, \underline{\theta}) > 0$. Thus, if the government does not regulate if it observes the dirty technology, and regulates with probability z^* upon observing the clean technology, the low-cost type's best response is always to overcomply, while the high-cost type is indifferent between overcomplying or not. On the other hand, when the low-cost type always overcomplies and the high-cost type overcomplies with probability x^*, the government's best response is not to regulate if firm A has adopted the dirty technology, while the government is indifferent between regulating or not if it has observes that firm A adopted the clean technology.

To show that the pooling equilibrium is also an equilibrium, consider the following strategies and beliefs. The government holds that $q = p$ when observing that firm A has adopted the dirty technology in the first period, and therefore it does not regulate. Moreover, it infers that $\theta = \overline{\theta}$, and therefore does not regulate, when observing that firm A has adopted the clean technology in the first period. Clearly, both types' best response to this strategy by the government is to adopt the dirty technology in the first period. To confirm that this is a sequential equilibrium, it remains to show that government's strategy and beliefs are consistent. To show this, consider a sequence of totally mixed strategies where the high-cost type adopts the clean technology with probability ε^n and the low-cost type adopts the clean technology with probability ε^{2n}, and take the limit as $n \to \infty$.

To show that there are no other equilibria, it suffices to note that if the government regulates with probability 1 upon observing overcompliance, both types would want to overcomply, but then regulating is not sequentially rational. *Q.E.D.*

3.3 Pooling equilibria

The separating and semi-separating equilibria analyzed so far entail overcompliance. However, the game also admits no-overcompliance equilibria. A trivial pooling equilibrium with no overcompliance emerges when the government prefers not to regulate in the absence of further information, and neither type may ever want to overcomply.

Proposition 3. If $p < q$ and $\Phi(1, \underline{\theta}) < 0$, the unique equilibrium is a pooling equilibrium where both types adopt the dirty technology in the first period, and the government does not regulate.

The proof is obvious.

So far I have focused on the case $p < q$; in this case, the assumption that there can be no regulation in the first period is not binding. For completeness, I next consider the case where government would choose to regulate on the basis of its prior beliefs p, i.e. $p > q$. In this case, the government would have regulated in the first period if it could, and ruling out first-period regulation becomes a restrictive assumption.

If the high-cost type never wants to overcomply, a unique no-overcompliance pooling equilibrium obtains.

Proposition 4. If $p > q$ and $\Phi(1, \overline{\theta}) < 0$, the unique equilibrium is a pooling equilibrium where both types adopt the dirty technology in the first period, and the government regulates.

Proof. It is immediate to confirm that this is, indeed, an equilibrium. Firm A's profit is highest when it chooses the dirty technology in the first period and the government regulates and therefore neither type may wish to deviate from the proposed equilibrium, and the government's strategy is sequentially rational.

To show that the equilibrium is unique, note that when $\Phi(1, \overline{\theta}) < 0$, the high-cost type never overcomplies in the first period. Thus, suppose to the contrary that there is an equilibrium where the low-cost type overcomplies. It can then profitably deviate by adopting the dirty technology in the first period. The government would regulate anyway, and the low-cost type would not have to forego its first-period profits. *Q.E.D.*

When the government prefers not to regulate in the absence of further information, but both types are willing to overcomply if this induces the government to regulate, things are more complex.

Proposition 5. If $p > q$ and $\Phi(1, \overline{\theta}) > 0$, there are two pooling equilibria. In the first equilibrium, both types adopt the dirty technology in the first period; in the second equilibrium, both types adopt the clean technology in the first period. In both equilibria, the government regulates.

Proof. As in the proof of Proposition 4, it is immediate to confirm that the first equilibrium is, indeed, an equilibrium.

With regard to the second equilibrium, consider the following strategies and beliefs. The government holds that $q = p$ when observing that firm A has adopted the clean technology in the first period, and therefore it regulates. However, it infers that $\theta = \overline{\theta}$, and therefore does not regulate, when observing that firm A has adopted the dirty technology in the first period. Clearly, both types' best response to this strategy by the government is to adopt the clean technology in the first period. It is straightforward to show that government's strategy and beliefs are consistent. *Q.E.D.*

The second pooling equilibrium described in Proposition 5 actually exhibits *excess* overcompliance. The government would have regulated even if firm A had adopted the dirty technology, and therefore overcompliance is inefficient from the viewpoint of firm A. (Even the government may prefer the first pooling equilibrium, because when firm A overcomplies a larger share of the first-period output is produced by firm B, which is inefficient if firm B's marginal cost is higher than A's.)

4 A simple example

In this Section I present a specific model of the product market under two different hypotheses on the mode of competition: Bertrand and Cournot. The purpose of this section is to confirm that the general analysis presented above is applicable to a broad set of circumstances (the example satisfies, for a sizeable set of parameters values, Assumptions 1-3), and to gain additional insights into the determinants of the various possible equilibria.

Firms A and B produce a homogeneous good whose inverse demand function is linear: $p = a - X$, where p is price and $X = x_A + x_B$ is total output. Environmental damages are zero when output is produced using the clean technology, and are given by $D = \gamma X$ when output is obtained through the dirty technology. With the dirty technology, firm B's marginal cost is c, while A's marginal cost is normalized to 0. With the clean technology, firm A's cost is θ and firm B's cost is $\theta + \tau$, with $\tau \geq 0$. The cost parameter $\theta \in \left\{\underline{\theta}, \overline{\theta}\right\}$, with $0 \leq \underline{\theta} < \overline{\theta}$, is private information to the firms. I assume that the lowest unit production cost associated with the clean technology is at least as large as firm B's cost when using the dirty technology: $\underline{\theta} \geq c$. To cut down on the number of cases that have to be considered, I further assume that no firm can engage in monopoly pricing without being outpriced by its competitor (this requires that a is sufficiently large relatively to marginal costs; more precisely, it must be that $a > \max[2c, \overline{\theta} + \tau]$).

4.1 Bertrand competition

Let us start by assuming that firms compete in prices (Bertrand). In this case, with constant marginal costs a limit pricing equilibrium will obtain with the low-cost firm serving the whole market at a price equal to the higher cost. Consequently, when both firms use the dirty technology we have $p^*(D, D) = c$, $\pi_B(D, D) = 0$ and $\pi_A(D, D) = c(a - c)$. When both firms use the clean technology, $p^*(C, C, \theta) = \theta + \tau$, $\pi_B(C, C, \theta) = 0$ and $\pi_A(C, C, \theta) = \tau(a - \theta - \tau)$. When firm A adopts the clean technology while firm B adopts the dirty technology, the equilibrium price equals firm A's cost, θ, and firms' profits are $\pi_B(D, C, \theta) = (\theta - c)(a - \theta)$ and $\pi_A(C, D, \theta) = 0$. Note that each firm's profit decreases in its own cost but increases in its rival's cost.[8]

In this example, firm A gains from regulation, and so Assumption 1 is satisfied, if and only if:

$$\tau(a - \theta - \tau) - c(a - c) > 0. \tag{6}$$

The function $\Phi(z, \theta)$ reduces to:

$$\Phi(z, \theta) = z\delta\tau(a - \theta - \tau) - (1 + z\delta)c(a - c), \tag{7}$$

[8] In this example, the assumption that only firm A can adopt the clean technology in the first period can be replaced by the assumption that firm B must pay an arbitrarily small fixed cost to adopt the clean technology. To show that this assumption implies that firm B never adopts the clean technology in the first period, note that firm A will never adopt the clean technology in the second period if the government has not regulated as this strategy is strictly dominated. Eliminating these strictly dominated strategies for firm A, it follows that firm B's second-period profit always vanishes. In the first period, firm B obtains a strictly positive profit if and only if it adopts the dirty technology and firm A adopts the clean technology. Given the (arbitrarily small) fixed adoption cost, this means that the adoption of the clean technology is a strictly dominated strategy for firm B. The assumption of Bertrand competition is crucial for the validity of the above argument. With Cournot competition, firm B's second-period profit may be greater when both firms adopt the dirty technology, and so firm B may also want to engage in signaling. The analysis of this double signaling game is beyond the scope of this paper.

which is clearly decreasing in θ; this means that Assumption 3 is always satisfied.

Consider next social welfare. In the absence of regulation, with $p^* = c$ and zero production costs (all of the output is produced by firm A at equilibrium), second-period social welfare is:

$$W^{NR} = (a - c)\frac{(a + c - 2\gamma)}{2}. \tag{8}$$

If instead the government regulates, both firms must adopt the clean technology and social welfare is:

$$W^{R}(\theta) = \tau(a - \theta - \tau) + \frac{(a - \theta - \tau)^2}{2}. \tag{9}$$

When $\gamma = 0$ social welfare is larger under no regulation since $c \leq \underline{\theta}$. As γ increases, however, W^{NR} goes down; thus, if γ is sufficiently high social welfare will be larger under regulation, irrespective of the compliance costs. Assumption 3 is satisfied for intermediate values of γ. In the remainder of this section, I assume that γ lies in such an interval, and that inequality (6) holds.

Tedious calculations show that in this example the critical value $\hat{q}$ is given by

$$\hat{q} = \frac{(a - c)(a + c - 2\gamma) - (a - \overline{\theta} - \tau)(a - \overline{\theta} + \tau)}{2\tau(\overline{\theta} - \underline{\theta})(2 - 2a - 2\tau - \overline{\theta} - \underline{\theta})}. \tag{10}$$

If γ lies in the interval defined above, $\hat{q}$ is positive and lower than 1. Define $\underline{\delta}$ as the solution to $\Phi(1, \underline{\theta}) = 0$; $\overline{\delta}$ is defined analogously. When (6) holds, $\underline{\delta} < \overline{\delta}$. Figure 2 displays the various equilibria in the (δ, p)-space. Unsurprisingly, overcompliance tends to obtain when δ is large (future matters),[9] and the prior belief p is low (the government must be convinced that compliance costs are low).

[9] Recall that δ reflects not only the level of the interest rate, but also the duration of the second period relative to that of the first.

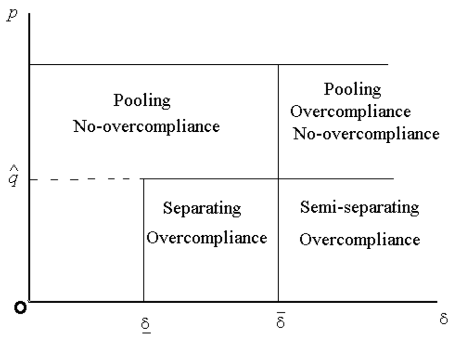

Figure 2: Equilibria of the signaling game

4.2 Cournot competition

With Cournot competition, when both firms use the dirty technology the product market equilibrium is:[10] $p^*(D,D) = \frac{1}{3}(a+c)$, $x_A(D,D) = \frac{1}{3}(a+c)$; $x_B(D,D) = \frac{1}{3}(a-2c)$, $\pi_A(D,D) = \frac{1}{9}(a+c)^2$ and $\pi_B(D,D) = \frac{1}{9}(a-2c)^2$. When both firms use the clean technology, $p^*(C,C,\theta) = \frac{1}{3}(a+2\theta+\tau)$, $x_A(C,C,\theta) = \frac{1}{3}(a-\theta+\tau)$, $x_B(C,C,\theta) = \frac{1}{3}(a-\theta-\tau)$, $\pi_A(C,C,\theta) = \frac{1}{9}(a-\theta+\tau)^2$ and $\pi_B(C,C,\theta) = \frac{1}{9}(a-\theta-\tau)^2$. When firm A adopts the clean technology while firm B adopts the dirty technology, the product market equilibrium is $p^*(C,D,\theta) = \frac{1}{3}(a+c+\theta)$, $x_A(C,D,\theta) = \frac{1}{3}(a-2\theta+c)$, $x_B(D,C,\theta) = \frac{1}{3}(a+\theta-2c)$, $\pi_A(C,D,\theta) = \frac{1}{9}(a-2\theta+c)^2$ and $\pi_B(C,D,\theta) = \frac{1}{9}(a+\theta-2c)^2$. As under Bertrand competition, each firm's profit decreases in its own cost but increases in its rival's cost, but now the role of own costs is more prominent.

Consequently, the condition that firm A gains from regulation tends to become more

[10] Recall the standard formulas for the Cournot duopoly equilibrium with linear demand and constant marginal costs c_1 and c_2: $p = (a + c_1 + c_2)/3$; $x_i = (a - 2c_i + c_j)/3$; $\pi_i = x_i^2$; $CS = (a - c_1 - c_2)/18$.

stringent. More precisely, it is now required that $a - \underline{\theta} + \tau > a + c$, or:

$$\tau > \underline{\theta} + c. \tag{11}$$

It can be shown that if a is sufficiently large (i.e., $a > 2\underline{\theta} + 3c$), condition (11) is more restrictive than (6); the opposite is true if $a < 2\underline{\theta} + 3c$ (but recall that I have assumed $a > \max[2c, \overline{\theta} + \tau]$ to rule the possibility that only one firm is active at the Cournot equilibrium).

It can be easily checked that the function $\Phi(z, \theta)$, that now reduces to:

$$\Phi(z, \theta) = \frac{1}{9}\left[z\delta(a - \theta + \tau)^2 + (a - 2\theta + c)^2 - (1 + z\delta)(a + c)^2\right], \tag{12}$$

is always decreasing in θ, whence Assumption 3 is satisfied.

With regard to Assumption 2, since $\underline{\theta} \geq c$ it is immediate that social welfare is higher under no regulation if $\gamma = 0$. Arguing as in the case of Bertrand competition, it follows that Assumption 2 is satisfied if γ is neither too low nor too large.

Although the expressions for $\overline{q}$, $\underline{\delta}$ and $\overline{\delta}$ are quite cumbersome, numerical calculations show that if a is sufficiently large the region of parameter values supporting an overcompliance equilibrium tends to shrink relative to that arising under Bertrand competition; yet, overcompliance equilibria continue to obtain for a fairly large set of parameter values.

5 A pre-emption model

In this Section I develop a variant of the model of the previous Section, where firm A is the incumbent and firm B is a potential entrant. Firm B can enter the market only in the second period; there is a fixed entry cost F. If firm B enters the market, in the second period firms compete *à la* Cournot. The fact that firm B must pay a fixed cost to enter the market *per se* guarantees that firms are asymmetric; thus, in this example, one can safely assume that firm B has the same variable costs as firm A, that is, $c = \tau = 0$. The other assumptions are the same as in the previous Section.

I assume that entry is profitable if the government has not regulated, while firm B prefers to stay out if it must use the clean technology. This implies that the following inequalities must hold:

$$\frac{(a - \underline{\theta})^2}{9} < F < \frac{a^2}{9}. \tag{13}$$

Assumption 1 requires that firm A must prefer to remain a monopoly when compliance costs are low. This means that A's monopoly profit with cost $\underline{\theta}$ must exceed duopoly profit with zero cost: $(a - \underline{\theta})^2/4 > a^2/9$, or equivalently:

$$a > 3\underline{\theta}. \tag{14}$$

Note that now firm A may gain from regulation even if $\tau = c = 0$, which was impossible in the model of the previous section.

The function $\Phi(z, \theta)$ is defined as the gain from regulation, $z\delta[(a - \theta)^2/4 - a^2/9]$, less the cost of signalling, $\frac{1}{4}[a^2 - (a - \theta)^2]$:

$$\Phi(z, \theta) = z\delta \left[\frac{1}{4}(a - \theta)^2 - \frac{1}{9}a^2\right] - \frac{1}{4}[a^2 - (a - \theta)^2]. \tag{15}$$

Assumption 3 is obviously satisfied.

Consider next social welfare. Under regulation, there is no entry. The market is a monopoly, and output is $q = \frac{1}{2}(a - \theta)$. Consumers' surplus is $(a - \theta)^2/8$ and social welfare is:

$$W^R(\theta) = \frac{3(a - \theta)^2}{8}. \tag{16}$$

Under no regulation, firm B will enter in the second period, so that the industry becomes a duopoly with zero costs. Equilibrium output is $\frac{2}{3}a$ and therefore consumers' surplus is $\frac{2}{9}a^2$. Industry profits, net of the entry cost, are $\frac{2}{9}a^2 - F$ and so social welfare is:

$$W^{NR} = \frac{4}{9}a^2 - \frac{2}{3}\gamma a - F. \tag{17}$$

When $\gamma = 0$, we have $W^{NR} > \underline{W}^R$ provided that:

$$\underline{\theta} > a - \sqrt{\frac{32}{27}a^2 - \frac{8}{3}F}. \tag{18}$$

If this inequality is satisfied, arguing as in the previous section it follows immediately that there exists a non-empty interval of values of γ such that Assumption 2 holds.

One can therefore apply all of the results obtained in Section 3 to this example. In particular, separating and semi-separating overcompliance equilibria exist. In this example, overcompliance is an entry-deterrence device. By overcomplying, the incumbent convinces the government that it is desirable to regulate and this allows it to maintain its monopoly in the second period.

6 Concluding remarks

In this paper, I have characterized overcompliance equilibria in a simple asymmetric duopoly model. Overcompliance obtains at equilibrium when two conditions are met.[11] First, it must be the case that the government would not regulate on the basis of its prior beliefs. The role of overcompliance is to induce the government to regulate by signaling that the cost of adhering to stricter environmental standards is not too high. Second, the low-cost type

[11] In the following discussion I do not stress the overcompliance pooling equilibrium described in Proposition 5, as such an equilibrium may be seen as an artifact of the assumption that the government cannot regulate in the first period..

must find it convenient to give up some first-period profits in order to induce the government to regulate.

The explanation of overcompliance developed in this paper complements, and is not intended as a substitute for, those proposed in the earlier literature. However, it is possible to tell which circumstances make each explanation more plausible. (Testing alternative theories must clearly await future work.) One difference between my model and the green-consumerism approach is that the latter requires that overcompliance is observed by the general public, whereas in my model what is crucial is that overcompliance is observed by the government. Thus, the green consumerism hypothesis tends to apply to *product overcompliance* cases, while the explanation put forward in this paper also applies to *process overcompliance*. The crucial difference between my model and the regulatory threat hypothesis is that here overcompliance triggers regulation; its goal is not to avoid regulation. Thus my explanation would be fully consistent with the observation that the government reacts to voluntary commitments by tightening environmental standards, whereas this observation may be problematic for the regulatory threat approach.

Nothing in the model hinges on the environmental nature of regulation. The model could be applied to any other regulatory framework where regulation affects firms asymmetrically. For instance, one can think of the introduction of tighter safety standards, or the prohibition of child labor, as other instances where the overcompliance theory developed in this paper may have some explanatory power.

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