A signaling model of environmental overcompliance

Abstract. We present a theory of unilateral regulatory overcompliance as a signaling device. Firms that have a competitive advantage in the use of a cleaner but more costly technology overcomply in order to signal to an imperfectly informed, benevolent government that compliance costs are low, thereby triggering tougher regulation. We identify the conditions under which such an overcompliance signaling equilibrium arises, showing that there may be over-overcompliance in that firms may overcomply even when tougher regulation is not socially desirable. We also discuss the differential implications of the signaling theory as compared to other theories of unilateral regulatory overcompliance.

1 Introduction

Although enforcing compliance is a constant preoccupation of regulatory agencies, sometimes firms voluntarily and unilaterally overcomply to current regulation. Unilateral overcompliance is especially well documented for environmental and ethical standards,[1] and its increasing importance has spurred a growing economics literature (see Lyon and Maxwell (2004) for an excellent survey). There are two main competing explanations of unilateral regulatory overcompliance.[2] One explanation contends that concerned consumers reward firms that overcomply by redirecting their demand towards these firms.[3] Another explanation is that firms overcomply to preempt the enactment of tighter regulation, or to induce the government to choose a form of regulation more favorable to them.[4]

Both theories offer valuable insights, but certain observed voluntary actions remain difficult to explain. First, the assumption that consumers are willing to pay more for a cleaner product, or a product produced without child labor, is not very convincing when applied to process overcompliance or to intermediate products. Second, there is ample evidence that overcompliance often precedes the strengthening of regulation.[5] Although this evidence may

[1] Overcomplying firms are typically eager to advertise their behavior to regulatory agencies, customers, and the public at large. This makes it easy to find anecdotal evidence of regulatory overcompliance. Lyon and Maxwell (2004) discuss a number of case studies. Mazurek (1999) surveys 42 environmental voluntary agreements in the U.S. and finds that about one quarter were voluntary actions. Kolk and van Tulder (2002) assess the role of corporate codes of conduct to address the issue of child labor.

[2] In their thorough analysis of environmental overcompliance, Lyon and Maxwell (2004) distinguish between public voluntary agreements, negotiated agreements, and voluntary actions. This paper focuses on voluntary actions (i.e., unilateral actions undertaken by firms without any explicit bargaining with regulatory authorities).

[3] See Arora and Gangopadhyay (1995) and Bagnoli and Watts (2003), among others.

[4] Prominent examples of this regulatory preemption approach are Lutz et al. (2000), Maxwell et al. (2000), and Lyon and Maxwell (2003). Related work by Segerson and Miceli (1999) focuses on public voluntary agreements and negotiated agreements.

[5] See the discussion of the National Appliance Energy Conservation Act of 1987 and the Clean Air Act

be reconciled with the preemption theory,[6] it may also be taken to suggest that overcompliance sometimes triggers regulation instead of preempting it. Last but not least, there is direct evidence that certain overcomplying firms actually called for stricter regulation, such as DuPont and Arco in the real-world examples we discuss in the concluding section.

Arora and Gangopadhyay (1995, p. 291) hint at another explanation of regulatory overcompliance that can help explain certain observed behaviors. They suggest that "overmeeting of standards by some firms could serve as a signal to the lawmakers to tighten up restrictions for industry as a whole." We extend this insight developing a model where a signaling overcompliance equilibrium can arise under certain circumstances. While it is well understood that regulation can be profitable to some firms by raising rivals' costs,[7] the existence of such a signaling equilibrium is not obvious. For a signaling equilibrium to arise, overcompliance must be an informative signal and a benevolent government must rationally react to the signal by enforcing a stricter regulation. Our analysis sheds light on the circumstances under which these additional conditions can be met and on the differential implications of the signaling theory as compared to the preemption theory.

Initially, we present a reduced-form model of an asymmetric duopoly with a low-cost firm and a high-cost firm (Section 2). In Section 3 we identify the conditions that must be met for an overcompliance equilibrium to occur. We show that the model exhibits sepa-

Amendments of 1990 in Lutz et al. (2000). In both cases, they document that firms took actions to overcomply before regulation was tightened, although they note that it is hard to tell "whether these actions are specifically motivated by a desire to influence the ultimate standards, or were purely anticipatory." (p. 333).

[6] Firms' attempt to preempt regulation may simply fail, or it may be only partially successful in that regulation might have been even stricter had firms not overcomplied.

[7] The classic raising-rivals'-costs paper of Salop and Scheffman (1983) mentions regulation as one of the devices firms can use to raise rivals' costs. Maloney and McCormick (1982) develop an early model where firms may benefit from regulation if it raises marginal costs more than average costs. In our model, marginal costs are constant.

rating, semi-separating, and pooling equilibria. Overcompliance emerges in the separating and semi-separating equilibria. In Section 4 we present two illustrative examples that fit the assumptions of the reduced-form model for a sizeable set of parameter values, namely, a model of Cournot competition with linear demand and constant marginal costs and a simple entry preemption model where the potential entrant can recoup the fixed entry cost only if the government does not regulate. In this latter example, overcompliance is in fact an entry-deterrence device. Section 5 offers some concluding remarks.

2 A reduced-form model

The signaling story we have in mind is very simple. A benevolent government is poorly informed about the cost of complying with a stricter regulation, while firms are better informed. Some firms are more efficient than others in complying with the stricter regulation, for example because compliance requires the use of proprietary innovative technological knowledge. In this framework, the more efficient firms may voluntarily comply before regulation is enacted in order to signal that compliance is not too costly. If the government reacts by enacting a stricter regulation, the more efficient firms gain by raising their rivals' costs.

The challenge in formalizing the above story is to eschew the unnecessary assumptions in order to highlight the phenomenon of interest. A two-period, two-firm model where costs are uncertain and are private information to the firms seems the minimal dimension of an appropriate model. However, other modeling choices are less obvious. In particular, signaling models often possess multiple equilibria, some of which are not entirely reasonable. In order to highlight that the signaling explanation of regulatory overcompliance is not an artifact of any particular equilibrium selection criterion, we make some unnecessarily strong assumptions with an eye toward identifying a unique equilibrium or a small set of equilibria that can be fully characterized.

In this spirit, a key simplifying assumption is that firms' technological choice is discrete (i.e., firms use either a "good" or a "bad" technology). Similarly, regulation is modeled as a discrete choice: the government can either force firms to adopt the good technology, in which case firms must comply, or let firms freely choose which technology to adopt (however, we allow players to use mixed strategies). These assumptions restrict the players' strategy spaces and lead to a small set of equilibria.

Consider then an industry in a partial equilibrium framework. There are two firms, 1 and 2, and two periods. Firms produce a good using either a good (G) or a bad (B) technology. At the beginning of each period, the government chooses whether or not to regulate; firms then choose whether to adopt the good or the bad technology (they must choose the former if the government regulates) and finally compete in the product market. This sequence of events is repeated twice.

The bad technology entails a negative externality D (e.g., the technology may be dirty, or it may use child labor). The good technology has no externalities, but is more costly. Firms have the same cost when they use the bad technology, but firm 1 is more efficient than firm 2 when both use the good technology. More precisely, normalizing to zero the unit cost associated with the bad technology, firm 1's cost with the good technology is θ, and firm 2's cost is $\theta + c$, where $\theta > 0$ is a random variable and the parameter $c \geq 0$ measures firm 1's competitive advantage in complying. For simplicity, we assume that θ can take on only two values, low ($\theta = \underline{\theta}$) or high ($\theta = \overline{\theta} > \underline{\theta}$). The value of θ is private information to the firms.

A benevolent government chooses whether to regulate in order to maximize social welfare. Social welfare is the sum of consumer surplus and profits, minus any externalities. The government faces a trade-off in that regulation raises firms' production costs and hence leads to lower output, but also brings about social benefits in terms of saved negative externalities D. In general, which policy is better depends on the government's assessment of the likelihood that the cost associated with the good technology is low. We denote by χ the government's prior belief that $\theta = \underline{\theta}$ (so $1 - \chi$ is the probability that $\theta = \overline{\theta}$). This probability is common knowledge. We assume that χ is small enough that the government prefers not to regulate on the basis of its prior beliefs (this assumption will be made precise later). This implies that the government never regulates in the first period. However, the government's beliefs are updated as the game unfolds. We assume that the government cannot make long-run commitments, so in the second period it chooses whether or not to regulate on the basis of its updated beliefs.

For simplicity, we assume that first-period prices and outputs are not observed by the government. This limits the set of possible signaling devices and implies that in each period firms play a standard one-shot game at the market competition stage.[8] Initially we analyze a

[8] If the government observes first-period prices and outputs, firms might try to use these variables as signaling devices, as complements to or substitutes for technology adoption. Our assumption rules out this possibility admittedly entailing some loss of generality. However, the circumstances in which firms might want to use prices or outputs as signaling devices seem limited. First, a firm that adopts the bad technology cannot signal by distorting its product market competition choices. The reason such a distortion could not represent an informative signal is that the cost of sending the signal would then be independent of the true state ($\theta = \underline{\theta}$ or $\theta = \overline{\theta}$). Second, in a separating equilibrium technology adoption is a fully informative signal, so there would be no room for sending further (costly) signals such as distorted first-period pricing and output choices. However, things are different in a semi-separating equilibrium where the low-cost type always chooses the good technology and the high-cost type randomizes between adopting the good and the bad technology in the first period. When such a semi-separating equilibrium occurs, the low-cost type may want to separate better from the high-cost type (e.g., by expanding output in the first period). This seems to be the only case

reduced-form model where the outcome of product market competition is summarized by the profit functions $\pi_i(T_i, T_j)$ denoting firm i's profits when it adopts technology $T_i \in \{G, B\}$ and firm j adopts technology $T_j \in \{G, B\}$, for $i, j = 1, 2$ and $i \neq j$. Any reasonable specification of product market competition would imply that each firm's per period profits are weakly decreasing in own cost and weakly increasing in rival's cost. In particular, this implies that:

$$\pi_i(G, B, \theta) \leq \pi_i(B, B) \text{ and } \pi_i(G, G, \theta) \leq \pi_i(B, G, \theta). \tag{1}$$

Inequalities (1) imply that adopting the bad technology would be a dominant strategy in a one-shot game. Consequently, if the government does not regulate, in the second period both firms will adopt the bad technology.[9] It is also reasonable to assume that

$$\pi_i(G, G, \underline{\theta}) > \pi_i(G, G, \overline{\theta}) \tag{2}$$

for $i = 1, 2$. Later we shall develop two more highly structured models that satisfy these assumptions.

Clearly, in our framework firm 2 has nothing to gain from the enforcement of stricter regulation, nor has it any credible way to signal that the cost associated with the good technology is high since any attempt to signal would be considered "cheap talk." Thus, firm 2 will always adopt the bad technology in the first period. Therefore, the game effectively unfolds as follows.

Stage 0. Nature chooses the cost associated with the good technology, $\underline{\theta}$ (with probability χ) or $\overline{\theta}$ (with probability $1 - \chi$). The outcome is observed by both firms, but not by the

in which our assumption entails some loss of generality.

[9] Here we are assuming that the adoption of the good technology in the first period is reversible. If the technology adoption were irreversible, the cost of overcomplying would be greater. As we proceed, we shall discuss in footnotes how our analysis would change if a switch to the good technology were irreversible.

government.

Stage 1. At the beginning of the first period, firm 1 chooses whether to adopt the *good* (G) or the *bad* (B) technology. This choice is observed by firm 2 and the government, which may revise its prior belief accordingly. Next, firms compete in the product market and collect first-period profits.

Stage 2. Based on its revised beliefs, at the beginning of the second period the government chooses whether to *regulate* (R) or *not to regulate* (NR). Firms then choose the second-period technology; they must choose the good technology if the government regulates. Finally, firms compete again in the product market and collect second-period profits.

Clearly, firm 2 is a dummy player in this reduced-form game. The game effectively involves only two active players, firm 1 and the government, and is represented in Figure 1. A pure strategy for firm 1 is a mapping $\{l, h\} \rightarrow \{G, B\}$, where l and h are the low- and high-cost types, and G and B denote adoption of the good and bad technology, respectively. A government's pure strategy is a mapping $\{G, B\} \rightarrow \{R, NR\}$ that specifies whether the government regulates (R) or not (NR) upon observing adoption of the good or bad technology by the firm. Mixed strategies are defined in the standard way. We denote by z_G and z_B the probability that the government regulates upon observing the adoption of the good or bad technology, respectively. Also, we denote by x_l and x_h firm 1's probability of adopting the good technology if the cost θ is low or high, respectively.

Firm 1's payoff is given by its total discounted profits $\pi_1^1 + \delta\pi_1^2$, where superscripts denote time periods and the parameter $\delta > 0$ captures discounting and the relative duration of the

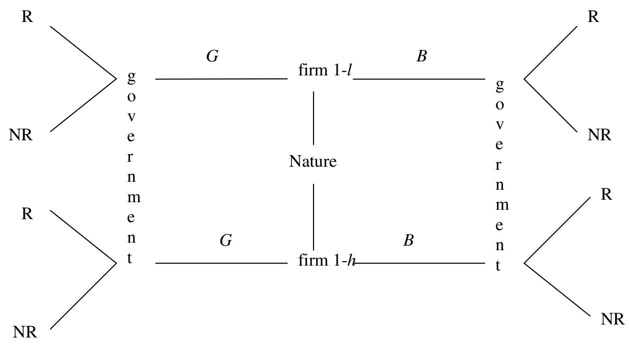

Figure 1: The signaling game

pre- and post-regulation periods.[10] Since the government never regulates in the first period and cannot pre-commit, at the beginning of the second period it chooses whether or not to regulate so as to maximize second-period social welfare. We denote by W^{NR} second-period social welfare if the government does not regulate, so that both firms adopt the bad technology. Likewise, we denote by $\underline{W}^R$ social welfare if the government regulates and costs are low ($\theta = \underline{\theta}$), and by $\overline{W}^R < \underline{W}^R$ social welfare if the government regulates and costs are high ($\theta = \overline{\theta}$). Again, we start from a reduced-form model, but later we shall develop more highly structured models where second-period social welfare is explicitly calculated as the sum of consumer surplus and profits, minus any externalities. Second-period social welfare will then be (dropping the time superscripts since there is no possibility of confusion) $W = \pi_1 + \pi_2 + CS - D$, where CS denotes consumers surplus.

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

3 Sequential equilibria

We shall focus on the sequential equilibria (or, equivalently, the perfect Bayesian equilibria) of this game. In a sequential equilibrium, strategies are sequentially rational; moreover, strategies and beliefs can be regarded as limits of totally mixed, sequentially rational strategies and associated beliefs (Kreps and Wilson, 1981). In particular, this means that the government's belief conforms with Bayes' rule whenever it applies.

Our first goal is to identify necessary conditions for an overcompliance signaling equilibrium to emerge.

*Assumption 1 (**cheap talk**).* Firm 1 always gains from regulation: $\pi_1(G, G, \overline{\theta}) > \pi_1(B, B)$.[11]

Assumption 1 actually performs two functions. First, it captures the notion that raising rivals' costs can be profitable even if it entails a rise in own costs. This is clearly necessary for overcompliance to occur. Second, Assumption 1 rules out the possibility of signaling by simply announcing that the cost is low. Indeed, if $\pi_1(G, G, \underline{\theta}) > \pi_1(B, B) > \pi_1(G, G, \overline{\theta})$, such an announcement would be informative since firm 1 would gain from regulation only if it were a low-cost type. By way of contrast, under Assumption 1 firm 1's announcement that the cost is low would be "cheap talk," and to induce the government to regulate firm 1 must resort to costly signaling.

The next assumption rules out trivial cases where regulation is always desirable or is never desirable.

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

*Assumption 2 (**no dominant strategy**).* With full information, regulation is welfare increasing if the unit cost with the good technology is low ($\theta = \underline{\theta}$) and is welfare decreasing if the cost is high ($\theta = \overline{\theta}$) : $\underline{W}^R > W^{NR} > \overline{W}^R$.

The no-dominant-strategy assumption guarantees that the government faces a non trivial policy problem. If it failed, the government would have a dominant strategy, and its second-period policy could not be influenced by first-period technology choices.

The no-dominant-strategy assumption, however, does not yet guarantee that signaling can be effective. To see this, consider the government's sequentially rational strategy. Denoting by q the government's second period up-dated belief that the cost associated with the good technology is low, expected social welfare under regulation is $W^R(q) = q\underline{W}^R + (1-q)\overline{W}^R$. The no-dominant-strategy assumption guarantees that there exists a critical value $\hat{q} \in (0, 1)$, which is implicitly defined as the solution to $W^R(\hat{q}) = W^{NR}$, such that the government regulates if $q > \hat{q}$ and does not regulate if $q < \hat{q}$. Now, if the government is sufficiently optimistic, it would regulate even in the absence of any further information; firm 1 would then have no motive to engage in costly signaling. Therefore we need the following:

*Assumption 3 (**pessimistic government**).* The government would not to regulate on the basis of its prior belief: $\chi < \hat{q}$.

Summarizing this discussion,

Proposition 1. *For overcompliance to occur in equilibrium, Assumptions 1-3 must hold.*

In the remainder of this Section we posit that Assumptions 1-3 are met. In general, under Assumptions 1-3 the game may admit separating, semi-separating, and pooling equilibria. To identify the circumstances under which each kind of equilibrium may occur, consider firm

1's incentive to signal in the first period. The cheap talk assumption guarantees that firm 1's second-period profit with regulation is greater than in its absence. However, there is an opportunity cost of overcomplying, which is given by firm 1's foregone first-period profit $\pi_1(B,B) - \pi_1(G,B,\theta)$. Thus, firm 1's gain from signaling is

$$\Phi(z_G,\theta) \equiv z_G\delta\pi_1(G,G,\theta) + \pi_1(G,B,\theta) - (1+z_G\delta)\pi_1(B,B) \tag{3}$$

where z_G is the probability that the government regulates when firm 1 adopts the good technology in the first period.[12] Note that $\Phi(z_G,\theta)$ is increasing in z_G by the cheap talk assumption. Our assumptions guarantee that the following single-crossing condition is satisfied.

Lemma 1 ***(single crossing).*** *$\Phi(z_G,\theta)$ is decreasing in θ.*

Proof. The assumption that each firm's profits decrease with own costs guarantees that $\pi_1(G,B,\theta)$ is (weakly) decreasing in θ. Inequality (2) guarantees that $\pi_1(G,G,\theta)$ is strictly decreasing in θ. Since $\pi_1(B,B)$ is independent of θ, inspection of (3) confirms that the single-crossing condition is met. *Q.E.D.*

To proceed, consider firm 1's incentive to engage in signaling in the most favorable case, that is, when first-period adoption of the good technology triggers regulation with certainty ($z_G = 1$). In view of Lemma 1, three cases are possible, depending on whether the gain from

[12] If the adoption of the good technology in the first period was irreversible, the cost of overcomplying would also include the term $(1-z_G)\delta[\pi_1(B,B) - \pi_1(G,B,\theta)]$ that corresponds to the foregone second-period profits in case the government does not regulate and firm 1 must stick to the good technology in the second period. The function $\Phi(z_G,\theta)$ would then become

$$\tilde{\Phi}(z_G,\theta) \equiv z_G\delta\pi_1(G,G,\theta) + [1+\delta(1-z_G)]\pi_1(G,B,\theta) - (1+\delta)\pi_1(B,B)$$

Clearly, $\tilde{\Phi}(z_G,\theta) < \Phi(z_G,\theta)$. However, it can be easily checked that Lemma 1 continues to hold by the same argument as in the text.

raising rivals' costs exceeds the cost of signaling for no type ($\Phi(1, \underline{\theta}) < 0$), for the low-cost type only ($\Phi(1, \overline{\theta}) < 0 < \Phi(1, \underline{\theta})$), or for both types ($\Phi(1, \overline{\theta}) > 0$) at $z_G = 1$. Which case applies critically depends on the "discount" factor δ. Define $\underline{\delta}$ as the solution to $\Phi(1, \underline{\theta}) = 0$ and $\overline{\delta}$ as the solution to $\Phi(1, \overline{\theta}) = 0$. By the cheap talk assumption and inequality (1), we have $\Phi < 0$ for δ close to zero, $\Phi > 0$ when δ is sufficiently large, and Φ increases continuously with δ. Therefore, $\underline{\delta}$ and $\overline{\delta}$ exist and are unique and positive. By Lemma 1, $\underline{\delta} < \overline{\delta}$.

When δ is low ($\delta < \underline{\delta}$) we are in the first case. Here the cost of overcomplying is so high that not even the low-cost type will ever find it profitable to overcomply. This leads to a pooling equilibrium with no overcompliance. For intermediate values of δ ($\underline{\delta} < \delta < \overline{\delta}$), we are in the second case where the low-cost type has an incentive to overcomply and the high-cost type has no incentive to mimic the low-cost type. Therefore, in this case there will be a unique separating equilibrium where the low-cost type overcomplies with probability one and the high-cost type never overcomplies. For large values of δ ($\delta > \overline{\delta}$), things are more complicated because the low-cost type has, again, an incentive to overcomply but the high cost type now has an incentive to mimic. The model then possesses two equilibria, one of which (arguably, the most reasonable one) is a semi-separating equilibrium in which the low-cost type overcomplies with probability one and the high-cost type overcomplies with a positive but lower than one probability. The next Proposition formalizes the above discussion:[13]

Proposition 2. (i) *If $\delta < \underline{\delta}$, there is a unique, pooling equilibrium where firm 1 never*

[13] The two critical values $\underline{\delta}$ and $\overline{\delta}$ exist and are positive even if a first-period switch to the good technology is irreversible, by the same argument as above. This means that separating and semi-separating equilibria continue to exist even under irreversibility. However, since $\tilde{\Phi}(z_G, \theta) < \Phi(z_G, \theta)$ (see footnote 12 above) both critical values $\underline{\delta}$ and $\overline{\delta}$ are larger under irreversibility, implying that the region of parameter values where there is a unique pooling equilibrium expands and overcompliance becomes less likely.

adopts the good technology in the first period.

(ii) *If* $\underline{\delta} < \delta < \overline{\delta}$*, there is a unique, separating equilibrium where in the first period the low-cost type adopts the good technology and the high-cost type adopts the bad technology, and the government regulates if and only if it observes that firm 1 has adopted the good technology.*

(iii) *If* $\delta > \overline{\delta}$*, there are two equilibria, one semi-separating and the other pooling. In the semi-separating equilibrium, the low-cost type always adopts the good technology, the high-cost type adopts the good technology with probability* x_h^* *such that*

$$\frac{\chi}{\chi + x_h^*(1-\chi)} = \hat{q}, \tag{4}$$

and the government regulates with probability z_G^* *such that* $\Phi(z_G^*, \overline{\theta}) = 0$*. In the pooling equilibrium, the government never regulates and both types adopt the bad technology.*

Proof. Case (i) is trivial since adopting the bad technology in the first period is a dominant strategy for both types.

In case (ii) we have $\Phi(1, \underline{\theta}) > 0 > \Phi(1, \overline{\theta})$. 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 one, but then the low-cost type must necessarily overcomply, since $\Phi(1, \underline{\theta}) > 0$.

Finally, consider case (iii). When $\delta > \overline{\delta}$ we have $\Phi(1, \overline{\theta}) > 0$, which implies that 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, the government's strategy supporting the separating equilibrium that obtains in case (ii) 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 $q = \hat{q}$). When the low-cost type always overcomplies ($x_l = 1$), the government revises its first-period belief using Bayes' rule as follows:

$$q = \frac{\chi}{\chi + x_h(1-\chi)}.$$

Denote by x_h^* the solution to equation $q(x_h) = \hat{q}$. For the high-cost type to be indifferent between adopting the good and the bad technology, the government must randomize between regulating and not regulating with probability z_G^* such that $\Phi(z_G^*, \overline{\theta}) = 0$. Since $\Phi(z_G, \theta)$ is decreasing in θ and $\Phi(1, \overline{\theta}) > 0$ by assumption, we have $\Phi(z_G^*, \underline{\theta}) > 0$. Thus, if the government does not regulate when it observes adoption of the bad technology, and regulates with probability z_G^* upon observing adoption of the good technology, the low-cost type's best response is always to overcomply, while the high-cost type is indifferent between overcomplying and not. On the other hand, when the low-cost type always overcomplies and the high-cost type overcomplies with probability x_h^*, the government's best response is not to regulate if firm 1 has adopted the bad technology, while the government is indifferent between regulating and not if it has observed that firm 1 adopted the good technology.

To show that the pooling equilibrium is also an equilibrium, note that firm 1 strictly prefers to adopt the bad technology if the government never regulates. As for the government, consider the following strategies and beliefs: the government holds that $q = \chi$, and thus does not regulate, when it observes that firm 1 has adopted the bad technology in the first period; moreover, the government infers that $\theta = \overline{\theta}$, and thus does not regulate either, when it observes that firm 1 has adopted the good technology in the first period. To confirm that this is, indeed, a sequential equilibrium, it must be shown that government's strategy and beliefs are consistent. Since in this equilibrium both types adopt the bad technology, Bayes' rule is inapplicable when the government observes that firm 1 has adopted the good technology. To show consistency, consider a sequence of totally mixed strategies where the high-cost type adopts the good technology with probability ε^n and the low-cost type adopts the good technology with probability ε^{2n}, where $\varepsilon > 0$ is arbitrarily small, 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.*

Overcompliance occurs in separating and semi-separating equilibria. Thus, under Assumptions 1-3 overcompliance always occurs provided that δ is large enough (future matters).

In a separating equilibrium, only the low-cost type overcomplies. Overcompliance is then a precise signal, and from the observation that firm 1 has adopted the good technology, the government correctly infers that the compliance cost is low. Thus, the government regulates, and in the second period firm 1 recoups the cost of first-period overcompliance. In a semi-separating equilibrium,[14] even the high-cost type overcomplies with positive probability, making the signal less precise. Overcompliance occurs up to the point where it makes the government just indifferent between regulating and not.

[14] In case (iii) there is also a pooling equilibrium, which however seems less reasonable than the semi-separating equilibrium, and indeed could be eliminated using appropriate refinements.

Will signaling guarantee second-period efficiency, in the sense that in equilibrium the imperfectly informed government regulates if and only if a fully informed government would regulate? Clearly, the answer is no. Since signaling is costly to the firm, it is obvious that sometimes regulation may not be enacted even if it is socially desirable (a type I error). This is precisely what happens in any pooling equilibrium when the compliance cost is actually low. Less obviously, the same outcome can also emerge in a semi-separating equilibrium. However, the problem here is not that signaling is too costly; rather, it is so "cheap" that even the high-cost type engages in signaling. This creates noise that confounds the signal, making the government indifferent between regulating and not. Less obviously still, in such a semi-separating equilibrium the noise created by the high-cost type, who mimics the low-cost type, may induce the government to regulate even when the actual compliance cost is high, that is, in cases in which it would not be socially desirable to regulate (a type II error). This means that in semi-separating equilibria there is excessive overcompliance from a social point of view – an *over*-overcompliance result.

4 Illustrative examples

In this Section we present two illustrative examples that fit the assumptions of the reduced-form model for a non-empty set of parameter values and offer additional insights into the determinants of the various equilibria exhibited by our model. Both examples share the following assumptions. The two firms 1 and 2 produce a homogeneous good whose inverse demand function is linear. Without any further loss of generality, by appropriately choosing the units of measurement of prices and output we can normalize to one the intercept and the slope of the demand curve. Thus, demand is $p = 1 - X$, where p is price and $X = x_1 + x_2$

is total output. The negative externality is zero when output is produced using the good technology and $D = \gamma X$ when the output is obtained through the bad technology. With the bad technology, firms' marginal costs are nil. With the good technology, firm 1's cost is θ and firm 2's cost is $\theta + c$, with $c \geq 0$. To cut down on the number of cases that have to be considered, we further assume that no firm can engage in monopoly pricing without being outpriced by its competitor. This requires that $\max[2c + \overline{\theta}, 2\overline{\theta}] < 1$.

4.1 Cournot competition

Suppose that both firms are active in both periods and compete in quantities.[15] With Cournot competition,[16] when both firms use the bad technology, the product market equilibrium price is $\frac{1}{3}$, individual output is $\frac{1}{3}$, and individual profits are $\pi_1(B, B) = \pi_2(B, B) = \frac{1}{9}$. When both firms use the good technology, the equilibrium price is $p = \frac{1}{3}(1 + 2\theta + c)$, individual outputs are $x_1(G, G, \theta) = \frac{1}{3}(1 - \theta + c)$ and $x_2(G, G, \theta) = \frac{1}{3}(1 - \theta - 2c)$, and individual profits are $\pi_1(G, G, \theta) = \frac{1}{9}(1 - \theta + c)^2$ and $\pi_2(G, G, \theta) = \frac{1}{9}(1 - \theta - 2c)^2$. When firm 1 adopts the good technology while firm 2 adopts the bad technology, the equilibrium price is $p = \frac{1}{3}(1 + \theta)$, individual outputs are $x_1(G, B, \theta) = \frac{1}{3}(1 - 2\theta)$ and $x_2(G, B, \theta) = \frac{1}{3}(1 + \theta)$, and firm 1's profit is $\pi_1(G, B, \theta) = \frac{1}{9}(1 - 2\theta)^2$. Clearly, each firm's profit decreases with own costs and increases with its rival's costs.

It is immediate to confirm that inequalities (1) and (2) are always satisfied. The cheap

[15] A signaling equilibrium can also emerge with Bertrand competition. However, with an homogeneous product, Bertrand competition implausibly requires firm 1 to signal by producing zero output in the first period.

[16] Recall the standard formulas for the Cournot duopoly equilibrium with linear demand and constant marginal costs c_1 and c_2: $p = (1 + c_1 + c_2)/3$; $x_i = (1 - 2c_i + c_j)/3$; $\pi_i = x_i^2$; $CS = (2 - c_1 - c_2)^2/18$.

talk assumption requires that $\frac{1}{9}(1-\overline{\theta}+c)^2 > \frac{1}{9}$, or:

$$c > \overline{\theta}. \tag{5}$$

Clearly, social welfare is higher under no regulation if γ is close to zero whereas it is always higher under regulation if γ is sufficiently large. Consequently, the no-dominant-strategies assumption requires that γ is neither too low nor too large. More precisely, γ must range in the following interval:

$$\frac{8c-11c^2+16\underline{\theta}-8c\underline{\theta}-8\underline{\theta}^2}{12} < \gamma < \frac{8c-11c^2+16\overline{\theta}-8c\overline{\theta}-8\overline{\theta}^2}{12}. \tag{6}$$

The assumption of pessimistic government is satisfied if

$$\chi < \frac{8c-11c^2+16\overline{\theta}+8c\overline{\theta}-8\overline{\theta}^2-12\gamma}{8\left(\overline{\theta}-\underline{\theta}\right)\left(2-c-\overline{\theta}-\underline{\theta}\right)}(=\hat{q}). \tag{7}$$

The critical value $\hat{q}$ is positive and lower than one when inequality (6) holds. For instance, with $\underline{\theta}=0$, $\overline{\theta}=\frac{1}{8}$ and $c=\frac{1}{4}$, the interval (7) becomes $.109 < \gamma < .245$. Note that in this example γ is naturally bounded above by $\frac{2}{3}$, since when $\gamma > \frac{2}{3}$ the environmental externality is so large that social welfare under no regulation would be negative and the government woud actually prefer to shut down production.

Inspection of (5), (6) and (7) shows that Assumptions 1-3 are more likely to be met the greater is the cost asymmetry with the good technology, c, the greater is the difference in the marginal costs associated with the two states of nature, $\left(\overline{\theta}-\underline{\theta}\right)$, and the more pessimistic is the government.

The function $\Phi(z_G,\theta)$ becomes $\Phi(z_G,\theta)=\frac{1}{9}[z_G\delta(1+c-\theta)^2+(1-2\theta)^2-(1+z_G\delta)]$. The critical value $\underline{\delta}$ is

$$\underline{\delta}=\frac{4\underline{\theta}(1-\underline{\theta})}{2(c-\underline{\theta})+(c-\underline{\theta})^2}, \tag{8}$$

and $\overline{\delta}$ is given by a similar expression with $\overline{\theta}$ replacing $\underline{\theta}$. Assuming again $\underline{\theta} = 0$, $\overline{\theta} = \frac{1}{8}$ and $c = \frac{1}{4}$, the two critical values are $\underline{\delta} = 0$ (when $\underline{\theta} = 0$, overcompliance is not costly for the low-cost type and thus the low-cost type will always engage in signaling) and $\overline{\delta} = 1.65$. Therefore, in this numerical example the over-overcompliance result can only emerge when $\delta > 1.65$. In this case, the probability that there is over-overcompliance is $1 - \chi$ (the probability that the actual compliance cost is high) times x_h^* (the probability that the high-cost type adopts the good technology).

4.2 Entry preemption

Suppose now that firm 1 is the incumbent and firm 2 is a potential entrant. Firm 2 can enter the market only in the second period upon payment of a fixed entry cost F. If firm 2 enters, in the second period firms compete *à la* Cournot. The fact that firm 2 must pay a fixed entry cost ensures that firms are inherently asymmetric, so there is no need of assuming further cost asymmetry. For simplicity, we therefore now set $c = 0$.

We assume that entry is profitable if the government does not regulate, while firm 2 prefers to stay out if it must use the good technology. Thus, in this example overcompliance is an entry-deterrence device. This requires that the following inequalities must hold:

$$\frac{(1-\underline{\theta})^2}{9} < F < \frac{1}{9}. \tag{9}$$

(Of course, this interval would be larger had we allowed for $c > 0$.)

The cheap talk assumption requires that firm 1 prefers to raise its cost but remain a monopoly over facing competition from the entrant. This means that firm 1's monopoly profit with cost $\overline{\theta}$, $\frac{(1-\overline{\theta})^2}{4}$, must exceed duopoly profit with zero cost, $\frac{1}{9}$, or

$$\overline{\theta} < \frac{1}{3}. \tag{10}$$

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

$$W^R(\theta) = \frac{3}{8}(1-\theta)^2. \tag{11}$$

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

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

Consequently, the no-dominant-strategy assumption requires that

$$\frac{2}{3} - \frac{9}{16}(1-\underline{\theta})^2 - F < \gamma < \frac{2}{3} - \frac{9}{16}(1-\overline{\theta})^2 - F. \tag{12}$$

It can be easily checked that conditions (9), (10) and (12) can simultaneously hold. For instance, when $\overline{\theta} = \frac{1}{4}$, $\underline{\theta} = \frac{1}{8}$ and $F = \frac{1}{10}$, inequalities (9) and (10) hold and the interval (12) becomes $.136 < \gamma < .25$.

The critical value $\underline{\delta}$ now is

$$\underline{\delta} = \frac{9\underline{\theta}(2-\underline{\theta})}{9(1-\underline{\theta})^2 - 4}, \tag{13}$$

and $\overline{\delta}$ is given by the corresponding expression with $\overline{\theta}$ replacing $\underline{\theta}$. For example, with $\overline{\theta} = \frac{1}{4}$ and $\underline{\theta} = \frac{1}{8}$, the two critical values are $\underline{\delta} = .73$ and $\overline{\delta} = 3.71$. In this case, a semi-separating equilibrium, with the associated over-overcompliance phenomenon, can only emerge for rather large values of the parameter δ.

5 Concluding remarks

In this paper we have formalized the intuitive argument that unilateral overcompliance to regulatory standards can be used as a signaling device. In a simple model of an asymmetric duopoly where a benevolent government is poorly informed about the cost of complying with a stricter regulation, the more efficient firm may voluntarily overcomply before a stricter regulation is enacted in order to signal that compliance is not too costly. If the government reacts by adopting a stricter regulation, the more efficient firm gains by raising its rival's costs.

Our analysis has identified the conditions that must be met for overcompliance to occur in equilibrium. First, the more efficient firm must gain by raising its rival's costs even if its own costs increase. Second, a stricter regulation must be socially desirable if and only if the cost of adhering to tougher regulatory standards is not too high. Third, the government must be pessimistic enough about such compliance costs that it would not regulate on the basis of its prior belief. Finally, firms must value future (post-regulation) profits highly enough.

Our analysis has also highlighted that firms may *over*-overcomply. That is to say, in semi-separating equilibria even the high-cost type overcomplies, confounding the government that may regulate even when regulation actually is welfare reducing. This result resonates with Lyon and Maxwell's (2003) finding that unilateral overcompliance is not necessarily beneficial from the social viewpoint in a regulatory preemption model.

It should be clear that the conditions that are required for overcompliance to occur in a signaling equilibrium are restrictive and that a signaling explanation of unilateral overcompliance is not always applicable. The signaling explanation may therefore complement, but is not intended as a substitute for the concerned consumers and the regulatory preemption approaches. From this perspective, it is interesting to discuss the differential implications of the signaling theory as compared to other theories of unilateral regulatory overcompliance.

One difference between the signaling approach and the concerned consumers approach is that the latter requires that overcompliance is observed by the general public, whereas what is crucial here is that overcompliance is observed by the government. Thus, the concerned consumers hypothesis better applies to product overcompliance cases, while the signaling explanation may also apply to process overcompliance and to cases involving intermediate products.

With respect to the regulatory preemption hypothesis, there are two main differences. First, in the signaling explanation overcompliance triggers regulation instead of preempting it. This is not to say that when overcompliance is followed by a strengthening of regulatory standards, one must necessarily resort to a signaling explanation. However, to make the regulatory preemption explanation applicable to these cases requires further arguments, such as that regulatory standards would have been even tougher had overcompliance not occurred, or that the overcompliance preemption strategy simply did not work. Second, in the regulatory preemption approach firms' most preferred (although unattainable) outcome would be that the tougher regulation is never enacted. In contrast, a signaling explanation is consistent with the observation that overcomplying firms may welcome the enactment of tougher regulation and may actually lobby for it.[17]

[17] In addition, in the regulatory preemption approach it is typically assumed that firms are symmetric or at least have aligned interests. Sometimes unilateral overcompliance is effectively modeled as an industry strategy, although this assumption is not really crucial to the regulatory preemption theory. In the signaling theory, in contrast, firms' conflict of interest is at the centre stage of the analysis.

Brown's (2005) case study of California environmental regulation nicely illustrates the role of these differential implications. In 1992, California's Air Resources Board (CARB) implemented Phase II of its gasoline regulations. These regulations, which were expected to raise refinement costs substantially, were strongly opposed by the industry association (WSPA). Consistently with our model, however, the regulations were supported by the largest firm, Arco. According to Brown (p. 9) "Arco's involvement in the development and support of the Phase II CARB gasoline regulations is well documented. This involvement had its roots in Arco's development of EC-X gasoline during the 1980s, and was made manifest in Arco's request that this gasoline be considered as the basis of CARB's 1996 performance standards." A signaling interpretation is that early adoption of a cleaner technology (i.e., the development of EC-X gasoline) served to signal the regulatory agency that a stricter environmental standard would not be too costly to comply with. Brown finds that industry concentration actually increased as a result of tighter regulation, which suggests that Arco may have gained from raising rival's costs.

The DuPont example discussed by Lyon and Maxwell (2004) is another case in point. Lyon and Maxwell (2004) document that by mid '80s DuPont departed fron an "Alliance" involving Chlorofluorocharbons (CFL) producers and started lobbying for a tigher regulation of use of CFL. Thank to its patents on CFL substitutes, when such tigher regulation was enacted, DuPont gained substantial market power.

In these examples, the competitive advantage of Arco and DuPont seems to arise from early investments in a "good" technology. Our model indeed implies that firms may have an incentive to engage in such investments and then overcomply. The analysis of an extended model with an early stage of R&D invstment may add further insigths and is left for future work.

References

Arora, S., Gangopadhyay, S., 1995. Toward a theoretical model of voluntary overcompliance. Journal of Economic Behavior and Organization 28, 289-309.

Bagnoli, M., Watts, S.G., 2003. Selling to socially responsible consumers: Competition and the private provision of public goods. Journal of Economics and Management Strategy 12, 419-445.

Brown , J., 2005. Raising rivals' costs via California's environmental regulations: An empirical test. Working Paper, University of California Santa Barbara.

Kolk, A., van Tulder, R., 2002. The effectiveness of self-regulation: Corporate codes of conduct and child labour. European Management Journal 20, 260-271.

Kreps, D., Wilson, R., 1981. Sequential equilibria. Econometrica 50, 863-894.

Lutz, S., Lyon, T. P., Maxwell, J. W., 2000. Quality leadership when regulatory standards are forthcoming. Journal of Industrial Economics 48, 331-348.

Lyon, T. P., Maxwell, J. W., 2003. Self-regulation, taxation and public voluntary environmental agreements. Journal of Public Economics 87, 1453-1486.

Lyon, T. P., Maxwell, J. W., 2004. Corporate Environmentalism and Public Policy. Cambridge: Cambridge University Press.

Maloney, M., McCormick, R., 1982. A positive theory of environmental quality regulation. Journal of Law and Economics 25, 99-123.

Maxwell, J. W., Lyon, T. P., Hackett, S. C., 2000. Self-regulation and social welfare: The political economy of corporate environmentalism. Journal of Law and Economics 43, 583-617.

Mazurek, J., 1999. Voluntary agreements in the U.S.: An initial survey. CAVAWorking Paper 98/11/1.

Salop, S. C., Scheffman, D. T., 1983. Raising rivals' costs. American Economic Review Papers and Proceedings 73, 267-271.

Segerson, K., Miceli, T., 1999. Voluntary environmental agreements: Good or bad news for environmental protection? Journal of Environmental Economics and Management 36, 109-130.