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Fondazione Eni Enrico Mattei

## **A Bargaining Model of Voluntary Environmental Agreements**

Paola Manzini and Marco Mariotti

**NOTA DI LAVORO 81.2000**

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# A bargaining model of voluntary environmental agreements

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## Abstract

We present an explicit model of firm-regulator negotiations in a market with several firms. We describe how the regulatory surplus is distributed between firms and regulator, and analyse the impact of various oligopoly parameters on the resulting level of environmental regulation. Our main result is that a ‘*toughest firm principle*’ holds: the outcome of negotiations is essentially determined by the firm with the most aggressive attitude towards environmental control.

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## 1 Introduction

It is widely recognised that a strong incentive for firms to voluntarily reduce polluting emissions, or in general comply with higher environmental standards, is represented by regulatory gains (e.g. Brau and Carraro (1999) and the literature cited therein). Namely,

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it may be the case that regulatory intervention with the consensus of the firms is less costly to the latter than mandatory legislative intervention. Similarly, for various reasons, a regulator may be willing to concede somewhat on the stricter regulation level that would be implemented by a legislative body. For example, if the regulator aims at maximizing social welfare, it may take into account the additional social costs associated with legislative intervention compared with mere regulation. Or, it may be the case that the regulator has a private agenda which differs from that of the legislator. In summary, there are several situations in which there is a *surplus* to be created between firms and regulator if legislative intervention can be avoided by voluntary agreement on an environmental standard.

In this paper, we present an explicit model of firm-regulator negotiations in a market with several firms, in which legislative intervention can be avoided provided *all* firms in the market agree to comply<sup>1</sup>. We describe how the regulatory surplus is distributed between firms and regulator, and analyse the impact of various oligopoly parameters on the resulting level of environmental regulation. There are a few models studying situations such as the one we consider (see e.g. Segerson and Miceli (1997) and Maxwell et al. (2000)).<sup>2</sup> However, our focus is rather different. We concentrate on the negotiation procedure itself rather than on the factors determining the size (or existence) of the regulatory surplus. In the alternative models it is assumed that firms play an essentially passive role and face an ultimatum offer by the regulator. If the firms do not accept, they face mandatory legislation with some probability. We observe though that firms *do* have some bargaining power of their own: after all, legislative intervention is a threat for the regulator as well as for the firms.

It seems therefore more natural to model the relationship between firms and regulator as a bargaining game in which parties alternate in making offers, and the cost of rejecting an offer for each party is the risk of triggering legislative intervention (with some given probability). Only in the limit as the risk of legislative intervention tends to one, and assuming - as we do - that the regulator has the initiative by making the first proposal,

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<sup>1</sup>The alternative assumption where compliance by only one firm is sufficient to preempt legislative intervention has also been explored in the literature.

<sup>2</sup>See also Hansen (1997), Segerson and Miceli (1998), Segerson (1998).

would one be led back to the ultimatum model. Our modelling task would be relatively trivial if there were only one firm, in which case the standard Rubinstein model of alternating offers could be used. However, we are mainly interested in the oligopoly case. Although firms are all ‘on one side’ of the bargaining table (they prefer less regulation to more), their preferences do not coincide, because in general regulation will imply different costs for each of them. We thus extend the standard bargaining model to allow for one of the parties to be a collection of heterogeneous players. This aspect of our paper may be of independent interest.

More specifically, we assume that firms play a Cournot game in the market phase. Their profits are thus endogenously determined given the demand, cost and abatement level parameters. Abatement levels are agreed upon in a previous stage of negotiations between firms and regulator. We consider the case in which higher abatement levels affect the marginal costs of production.

The most interesting conclusion of our model, from which all the comparative statics follows, is that a ‘*toughest firm principle*’ holds: the outcome of negotiations is essentially determined by the firm with the most aggressive attitude towards environmental control. In other words, roughly speaking, the equilibrium negotiated abatement level is the same that would result in *bilateral* negotiations between the regulator and the most aggressive firm. This surprising result is robust to some modifications of the bargaining procedure and seems to be independent of the specific functional forms used in the paper.

As a consequence of the toughest firm principle, the effect of changes in market parameters on the level of environmental control is quite subtle. Contrary to our initial expectations, one cannot relate the equilibrium abatement level to the common aggregate statistics measuring, say, market concentration. The effect of changes in parameters is *firm-specific*, not ‘anonymous’. Essentially everything depends on how the change in parameters affects the market position, and hence the bargaining position, of the ‘toughest firm’. For example, consider an increase in the per-unit abatement cost of a firm. If this firm is the toughest one, this reduces - *ceteris paribus* - its equilibrium oligopoly profits: this will imply a lower regulatory gain, with a tendency for the firm to be tougher in negotiations, but also a lower profit in case of disagreement, with a tendency to become

more willing to concede. In the text we calculate how these tendencies play off, but the point to make here is that those tendencies are exactly reversed if the increase in abatement costs concerns other firms, thus strengthening the market position of the toughest one. For this reason, it is impossible to say what happens if, say, average abatement costs increase, unless it is specified how the average increase is distributed. In terms of policy implications, this suggests the superiority a ‘firm-targeted’ approach rather than ‘generic’ ones.

Finally, our model also shows that the effect of changes in the probability of legislative intervention on the equilibrium negotiated abatement level is in general ambiguous. We are able to sign it only when firms are sufficiently homogeneous, in which case an increase in the probability of legislative intervention increases equilibrium abatement levels. In the limit in which the probability of legislative intervention tends to one, then, the regulator will be able to extract all the regulatory surplus, and the level of abatement will be maximal.

## 2 The model

There are  $F$  profit maximizing firms in the market for a homogeneous product competing in output. The inverse linear demand function is  $P(Q) = a - Q$ , where  $Q = \sum_i q_i$ . We assume that firms have different technologies regarding both production and pollution control. Specifically, each firm  $i$  produces at constant marginal cost  $c_i$ , and bears pollution abatement costs  $\alpha_i f$  per unit of output, where  $f$  is the (negotiated) abatement level. Denote by  $f_L$  the abatement level that would be mandated by the legislative body, should it intervene. Before market competition,  $f$  is determined in negotiations with the regulator, and ranges in an interval  $[0, f_L] \in \mathcal{R}_+$ . These bounds reflect our discussion in the introduction. The regulator’s utility from establishing pollution abatement level  $f$  is simply  $u_R(f) = f$  (as it will be clear later, this assumption of risk neutrality does not affect the qualitative nature of our conclusions). The utility of the regulator in case of legislative intervention is normalised to zero, and thus corresponds to the worst agreement that the regulator could negotiate with firms.

Standard calculations show that firm  $i$ 's profits as a function of the negotiated  $f$  are

$$\pi_i(f) = \frac{\left(a - N(c_i + \alpha_i f) + \sum_{j \neq i} (c_j + \alpha_j f)\right)^2}{(N+1)^2}$$

We assume the standard restriction on parameters,

$$a - Nc_i + \sum_{j \neq i} c_j > 0$$

Indeed, because at the moment we do not consider exit from the market by firms, we assume that firms will not make negative profits if they produce a positive amount whatever the level of regulation, in other words:

$$\begin{aligned} a - N(c_i + \alpha_i f_L) + \sum_{j \neq i} (c_j + \alpha_j f_L) &> 0 \\ \Leftrightarrow a - \left(Nc_i - \sum_{j \neq i} c_j\right) - \left(N\alpha_i - \sum_{j \neq i} \alpha_j\right) f_L &> 0 \end{aligned}$$

In addition, we also require that the parameters are such that no firm prefers higher levels of regulation to lower ones. This can happen because, as is well known, in a Cournot oligopoly common increases in marginal costs can actually *increase* the profits of some firms. In our model ruling this out requires  $N\alpha_i > \sum_{j \neq i} \alpha_j$  (that is, the abatement costs do not differ too much across firms). In the bargaining process, the firms must make unified proposals to the Regulator. This means that they must reach an agreement prior to tabling their offer.

Negotiations between firms and the regulator proceed in an alternating offers fashion. That is, first the regulator proposes a value of  $f$ , which firms (by some procedure discussed below) can *collectively* either accept or reject. In the former case, abatement level  $f$  is voluntarily agreed upon. Otherwise, with probability  $1-p \in (0, 1)$  the legislator intervenes and terminates negotiations while at the same time mandating pollution abatement level  $f_L$ .

If negotiations continue (with probability  $p$ ), firms have to agree (by the procedure described below) on a value of  $f$  to counterpropose to the regulator. Negotiations proceed in this way over an unbounded number of rounds (numbered  $r = 0, 1, 2, \dots$ ) until agreement is reached. Perpetual disagreement implies legislative intervention with probability one.

We now discuss the procedure through which collective decisions (proposals as well as acceptances) are made by the industry. We will in fact consider two natural such procedures. In both, a non-cooperative protocol is followed, one simultaneous and one sequential. In the *simultaneous* protocol, when confronted with a proposal by the regulator, each firm  $i$  independently either accepts (Y) or rejects (N). If all firms accept, then the proposal is agreed upon, negotiation ends, and firm can compete in the product market. Otherwise, negotiations move to the following round (with probability  $p \in (0, 1)$ ), in which a proposal to the regulator by the industry must be made in the following way. Each firm  $i$  puts forward a value  $f_i$  independently of the other competitors. If all firms propose the same value, that will constitute the industry's proposal to the regulator. Failure to agree results in legislative intervention (i.e. irreversible breakdown of internal negotiations) with probability  $1 - q \in (0, 1)$ . If internal negotiations continue (with probability  $q$ ), each firm makes a new proposal, and so on. This concludes the description of the simultaneous protocol.

The *sequential* protocol is analogous, except that instead of making choices simultaneously, firms follow some prespecified order.

We now discuss the equilibrium concept we use. The basic notion is that of subgame perfect equilibrium. However, in the simultaneous protocol we model a situation in which firms act non-cooperatively but can openly negotiate and sign binding agreements to coordinate their strategies. In these conditions, a Nash equilibrium must be stable not only with respect to *individual* deviations by each player but also with respect to *joint* deviations by *groups* of firms. In particular, there have to be no incentives for the whole group of firms to make collectively a different proposal. Thus we consider the *strong* Nash equilibria of the internal negotiations game. We define a subgame perfect equilibrium with this property a *robust* subgame perfect equilibrium (rspe). The requirement of robustness merely serves the function of ruling out artificial equilibria which are created by the choice of modelling the negotiation between firms as a simultaneous move game. This is clarified further after the proof of proposition 2.



### 3 Results

We first characterise the solution of the negotiation game. This will allow us to relate the equilibrium abatement level to market parameters and derive directly some comparative statics results.

The analysis merely consists of a careful adaptation of the arguments in the standard alternating offer bargaining model. Here we consider *stationary* strategies<sup>3</sup>. For the proof that this does not constitute a restriction we refer the reader to Manzini and Mariotti (2000).

Let  $f_R$  be the (stationary) abatement level that the regulator proposes. Let  $f_F$  be the (stationary) abatement level that the firms (collectively) propose. Since we are considering a robust equilibrium, firms will always all coordinate on the same abatement level in internal negotiations, since otherwise perpetual disagreement would ensue.

Consider the regulator first. The abatement level that he is willing to accept from the firms,  $f_F$ , must satisfy

$$u_R(f_F) \geq pu_R(f_R) + (1 - p) \cdot 0$$

That is, the regulator will accept any abatement level which yields a utility at least equal to the expected utility from the ‘gamble’ in which with probability  $p$  the regulator gets the opportunity to make a counteroffer, and with probability  $(1 - p)$  negotiations break down because of legislative intervention. Given the assumption of robustness, however, firms will never concede to the regulator a utility strictly greater than that of the gamble, so that the condition above holds with equality. Since  $u_R(f) = f$ , this reduces to

$$f_F = pf_R$$

Consider now the firms’ side of the bargain. Each firm  $i$  will be willing to accept any abatement level  $f_R$  such that

$$\pi_i(f_R) \geq p\pi_i(f_F) + (1 - p)\pi_i(f_L)$$

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<sup>3</sup>A stationary equilibrium is an equilibrium in which for each player his strategy prescribes the same action at identical subgames, independently of the previous history.

The regulator must ensure that the abatement level he proposes is acceptable to *all* firms. So let  $i^*$  index a firm with the lowest  $f_R$  in the unique admissible solution to the system of equations

$$\begin{aligned} f_F &= p f_R \\ \pi_i(f_R) &= p \pi_i(f_F) + (1 - p) \pi_i(f_L) \end{aligned}$$

and denote the corresponding solution by  $(f_R^*, f_F^*)$ . Then, the following strategy profile constitute a robust s.p.e. of the game:

**Regulator:** propose  $f_R^*$ ; accept any  $f \geq f_F^*$  and reject otherwise.

**Firm  $i$ :** propose  $f_F^* = p f_R^*$ ; accept any  $f \leq f_R^*$ .

It is easy to verify that the above constitute a robust equilibrium, so we omit a detailed verification. Just notice that since profits are monotonically decreasing in  $f$ , for all firms  $i \neq i^*$  it is true that  $\pi_i(f_R^*) > p \pi_i(f_F^*) + (1 - p) \pi_i(f_L)$ . Therefore, it is optimal for firm  $i \neq i^*$  to accept the regulator's proposal whenever it is optimal for firm  $i^*$  to do so. Furthermore, it is optimal for firm  $i$  to choose  $f_F^*$  when involved in internal negotiations with other firms, given that all the others do so. Finally, robustness follows from the fact that  $f_F^*$  is the lowest abatement level that the regulator accepts, so there can be no profitable joint deviations by firms.

By replacing the expressions for profits in the formulas characterising the equilibrium we have thus obtained:

**Proposition 1** *In a robust subgame perfect equilibrium of the simultaneous protocol negotiation, agreement is reached immediately on one of the following abatement level*

$$f_R^* = f^* = \frac{(a - C)(1 + p) \pm \sqrt{(a - C)^2(1 + p)^2 - (1 + p + p^2)(2(a - C) - A f_L) A f_L}}{A(1 + p + p^2)}$$

where  $C = (N c_{i^*} - \sum_{j \neq i^*} c_j)$ ,  $A = (N \alpha_{i^*} - \sum_{j \neq i^*} \alpha_j)$ .

**Remark 1** *Although we have found two possible equilibrium abatement levels<sup>4</sup>, it is easy to show that if the probability of legislative intervention is sufficiently high, the largest of the two roots can be ruled out. See section 4 below.*

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<sup>4</sup>This is because the bargaining optimality equations for the firms are nonlinear.

In this proposition  $i^*$  denotes the “toughest” firm, that is the one that in a bilateral bargain with the regulator would obtain the lowest level of abatement. Our result says that *this firm entirely drives negotiations*, even when all other firms are present.

It is clear from the proof that the only role of the robustness requirement is to rule out ‘silly’ equilibria in which the regulator is allowed to extract a rent because firms fail to coordinate on the best (from their point of view) abatement level compatible with the regulator accepting. Indeed, given that firms formulate their proposal by playing a simultaneous move game, in the absence of robustness it may be a (stationary) equilibrium, for example, that they always propose  $f = f_L$ . No firm *individually* can profitably deviate because this would just postpone the same agreement by one period. But it seems compelling to expect that with the possibility of communication and of making binding agreements in the formulation a proposal by the firms such a lack of coordination will be avoided.

In fact, when a sequential protocol is followed in internal negotiations among firms we do not need robustness:

**Proposition 2** *The subgame perfect equilibrium of the sequential protocol game is the same as the robust subgame perfect equilibrium in the simultaneous protocol game. As a particular implication, the choice of a specific protocol does not affect the equilibrium abatement level  $f^*$ .*

This is proved easily by contradiction. First of all note that the internal negotiations among firms amount to a coordination game in which  $f^*$  is preferred by all firms to any other abatement level acceptable to the regulator. Then, suppose there is a subgame perfect equilibrium where firms do not coordinate on the best abatement level  $f^*$  (either because they never reach agreement, or because they coordinate on some other  $f' > f^*$ ). Take the *first* firm *not* to choose  $f^*$ , indexed by  $i_1$ . Its proposal of an abatement level different from  $f^*$  can only be optimal if in the subgame that would have followed  $i_1$ ’s choice of  $f^*$  some other firm would itself propose an abatement level different from  $f^*$ . Let  $i_2$  be the *first* such a firm. In turn, this could only have been optimal for firm  $i_2$  if in the subgame that would have followed this firm’s choice of  $f^*$  some other firm would

propose an abatement level different from  $f^*$ , and so on. This argument shows that in order to construct a subgame perfect equilibrium in which firms do not coordinate on  $f^*$  one needs an infinite sequence of “first” deviators  $i_1, i_2 \dots$  whereas there is only a finite number of firms. ■

## 4 Comparative statics

The formula derived for  $f^*$  allows us to draw some interesting conclusion as to the effects of the various parameters on the equilibrium abatement level. We will concentrate on the case in which the probability of legislative intervention is sufficiently large. In fact, for  $f^*$  to be an equilibrium abatement level, it must not be greater than  $f_L$ . This is true if

$$A(1+p+p^2)f_L \geq (a-C)(1+p) \pm \sqrt{(a-C)^2(1+p)^2 - (1+p+p^2)(2(a-C) - Af_L)Af_L}$$

For the positive value of the radical, this implies:

$$-(a-C-Af_L)(1+p) + p^2 Af_L \geq \sqrt{(a-C)^2(1+p)^2 - (1+p+p^2)(2(a-C) - Af_L)Af_L}$$

which is impossible for sufficiently low levels of  $p$ .

Because of the equilibrium equivalence established in proposition 2, in what follows we simply refer to “equilibrium abatement level” without further specifying whether the internal bargaining protocol followed by firms is sequential or simultaneous. Let us call firm  $i^*$ , which determines the equilibrium  $f$  as if in bilateral negotiations with the regulator, the *pivotal* firm. In what follows we consider only changes in the parameters such that the pivotal firm remains  $i^*$ . Then:

- the effect of an increase in the marginal cost of pollution abatement for firm  $i$  has opposite effects depending on whether or not firm  $i$  is pivotal. In particular, the equilibrium abatement level  $f^*$  *increases* as the marginal abatement cost of the pivotal firm,  $\alpha_{i^*}$ , *decreases* and if the marginal abatement cost of a non-pivotal firm,  $\alpha_j$ ,  $j \neq i^*$  *increases*. *Common* increases in the abatement costs of all firms impact in the same direction as an increase in the abatement cost of the pivotal firm.

- the effect of an increase in the marginal cost of production for firm  $i$  is qualitatively the same as the effect of an increase in the marginal abatement cost. Note that regarding *common* increases in costs this implies that a per unit production subsidy across the industry would increase the equilibrium abatement level.
- the effect of a change in the probability of legislative intervention is in general ambiguous. We are able to sign it only when firms are sufficiently homogeneous, in which case an increase in the probability of legislative intervention (i.e. an increase in  $(1 - p)$ ) increases the equilibrium abatement level.

Let us consider these effects in turn, starting from the marginal abatement cost.

Recall that  $A = (N\alpha_{i^*} - \sum_{j \neq i^*} \alpha_j)$ . Then,  $A$  increases with  $\alpha_{i^*}$  and decreases with  $\alpha_j$ ,  $j \neq i^*$ .

In general, for any firm  $i$  an increase in own marginal abatement cost  $\alpha_i$  or a decrease in the rival firms' abatement costs  $\alpha_j$  produces two contrasting effects. On the one hand, profits in case of agreement are reduced, narrowing the scope for negotiations and making the firm more “aggressive”, i.e. willing to concede less to the regulator. On the other hand, the firm's disagreement profits are reduced by an increase in  $\alpha_i$ , thus weakening the firm's bargaining position. As we show below, in our model the net effect of these two contrasting forces for the pivotal firm reduces the equilibrium abatement level:

$$\frac{\partial f^*}{\partial A} < 0$$

To simplify notation, let  $K = (a - C)^2 (1 + p)^2$ ,  $P = (1 + p + p^2)$ ,  $M = 2(a - C)$ . Then

$$\begin{aligned} & \frac{\partial \left( \frac{1}{AP} \left( \sqrt{K} - \sqrt{K - P(M - Af_L) Af_L} \right) \right)}{\partial A} \\ &= -\frac{1}{A^2 P} \left( \sqrt{K} - \sqrt{K - PAMf_L + PA^2 (f_L)^2} \right) - \frac{(2Af_L - M) Pf_L}{2AP \sqrt{K - PAMf_L + PA^2 (f_L)^2}} \end{aligned}$$

The sign of the derivative will therefore depend on which of the two terms is greater. The derivative can be rearranged as

$$-\frac{1}{2} \frac{2\sqrt{K(K - PAMf_L + PA^2 (f_L)^2)} - 2K + PAMf_L}{A^2 P \sqrt{K - PAMf_L + PA^2 (f_L)^2}} < 0 \Leftrightarrow$$

$$2\sqrt{K(K - PAMf_L + PA^2(f_L)^2)} > 2K - PAMf_L$$

Since  $2K - PAMf_L$  is positive<sup>5</sup>, we can square both sides of the last expression to obtain:

$$\begin{aligned} 4K(K - PAMf_L + PA^2(f_L)^2) &> 4K^2 + (PAMf_L)^2 - 4KPAMf_L \Leftrightarrow \\ 4KPA^2(f_L)^2 - P^2A^2M^2(f_L)^2 &> 0 \Leftrightarrow 4K - PM^2 > 0 \Leftrightarrow \\ P &< \frac{4K}{M^2} = \frac{4(a - C)^2(1 + p)^2}{(2(a - C))^2} = (1 + p)^2 \Leftrightarrow \\ (1 + p + p^2) &< (1 + p^2 + 2p) \end{aligned}$$

which is always true.

Consider now the marginal cost of production. Recall that  $C = (Nc_{i^*} - \sum_{j \neq i^*} c_j)$ , so that  $C$  increases with  $c_{i^*}$  and decreases with  $c_j$ ,  $j \neq i^*$ . It is clear that the effects on firms' incentives in negotiations of a change in the marginal cost of production are similar to those of a change in the marginal abatement cost. So, not surprisingly:

$$\frac{\partial f^*}{\partial C} < 0$$

We show this below. To simplify notation, let again  $P = (1 + p + p^2)$  and  $R = (1 + p)$ . Then the expression for the equilibrium abatement level becomes

$$f^* = \frac{1}{AP} \left( (a - C)R - \sqrt{(a - C)^2 R^2 - P(2(a - C) - Af_L)Af_L} \right)$$

Differentiating with respect to  $C$  yields:

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<sup>5</sup>Substituting back into  $2K - PAMf_L$  the requirement simplifies to

$$2(a - C)^2(1 + p)^2 - (1 + p + p^2)2(a - C)Af_L > 0.$$

which can be rearranged as

$$\begin{aligned} (a - C)(1 + p^2 + p + p) &> (1 + p + p^2)Af_L \Leftrightarrow \\ (a - C - Af_L)(1 + p^2 + p) + (a - C)p &> 0, \end{aligned}$$

which is always true, since  $(N + 1)q_i(f_L) = (a - C - Af_L) > 0$  by assumption.

$$\begin{aligned}
& \frac{\partial \left( \frac{1}{AP} \left( (a-C)R - \sqrt{(a-C)^2 R^2 - P(2(a-C) - Af_L) Af_L} \right) \right)}{\partial C} \\
&= \frac{1}{AP} \left( -R + \frac{R^2(a-C) - PAf_L}{\sqrt{(a-C)^2 R^2 - P(2(a-C) - Af_L) Af_L}} \right) < 0 \\
&\Leftrightarrow \frac{R^2(a-C) - PAf_L}{\sqrt{(a-C)^2 R^2 - P(2(a-C) - Af_L) Af_L}} < R \\
&\Leftrightarrow R^2(a-C) - PAf_L < R\sqrt{(a-C)^2 R^2 - P(2(a-C) - Af_L) Af_L}
\end{aligned}$$

Since both sides in the last inequality are positive, we can square both sides to obtain

$$R^2 \left( (a-C)^2 R^2 - P(2(a-C) - Af_L) Af_L \right) > R^4 (a-C)^2 + P^2 A^2 (f_L)^2 - 2R^2 (a-C) PAf_L$$

which reduces to

$$R^2 PA^2 (f_L)^2 > P^2 A^2 (f_L)^2 \Leftrightarrow R^2 = (1 + 2p + p^2) > (1 + p + p^2) = P$$

which is always verified.

Regarding the effect of  $p$ , one would expect that the equilibrium abatement level should be reduced by a decrease in the probability of legislative intervention (i.e. an increase in  $p$ ): in fact, the first mover (regulator) advantage should decrease when the breakdown cost imposed on the opponent decreases. However, this turns out to be unambiguously true only if firms are sufficiently homogeneous. We develop the analysis for identical firms below.

## 5 Identical firms

The forces at play become particularly stark in the case where  $\alpha_i = \alpha$  and  $c_i = c$  for all  $i$ . In this case firms' profits in case of legislative intervention are the same, so that we can normalise all of them to zero without loss of generality.

In this case the equilibrium conditions in regulator-firms negotiations become simply

$$\begin{aligned}
f_F &= pf_R \\
\pi(f_R) &= p\pi(f_F)
\end{aligned}$$

Substituting the expression for profits this leads to the unique equilibrium abatement level

$$f_R^* = f^* = \frac{(a - c)}{\alpha(1 + \sqrt{p} + p)}$$

and again  $f_F^* = pf_R^*$ . The formula above shows in particular the previously discussed unambiguous effect of  $p$ , and confirms the results already derived on the marginal costs.

This case also highlights the irrelevance of market concentration measures (discussed in the introduction) for the equilibrium abatement level, which is independent of the number of firms.

Note, however, that market concentration is indeed important from the social welfare point of view. Obviously, the overall pollution levels after regulation depend on market concentration, and because of the toughest firm principle pollution abatement levels could very far from the average one that would arise if the regulator were to negotiate with each firm separately.

## 6 Conclusion

We have presented a model of negotiation on pollution abatement levels between a regulator and an industry. Although some specific quantitative results do clearly depend on the special functional forms we have used, we hope to have shown that the basic qualitative nature of the equilibrium we have characterised is a robust phenomenon. In particular, we have identified a ‘toughest firm principle’ which governs negotiations and drives the comparative statics results. This principle is relatively independent both of the nature of market competition and of the details of the demand function and cost structure. It is worth stressing that being ‘toughest’ in negotiations means in our case to be weakest in market competition (i.e. high costs relative to the rivals). This weakness is exploited in negotiations with the regulator to achieve a better deal. All other firms effectively free-ride on the ‘toughest’ one: legislative intervention is avoided at a minimum cost. The seminal papers by Segerson and Miceli (1997,1998) also stressed the importance of free-riding, but in our different setup we highlight a different phenomenon: regulating the whole industry does not necessarily eliminate free-riding if firms are heterogeneous.



We have also shown that the model is robust to at least some modifications of the structure of negotiations between regulator and firms.

As to policy implications, this paper suggests a role for the use of taxes/subsidies as a means to affect negotiated abatement levels through their impact on bargaining incentives. Finally, we have assumed that the regulator has a private agenda, and his preferences over abatement levels are exogenously given. Presumably, a ‘sophisticated’ regulator who at least partially cares about social welfare would have preferences defined directly on the final level of industry pollution. We leave this issue open for further research.

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