

A Penalty System as Enforcement Device of Policy Measures Under Incomplete Information

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Abstract:

In enforcing policy measures under incomplete information neither an individual nor a collective penalty may generate sufficient incentive compatibility. Individual monitoring may be avoided, while collective penalties may lead to multiple Nash-equilibria. In this paper it is shown that by combining elements of both kind of penalties these problems are solved: circumventing monitoring devices does not pay and multiple Nash-equilibria are excluded. Socially optimal behavior is selected as unique Nash-equilibrium.

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1 Introduction

Year after year new laws are ratified without taking too much care for the executive side of the new rules. Yet, the real change starts only when a law is *enforced*. Since in particular in the environmental sector detection rates are rather decreasing¹ - the problem is that firms had successfully evaded the control points - this paper presents a general mechanism, applied to the enforcement of environmental regulations, which aims at inducing firms to desist from circumvention.

Preventing "evasion" would be easy if the administration had complete information about all firms. Complete control is usually impossible to achieve, either for technical reasons or due to prohibitive costs. Yet, even if firms cannot be completely observed, e.g. in the environmental sector the following evidence can be gathered: 1) The administration can measure the overall concentration of the pollutant at certain receptor points. 2) By an unannounced monitoring of arbitrarily chosen firms the keeping of individual emission limits can be spot-checked.

This paper analyzes the necessary conditions for a mechanism enabling to enforce an environmental protection law at reasonable enforcement effort provided that these two sources of information are available. The mechanism will have to make sure that (i) all firms able to bear the cost of their waste discharges and reduction have an incentive to comply with their individual emission limits. (ii) For firms unable to do so the mechanism will have to give an incentive to shut down their production facilities even if incompletely monitored. Of course, (ii) is a special case of (i), but as a corner solution (ii) needs additional attention. So far, this problem of missing incentives for the special case of (ii) has not been adequately examined.

In the previous discussion there were two mechanisms introduced to achieve the enforcement of an environmental target under incomplete information: individual and collective penalty (cf. e.g. Harford [1987], Segerson [1988]). It was shown that under certain conditions neither of them provides firms with sufficient incentives to reduce emissions to a socially optimal level (cf. Harford [1991], Keeler [1991] Kritikos [1993], Lee [1984], Meran and Schwalbe [1987], Nowell and Shogren [1994]). When combining individual and collective penalty, a firm has to pay an individual fine if monitoring proves that it has exceeded its revealed emission level, while the administration may impose a fine on all firms if total pollution exceeds the previously fixed level. The main insight of this paper is that in a very simple model this mechanism induces a unique equilibrium where all firms reduce pollution to the socially efficient level even if they have to go out of business.

¹ Cf. Helland (1998). For a rationale why this has to be expected in democracies, c.f. Selden, Terrones (1993).

The paper is organized as follows: Section 2 presents the model and the policy setting. Section 3 analyzes the individual and the collective penalties and their effects when implemented solely. Section 4 develops the incentive compatible mechanism which combines both kind of penalties. In section 5 the paper closes with a discussion of the mechanism and presents a conclusion.

2 Model and Policy Setting

Since the environmental sector is used as an example and the paper is focused on the implications of the mechanism, the framework of the model is kept very simple. It is familiar from earlier approaches of the price-standard model of Baumol, Oates (1988). j risk-neutral², single-product firms (with $j=1, \dots, M$) operate in a competitive economy. The profit of firm j

$$(1) \quad \pi_j = \pi_j(\varepsilon_j)$$

represents the benefits of a firm depending on its emissions ε_j which are generated as a by-product of the firm's production. It will be assumed that $\pi_j(0)=0$ and that the profit increases at a decreasing rate, i.e. $\partial \pi_j / \partial \varepsilon_j \geq 0$, $\partial^2 \pi_j / \partial \varepsilon_j^2 < 0$. In the absence of any environmental control the firm will release pollution up ε_j° where $\pi_j'(\varepsilon_j^\circ)=0$. Due to the concavity of π_j the firm's profit will be $\pi_j(\varepsilon_j^\circ)$. For $\varepsilon_j > \varepsilon_j^\circ$, $\pi_j'(\varepsilon_j)$ becomes negative. Total emissions are defined as $E^\circ = \sum \varepsilon_j^\circ$.³

The administration plans to reduce emissions in a well-defined region from the actual quantity E° to E^* . In order to secure an efficient allocation of the remaining emissions, the firms have to pay for every unit of emission a tax t so that the total tax paid by a firm amounts to $t\varepsilon^z$ with ε^z being the units of emissions revealed by the according tax payment. Firms will have the option to reduce emissions either by reducing their production level or by investing in an abatement technology. For reasons of simplicity both options are implicitly contained in $\pi_j(\varepsilon_j)$.

In the framework of the first-best world, the optimal policy for a government to achieve a given environmental target⁴ E^* can be derived from the following program:

$$(2) \quad \max_{\varepsilon_j} \sum \pi_j(\varepsilon_j) \quad \text{s.t.} \quad \sum \varepsilon_j \leq E^*$$

The solution ε^* satisfies the necessary condition (with β as Lagrangian multiplier):

$$(3) \quad \pi_j'(\varepsilon_j^*) = \beta > 0 \quad \text{if } \varepsilon_j^* > 0 \text{ and the restriction is binding,}$$

$$(4) \quad 0 \leq \pi_j'(0) < \beta \quad \text{if firm } j \text{ has to leave the market,}$$

$$(5) \quad \pi_j' = \beta = 0 \quad \text{if the restriction is not binding.}$$

² The reaction of risk averse firms to an individual penalty is investigated by Malik (1990).

³ There are no essential differences if it is assumed that dispersions are stochastic, c.f. Harford (1991) and Knupp and Olson (1995).

⁴ Fixing the environmental target has been widely discussed, cf. e.g. Baumol and Oates (1988).

β determines the shadow price of one emission unit which should be set equal to t . In a first-best world where monitoring is costless the enforcement of the emission tax would not pose any problem. Firms would reveal their pollution quantities. In a world where monitoring is costly, additional incentives have to be created enabling the enforcement of the environmental target even under incomplete information. Let us further assume that the administration will fix the tax level t such that the environmental target will be satisfied⁵ if the environmental regulation is fully enforced,⁶ i.e. $\sum \varepsilon^z = E^z = E^*$.⁷ Moreover, it is assumed that the administration is able to observe the ambient pollution level at certain receptor points, to identify the polluting firms in the region, and to monitor with probability ψ the quantity of pollution ε_j emitted by a single polluter. In order to secure an outcome close to a model under complete information an incentive-compatible mechanism has to secure under incomplete observability of emissions that all polluters will either pay the emission tax until the marginal benefit of an additional unit of emissions equals the emission tax (with $t = \beta$), or that they will have to leave the market.

3 Previous Models

3.1 The Individual Penalty

One approach to secure an efficient emission reduction is the individual penalty. According to the common models⁸ such a penalty is to be implemented when the administration is able to monitor and to detect a default of any firm with a probability ψ (with $0 < \psi \leq 1$). Firms will be punished if the revealed emissions (by the tax payment) are less than observed. ψ should be the result of optimal social planning. If monitoring proves that firm j has violated its pollution limit, the administration is entitled to impose a fine Φ_j^I on the firm.

Without going into the details, the mechanism has been criticized for two reasons.

(1) If the nominal level of the penalty is high due to a low monitoring probability and cannot be enforced upon every firm because it exceeds the liability of some firms, the "first-best-solution" cannot be achieved. Cheating will increase with decreasing liability. This problem can be solved by

⁵As to the problem how to reveal the firms' cost functions, cf. Kwerel (1977) and Benford (1998). An alternative for fixing t is a damage based tax mechanism, cf. Hansen (1998).

⁶Instead of imposing a tax the selling of certificates at a multiple-bid auction as designed by Vickrey (1961) would also be an incentive-compatible mechanism to secure an efficient allocation. Without loss of generality it can be assumed that the optimal price t for selling certificates can be revealed as well, c.f. Bolle (1997).

⁷Note that we define E^o as the actual quantity of total emissions, E^* as the quantity which is aimed to be realized by the regulation and E^z as the total tax payments for emissions revealed to the government.

⁸Individual fines were proposed by Harford (1978,1987), Beavis and Dobbs (1987), Beavis and Walker (1983). Modified approaches including deposit-fund systems as proposed by Mookherjee and Png (1989) and Swierzbinski (1994) are facing similar problems which will be discussed here.

increasing the probability of being monitored. Although expensive, the solution will yield a lower amount for the optimal fine which might not exceed any firm's liability.⁹

(2) The individual penalty mechanism is based on the implicit assumption that the violation of the revealed emission level of a "spot-checked" firm is discovered with certainty. For a violating firm the probability ψ of being penalized is therefore supposed to be equal to the probability of being monitored. This assumption is correct only if all emissions of a firm - whether revealed or not - are released through the same observable channel. Lee [1984] criticizes this assumption for neglecting the "transaction costs" of any state policy. A firm may invest in "secret" channels to evade the control points and, thus, prevent the state from detecting parts of its emissions.

Harford [1987] proposes a supplementary fine for secret emissions. In order to deter firms from investing in monitoring evasion, this fine must secure that the expected fine level exceeds the profit of the 'avoidance investment'. That fine requires that the agency will detect secret emissions and that it will know the probability of detection or that it sets the fine at an extremely high level (which may be restricted by the liability of the firms). Neither case is realistic so that this problem remains unsolved. Moreover, Meran and Schwalbe [1987] emphasize that "firms often employ highly skilled engineers who are able to find ways and means of circumventing any monitoring devices". Firms can be even sure that "secret" emissions are not detected.

Thus, in this discussion it was shown that firms may have an incentive to pollute illegally by avoiding the administration's monitoring devices. In that case the administration's aim to enforce its environmental target is not realized: undiscovered emissions cannot be penalized. It was concluded that an individual penalty is not sufficient to enforce emission reductions if firms have a low-cost opportunity to discharge emissions "secretly" by evading monitoring devices.

3.2 The Collective Penalty

3.2.1 The Basic Model

Since the individual penalty may fail to yield satisfying results, the principal-agent literature suggested another enforcement mechanism. Instead of observing individual emissions, the monitoring is focused on the overall pollution concentration in a region. If the administration observes that total waste discharges exceed the total amount of collected emission taxes it may impose a collective penalty on every firm polluting the region.¹⁰

⁹ These cases are extensively discussed in Harford (1978, 1987) and in Keeler (1991). Another costly mechanism might be a compulsory liability insurance.

¹⁰ This approach resembles to Holmström (1982).

This mechanism makes it possible to overcome the restrictions of the individual penalty. When the ambient pollution level is observed, no firm can discharge any waste without being detected because every unit of pollution - whether legally or illegally emitted - will be registered. Under these conditions, avoiding individual monitoring devices is an irrelevant strategy.

Although the collective penalty can be shaped in various ways,¹¹ all models have two obstacles in common: the problems of multiple Nash equilibria and of penalizing non-guilty firms for breaking (environmental) standards. Therefore, the collective penalty does not provide firms with sufficient incentives to reduce pollution to the socially optimal amount.

Before analyzing the implications of a collective penalty, the choices of the firms must be announced. Threatened with such a fine, firms have to take into account the other firms' possible actions. In order to maximize their profits, firms will choose the appropriate level of waste ε_j and of emission tax payments $t\varepsilon_j^z$. This includes the possibility of paying additional emission taxes in order to compensate other firms' excess pollution (this strategy may be called "compensation"). If firms decide to release emissions illegally they will realize an additional profit. Thus, firms face an entire continuum of strategies between excess pollution and excess tax payments.

The set of firms will be divided into two groups. Firms of the first group (in Figures 1a and b: firms 1 and 2) - to be called efficient firms - are able to reduce emissions to the socially optimal level, to pay taxes and to generate a positive profit. The second group consists of inefficient firms whose equipment excludes a waste reduction to the socially optimal level. Under complete enforcement these firms had gone out of business (in Figure 2a: firm 3).

The focus will be on a collective penalty design Φ_j^K where the level of the fine is determined by the damage of the total surplus pollution $(E-E^z)$, with $E=\sum\varepsilon_j$ and $E^z=\sum\varepsilon_j^z$. It is assumed that the fine Φ^K is a linear function of the excess pollution in the whole region which has to be paid by every firm and which will be implemented without any ceiling:

$$(6) \quad \Phi^K = \phi^K \cdot \max(E-E^z, 0) .$$

3.2.2 The Social Dilemma Problem

If the amount of the fine for every unit of surplus pollution is lower than the emission tax ($\phi^K < t$), no firm will pay any taxes because for every additional unit of emission the marginal amount of the induced penalty is smaller than of the required tax payment. In order to minimize costs all firms will reduce emissions ε_j to the point where $\pi_j'(\varepsilon_j) = \phi^K$.

¹¹ see e.g. Meran and Schwalbe (1987), Segerson (1988), Xepapadeas (1991).

Thus, there will be unwanted pollution because emissions will not be reduced to E^z - the amount that could be realized under an incentive-compatible mechanism. At the same time the fine imposed on all firms will be very high (a multiple of the cost of paying emission taxes)¹² because every firm will have to pay that fine which results from the total illegal waste discharges of *all* firms. Obviously, a collective penalty with the level $\phi^K < t$ is not incentive compatible and will lead to a Social Dilemma: although each firm would be better off under compliance with the environmental target by paying emission taxes and releasing emissions according to equations (3) and (4), firms will have the dominant strategy not to comply.¹³

3.2.3 Multiple Nash Equilibria

Figures 1a and b illustrate a firm's reaction to the implementation of a collective penalty with $\phi^K > t$ when two firms are considered.¹⁴ The best-response strategy of an efficient firm 1 is described in Figure 1a. At point A₁, firm 1 releases the same maximum amount of pollution ($\varepsilon_1 = \varepsilon_1^\circ$) as it did before the implementation of the environmental policy, and does not pay any emission taxes ($\varepsilon_1^z = 0$) which is a best-response strategy if firm 2 chooses $\varepsilon_2 = \varepsilon_2^*$ and $\varepsilon_2^z = \varepsilon_2 + \varepsilon_1^\circ$ (with ε^* defined as in equation 3). Firm 2 will pay the tax firm 1 was supposed to pay.

- insert Figure 1a about here -

Between B₁ and D₁ firm 1 will reduce its emissions to the socially optimal quantity ($\varepsilon_1 = \varepsilon_1^*$). In B₁ it will not pay any taxes ($\varepsilon_1^z = 0$), which is a best-response strategy if firm 2 chooses $\varepsilon_2^z = \varepsilon_2 + \varepsilon_1$ which means that firm 2 pays emission taxes for the entire pollution of both firms.

At point C, firm 1 reduces pollution to the desired quantity ($\varepsilon_1 = \varepsilon_1^*$) and pays taxes for its remaining waste ($\varepsilon_1 = \varepsilon_1^z$). This is a best-response strategy if firm 2 behaves the same way. If firm 2 releases waste illegally, it is (up to point D₁) a best-response strategy of firm 1 to compensate the illegal pollution of firm 2 by paying additional emission taxes so that the environmental target will be met and no collective penalty imposed. D₁ is a threshold of firm 1 because its profits do not allow any further compensation, i.e. $\pi_1(\varepsilon_1^*) - t\varepsilon_1^z = 0$. If firm 2 releases waste beyond this point it is a best-response strategy of firm 1 to leave the market.

- insert Figure 1b about here -

¹² If, therefore, ϕ^K is reduced in order to reduce the total amount of the penalty which has to be paid by every firm, there will be even more illegal pollution until $\pi_j'(\varepsilon_j) = \phi^K$ holds.

¹³ If the collective penalty is structured like this it contains the same social dilemma problem as the private provision of a public good. For a survey over the literature, cf. Ledyard (1995).

¹⁴ Before analyzing the firms' behavior, it must be reminded that the additional profit made by excess pollution (by not paying emission taxes) equals the cost of compensating the excess pollution of other firms (by paying additional emission taxes) and this additional profit is, therefore, lower than the collective penalty.

Figure 1b shows that the best-response strategy curves of the two firms coincide along a certain interval. Thus, there are infinitely many Nash equilibria between D1 and D2. Any combination will lead to a non-dominated Nash equilibrium where the illegal pollution by one firm will be compensated by the other firm because paying additional emission taxes is cheaper than paying the fine. Similar to the core solution, any combination between B1 and B2 is "ecologically equivalent" as to the environmental aim because the environmental target will be met, but the allocation of the tax payments among the firms remains an unsolved problem. In contrast to that, any combination between B1 and D2 as well as between B2 and D1 is inefficient.

- insert Figure 2a about here -

Since all Nash equilibria between D1 and D2 are non-dominated, it is not possible to predict the outcome of the game. The outcome may be even worse if inefficient firms with the characteristics of the profit function $0 < \pi_j'(0) < t$ remain in the market as shown for firm 3 in Figures 2a and b. Firm 3 will not pay any emission taxes. If it stays in the market, its best response strategy is to discharge all waste illegally, i.e. it will choose $\varepsilon_3 > 0$, and $\varepsilon_3^z = 0$ and firm 1 will compensate the illegal pollution caused by firm 3 by paying emission taxes in excess, which is still cheaper than paying the fine (firm 1's possible best-response strategies lying between A1 and D1). If possible, firm 3 will realize point A3 with $(\varepsilon_3 = \varepsilon_3^0)$.

- insert Figure 2b about here -

Thus, as long as firm 3 will remain in the market the outcome will be inefficient because the environmental aim will not be met at minimum cost. The possible best-response strategies of firm 3 lie between A3 and C, with only C indicating the socially (but not individually) optimal strategy of firm 3. Any Nash equilibrium between D1 and C can be the outcome of the game in Figure 2b. Again the outcome cannot be predicted because all Nash equilibria are non-dominated. A focal point might be A3 because firm 3 has no incentive to go out of business.¹⁵

When more than two firms are affected a collective penalty of the shape $\phi^K > t$ can lead to the following outcomes: If $M \neq 1$ firms decide to produce emissions without paying taxes $\varepsilon_{-1} - \varepsilon_{-1}^z = \sum_{M \neq 1} \varepsilon_M - \varepsilon_M^z$, the best-response strategy of firm 1 is shown in Figure 1b if $\varepsilon_2 - \varepsilon_2^z$ is substituted by $\varepsilon_{-1} - \varepsilon_{-1}^z$. Every outcome $(\varepsilon_1, \varepsilon_1^z, \dots, \varepsilon_m, \varepsilon_m^z)$ on the hypersurface is an equilibrium where all mutual best-response strategies are satisfied. In equilibrium, some firms may pollute waste illegally while other firms will compensate the illegal pollution in order to prevent the collective penalty. Thus, these

¹⁵ Due to the existing multiple equilibria under the collective penalty it is important to mention the potential outcomes if coordination fails. If e.g. A3 is realized and firm 1 is not able to compensate the excess pollution of firm 3 for want of profits (i.e. if A3 is beyond D1), firm 1 will not carry out any compensation and, consequently, the environmental aim will be missed.

firms are forced to cross-subsidize the illegally polluting firms (at least all inefficient firms) in order to prevent a penalty the subsidizing firms have not caused. Even if the environmental target will be met, the outcome will be inefficient if at least one firm chooses its emission level $\varepsilon_j > \varepsilon_j^*$.

Again, it is not possible to predict the expected outcome of the game among the multiple Nash equilibria. Moreover, the more firms of a region are tied together by the collective penalty, the higher is the probability of a non-equilibrium outcome because the collective penalty may cause a coordination failure. Further problems under this fine are: (1) When exogenous factors influence the outcome, an unlimited collective penalty may become a strategic factor. By discharging waste illegally (e.g. at point A_1) firms competing in the same product market may try to force their competitors out of business. (2) A collective penalty without any ceiling may exceed the liability of a firm. In that case, the firm may discharge all emissions illegally.¹⁶

To suppose, therefore, an unrestricted collective penalty is not a credible threat and may not be enforceable.¹⁷ To solve these coordination problems a fine will have to be chosen in a way that

- it will be higher than the additional profit of any of the firms concerned, and that
- it will be lower than the cost t of compensation.

The latter condition cannot be realized because the penalty loses its incentive-compatibility (discussion of the case $\phi^K < t$) if the fine level is lower than the cost of compensation. At this point it should be recalled that the purpose of a mechanism is to induce every firm to limit its emissions to the amount revealed by the payment of emission taxes. A second requirement is that no additional cost should be imposed on firms behaving socially optimal. The collective penalty is, thus, not a suitable instrument to fulfill any of the two requirements. We summarize the results in

PROPOSITION 1: A reduction of emissions to achieve the socially optimal level at minimum cost cannot be secured by any collective penalty. For $\phi^K < t$ a Social Dilemma results with emissions only reduced to $\pi_j'(\varepsilon_j) = \phi^K$ and no tax payments so that a collective penalty is levied on all firms where every firm has to pay a fine which results from the total amount of illegal discharges of all firms. For $\phi^K > t$ multiple equilibria and an inefficient reduction of emissions has to be expected where at least all inefficient firms are subsidized by efficient firms. Moreover, due to the multiplicity problem coordination failure cannot be excluded.

¹⁶ Firms may even have an incentive to collude in order to ignore the environmental aim so that it becomes impossible for the administration to enforce the cumulated collective penalty.

¹⁷ If the collective penalty is imposed with a ceiling so that the profit of a firm is not exceeded, the strategic problems might be solved, but in that case it is even a dominant strategy of inefficient firms to stay in business. They will discharge emissions illegally and violating the environmental target will be an equilibrium outcome.

4. The Combined Incentive Mechanism

4.1 Individual and Collective Penalty

In this section it will be shown that the administration can implement an incentive-compatible mechanism for an efficient pollution reduction, if it observes the ambient pollution level and monitors single dischargers. Incentive-compatibility is guaranteed by the two-part penalty-system of individual and collective fines. The *collective* penalty will be levied on all firms of a region, if the ambient pollution level E exceeds the allowed quantity E^Z . The amount of this penalty is a linear function of the difference between actual (E) and revealed (E^Z) pollution level. In order to exclude strategic factors as mentioned above, the collective penalty will have to be limited to the profit each firm generates. Therefore, the collective penalty is

$$(7) \quad \Phi_j^K = \min (\pi_j, (E - E^Z) \cdot \phi^K).$$

The *individual* penalty will be imposed only on a monitored firm whose emissions exceed the amount revealed by the payment of emission taxes. The penalty is supposed to be a linear function of the individual excess emissions. In contrast to Harford's mere individual penalty scheme the *actual* amount of the penalty does not depend any longer on the probability of being monitored because the amount does not have to be related to ψ (the monitoring probability) to make the fine incentive-compatible. It is:

$$(8) \quad \Phi_j^I = (\varepsilon_j - \varepsilon_j^Z) \cdot \phi^I$$

Firms being individually monitored will be punished with both the individual and collective penalty simultaneously, while the administration is in the position to refrain from imposing the *collective* penalty on a firm if the monitoring proved that the firm did not emit more than the allowed quantity of pollution. Moreover, the collective penalty will be levied on those firms which have *not* been individually monitored.

A two-part penalty mechanism as described above results in the following fine system:

$$(9) \quad \phi_j = \alpha \phi_j^I + \beta \phi_j^K \text{ with}$$

$$\alpha = \begin{cases} 1 & \text{if inspected and } \varepsilon_j > \varepsilon_j^Z \text{ is found} \\ 0 & \text{otherwise} \end{cases}$$

$$\beta = \begin{cases} 0 & \text{for } E \leq E^Z \\ 0 & \text{for } E > E^Z \text{ if inspected and } \varepsilon_j \leq \varepsilon_j^Z \\ 1 & \text{otherwise} \end{cases}$$

4.2 Firms' Equilibrium Behavior

As shown above, the collective penalty leads to multiple Nash equilibria. This coordination problem is solved under the two-part penalty system. The mechanism is considered in Figure 3 under the assumptions (10) and (11) below. Again, we distinct between efficient and inefficient firms.

- insert Figure 3 about here -

The combined mechanism will secure that the strategy of compensating other firms' illegal pollution is a strictly dominated strategy, and socially optimal behavior is the iterated strict dominant strategy (for a definition, cf. Kreps [1990]): Efficient firms should reduce emissions and pay taxes due to their emissions, inefficient firms should go out of business. This is secured if the following inequality system holds which will be explained in the following:

$$(10) \quad t - a < (1 - \psi) \phi^K < t < \phi^K + \psi \phi^I \quad \text{and } 0 < \psi < 1$$

with a being the marginal cost of avoidance. All - but the first - inequalities are fulfilled if both fines are fixed at a level equal to the emission tax, i.e.

$$(11) \quad t = \phi^K = \phi^I.$$

An advantage of the combined system is that both fines can be set equal to the emission tax. The enforcing agency does not need any further information when seeking the optimal fine level.

Provided that (10) and (11) hold, compensation is a dominated strategy. In this case the compensation cost exceed the expected amount of the collective penalty $(1 - \psi) \phi^K$ when firms are monitored with a strictly positive probability. Given the fact that no firm is willing to compensate any other firm's illegal pollution it has to be secured that socially optimal behavior is the iterated strict dominant strategy. For that the payoff of the strategy of socially optimal behavior has to be higher than the payoff of any illegal pollution. Thus, in order to avoid observable illegal pollution, the expected amounts of the individual and the collective penalty must be higher at any point than the emission tax. We will show that firms are prevented from non-compliance, if (10) and (11) hold.

Given (10) and (11), Figure 3 shows that e.g. firm 1 will *not* compensate firm 2's illegal pollution. This is because every unit of additional compensation ϵ_j^z costs t , while under the monitoring probability of ψ socially optimal behavior will yield the entire profit because the collective penalty induced by the other firm will be removed, while with $1 - \psi$ firm 1 faces due to the collective penalty the same profit reduction as under the compensation strategy. Due to the higher expected profit under "socially optimal" behavior the best-response strategy of firm 1 is kinked at point C. Firm 1

is ready to take advantage of the excess emission taxes paid by other firms but it is not ready to provide other firms with such a "free lunch".

This shows at the same time that illegal waste discharges are excluded because it is the iterated strict dominant strategy of firm 1 to behave socially optimal (C in Figure 3). This is due to the fact that socially optimal behavior will be a guarantee for firm 1 to realize the profit $\pi_j(\varepsilon_j^*)$ with certainty if all other firms behave socially optimal as well, while illegal pollution (e.g. A₁ or B₁ in Figure 3) reduces the probability to realize this profit to $1-\psi$. At the same time illegal discharges will lead to a collective penalty, which is equal to the additional profit of illegal pollution. If firm 1 is not monitored, illegal pollution will not lead to higher profits; if firm 1 is monitored, its profit will be reduced by the amount of the individual fine. Thus, it is the iterated strict dominant strategy of firms 1 and 2 to reduce the pollution and to pay the emission taxes according to the optimality condition of equation (3).

Figure 3 also exemplifies that it is the iterated strict dominant strategy of firm 3 (being an inefficient firm) to reduce its pollution to zero by going out of business.¹⁸ Market exit guarantees zero profits (C in Figure 3) while under illegal pollution firm 3 has to expect losses. Consequently, any illegal discharge by firm 3 would induce the implementation of the collective penalty, reducing the profit of firm 3 to zero.¹⁹ At the same time, the expected profit is negative because the probability of being individually monitored is strictly positive and the individual fine will drive the violating firm 3 into losses.

In order to prevent investment in secret pollution-channels, the savings generated by secret discharges must be smaller than the cost of investment in avoidance behavior. When (10) applies, no firm has an incentive to compensate any illegal pollution. It is, therefore, necessary to compare the profits a firm can realize under secret pollution and under socially optimal behavior. Suppose either firm 1, 2 or 3 plans to invest in avoidance behavior. The cost it will save will not exceed the emission tax t for every unit polluted secretly while due to the necessary investment in secret channels each unit of illegal discharges induces the cost a (defined as avoidance cost). In addition, the firm has to take into account that it induces a collective penalty because in the case of (10) no firm will compensate the illegal pollution. The firm will be charged with the collective penalty if it is *not* individually monitored. This means that it will be charged with the additional cost of $(1-\psi)\phi^K$. Only if the firm is individually monitored, it can avoid both fines because the monitoring will seemingly "prove" that its individual pollution does not exceed the amount of the tax payments.²⁰

¹⁸ The best-response curve of firm 3 has the same shape as that of firm 2 in Figure 3. Note, however, that any production of firm 3 will always be inefficient.

¹⁹For inefficient firms, the full amount of the collective penalty will always exceed the firm's profit. According to equation (7), the collective penalty is therefore limited to a reduction of the firm's profit to zero.

²⁰ Of course, the linear model poses in this case a certain problem. If avoiding devices is optimal all pollution will be

Thus, according to (10) the administration has to set the monitoring probability (ψ) at a level that will deter firms from investing in avoidance behavior. It must assure that the cost savings (left-hand side of inequality 12) are lower than the sum of all costs for secret emissions (right-hand side of inequality 12):

$$(12) \quad t < a + (1-\psi)\phi^K.$$

Due to (11) ϕ^K is set equal to t so that the following condition results:

$$(13) \quad a > \psi\phi^K = \psi t$$

The probability ψ of an individual monitoring must be chosen sufficiently *low* for a given cost of avoidance a to make the expected profit under avoidance behavior smaller than the profit under compliance. Thus, the mechanism is incentive-compatible, and a socially optimal result can be achieved in particular when the monitoring probability is *small*, which makes the combined mechanism a cheap instrument for the administration.

PROPOSITION 2: Under the penalty scheme ϕ defined in (9), a sufficiently low monitoring probability (ψ) for a given cost of avoidance (a) and a fine level for the individual and the collective component satisfying the conditions (10), (11) are the necessary conditions for a unique equilibrium inducing a socially optimal pollution reduction with $\varepsilon_j = \varepsilon_j^z = \varepsilon_j^*$ for all firms. Efficient firms have the iterated strict dominant strategy to pay emission taxes and to reduce pollution according to the optimality condition (3) and inefficient firms have the iterated strict dominant strategy to go out of business according to the optimality condition (4).

PROOF: In the Appendix proof is given for the general case of j firms.

5 Discussion and Conclusion

The combined mechanism proposed in this paper is an instrument which enables the enforcement of a regulatory law under incomplete information of the monitoring agency. Applied to a targeted reduction of emissions, firms face sufficient incentives to reduce their individual emissions to the amount they are (by the payment of taxes) allowed to discharge. It has been shown that all firms - even those which have to go out of business - have the iterated strict dominant strategy to comply to the regulation and to refrain from illegal emissions.

secretly discharged. Thus, an inspector could find a producing firm apparently emitting no pollution, which may be technologically impossible. Note that this is not a valid counterargument against the efficiency result derived from the considerations in the present paper. Avoiding is simply more difficult than assumed here, and if avoiding does not pay for any firm under "unintelligent" or badly paid inspectors (as assumed e.g. in Güth and Pethig (1992)), it will not pay under "intelligent" inspectors, either.

The final section discusses two crucial questions - the complexity and the applicability - of the combined mechanism: In discussing the first point, it is necessary to compare its effectivity with that of the two single mechanisms. *An individual penalty* cannot solve the problems of liability and avoidance behavior. Different kind of multiple Nash equilibria and high social cost of penalizing compliant firms are the arguments against a *collective penalty*.

Liability problems may arise because an incentive-compatible individual penalty has to be higher than the ratio of illegal emissions over the monitoring probability. If the individual penalty exceeds a firm's liability the fine cannot be fully collected, a problem more likely to arise when the monitoring probability is low. The combined mechanism avoids this problem by limiting the collective penalty to each firm's profit, while the individual penalty is set equal to the emission tax ($t=\phi^I$). Its actual amount is independent of the monitoring probability.²¹

Furthermore, while the mere individual penalty is not incentive-compatible if the full amount of the individual penalty cannot be imposed on a firm, the combined mechanism remains incentive-compatible even. This also holds for inefficient firms because the collective penalty reduces their profits to zero, and the mere probability that an individual penalty with any amount higher than zero may be imposed is sufficient to induce inefficient firms to go out of business.

Turning to collective penalty the problem of multiple Nash equilibria can be solved by the combined mechanism. By individual monitoring of single firms, complying agents can be "rewarded" by having their payment of the collective penalty refunded, while an additional penalty will be imposed on firms discharging pollution illegally. Moreover, if the mere collective penalty is implemented without any ceiling, the problem of social costs will be aggravated. In section 3 it was mentioned that the cumulated illegal emissions by non-complying firms might induce a collective penalty sufficiently high to force complying but financially weak firms to leave the market. When discussing its applicability, it is reasonable to assume that any firm in this situation could successfully sue the state for deliberate discrimination. The enforcement of the collective penalty therefore becomes very unlikely.²²

In contrast, the incentive structure of the combined mechanism excludes outcomes where firms compensate the illegal pollution of others or where imposing the collective penalty becomes an equilibrium point. Even if imposed on all firms because of illegal emissions of one firm, its amount will be significantly smaller in a combined mechanism than under a mere collective penalty. Compliant efficient firms can always expect a profit even after paying a fine. Social costs for

²¹This is also a central result for lenders since the liability in the context of environmental damages influences the outcomes in the financial markets, cf. Heyes (1996).

²² In this context it should be reminded that under an unlimited collective penalty liability problems may arise. If all firms pollute illegally, the collective penalty may turn out to be so high that some firms will be insolvent.

complying firms can therefore not be entirely excluded by a combined mechanism, but in comparison to the mere collective penalty they are substantially reduced. This shows that the collective penalty might be rather applicable within the framework of the combined mechanism.

A further argument for the applicability is given when the possibility for self-reporting is allowed. Self reporting of an insufficient emission tax payment is a viable option for any violating firm as well as for the executive agency. On the one side the incentive structure is not destroyed. On the other side even violating firms are able to reduce the amount of fines even to zero. These firms simply have to pay the emission tax for every unit of reported illegal pollution (equal to the individual penalty) which is less than the fine under the combined mechanism.²³ And non-violating firms will not have to pay any penalty at all when the amount of reported violations is equal to the measured violations at the receptor points.

The introduction of a signaling option is not feasible where firms had the opportunity to ask for monitoring where they would - if found compliant - be exempted from the collective penalty. This is because the administration has no opportunity to distinguish between complying firms and those which only pretend to comply while having invested in avoidance behavior. To the contrary, individual monitoring has to be randomized. Only then the combined mechanism provides sufficient incentives to firms not to emit pollution through any 'black channels'.

There is another reason which supports the combined mechanism: While individual and the collective penalty scheme lack such incentive, inefficient firms will go out of business although the administration has only incomplete information about their behavior. In particular, because efficient firms will not compensate other firms' illegal pollution in order to prevent a collective penalty, it is the iterated strict dominant strategy of inefficient firms to stop production.

The aim of the paper is to demonstrate the effectiveness of different enforcement mechanisms. It is shown that the combined penalty system is a mechanism solving different problems of coordination and enforcement. There are neither multiple equilibria nor liability problems, avoidance behavior does not pay and the mechanism is shaped in a way that no penalties will be imposed in an equilibrium situation. Finally, it is the combined mechanism which opens the possibility of applying any collective penalty at all because the incentive structure which is created by this mechanism keeps the social cost of the collective penalty at a relatively low level.

Since the focus of the paper was on the implications of the mechanism, the model to which it was applied is kept simple. The analysis how this mechanism relates to modified approaches - as the non-point pollution models (cf. e.g. Shortle et al. [1998]) - is left for future research.

²³ Thus, this mechanism even strengthens the option of self reporting of violations, see also Malik (1993).

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Appendix A: Proof of Proposition 2

It has to be proved that the socially optimal behavior is an iterated strict dominant strategy for all firms so that the waste reduction to E^* is replicated as the unique Nash equilibrium by implementing the two-part penalty-system.

(1) It has to be proved that under the fine system of equation (9) compensation is a dominated strategy. The profit π_j° under the compensation strategy is

$$\pi_j^\circ = \pi_j(\varepsilon_j^*) - t\varepsilon_j^z \quad \text{with } \varepsilon_j^z = \varepsilon_j^* + \sum_{k \neq j} \varepsilon_k - \varepsilon_k^z \quad \text{and } \sum_{k \neq j} \varepsilon_k - \varepsilon_k^z > 0$$

while the expected profit $E\pi_j^*$ under socially optimal behavior is equal to

$$E\pi_j^* = \pi_j(\varepsilon_j^*) - t\varepsilon_j^* - (1-\psi) \Phi_j^K.$$

If the collective penalty is set equal to the emission tax (equ. (11)) and the monitoring probability for firm j is positive so that equation (10) holds, it is secured that $\pi_j^\circ < E\pi_j^*$ because with probability $1-\psi$ the profit π_j° equals π_j^* and with probability ψ the profit π_j° is smaller than π_j^* . Compensating illegal pollution is therefore a dominated strategy for all firms.

(2) Given the fact that no firm can expect compensation for its illegal emissions, it has to be proved that under the fine system of equation (9) socially optimal behavior is a iterated strict dominant strategy. It must be shown that illegal pollution a) through the observable channel and b) through the "secret" channel are not best response strategies.

a) The expected profit $E\pi_j$ for firms $j=\{1\dots F\}$ (efficient firms) by illegal pollution through the observable channel is

$$E\pi_j = \pi_j(\varepsilon_j) - \Phi_j^K - \psi\Phi_j^I \quad \text{with } \varepsilon_j - \varepsilon_j^z > 0,$$

while the profit π_j^* under socially optimal behavior is

$$\pi_j^* = \pi_j(\varepsilon_j^*) - t\varepsilon_j^* - (1-\psi) \Phi_j^K.$$

It is secured that $E\pi_j < \pi_j^*$ because with probability $1-\psi$ the profit $\pi_j = \pi_j^*$ and with probability ψ the profit $\pi_j < \pi_j^*$, if the collective penalty is set equal to the emission tax (equ. (11)) and if the monitoring probability for firm j is positive so that equation (10) applies.

The expected profit $E\pi_j$ for firms $j=\{F+1\dots M\}$ (inefficient firms) by discharging emissions illegally through the observable channel is equal to

$$E\pi_j = \pi_j(\varepsilon_j) - \Phi_j^K - \psi\Phi_j^I \quad \text{with } \varepsilon_j - \varepsilon_j^z > 0,$$

while the profit π_j^* under socially optimal behavior (i.e. market exit) is equal to zero ($\pi_j^* = 0$). If the collective penalty equals the emission tax but reduces profits only to zero and if the monitoring

probability for firm j is positive, it is secured that $E\pi_j < 0$ because with probability $1-\psi$ the profit $\pi_j = \pi_j^* = 0$ and with probability ψ the profit $\pi_j < 0$. Thus, the strategy of illegal pollution is not a best response strategy for any firm.

b) Under "secret" illegal pollution the expected profit $E\pi_j$ is for all firms

$$E\pi_j = \pi_j(\varepsilon_j) - (1-\psi) \Phi_j^K - a(\varepsilon_j - \varepsilon_j^0),$$

while the profit π_j^* under socially optimal behavior is equal to

$$\pi_j^* = \pi_j(\varepsilon_j^*) - t\varepsilon_j^* - (1-\psi) \Phi_j^K \text{ for firms } j = \{1 \dots F\} \text{ and zero for firms } j = \{F+1 \dots M\}.$$

If the collective penalty is equal to the emission tax and if the monitoring probability is chosen (for given cost of avoidance) in a way that equation

$$(13) \quad a > \psi \phi^K = \psi t$$

holds, it is secured that $E\pi_j < \pi_j^*$. This is due to the fact that the cost of avoidance behavior plus the expected value of the collective penalty exceed the avoided cost of non-paid emission taxes t for every possible unit of secretly released emissions. Thus, the illegal emission of waste by avoiding individual monitoring devices is not a best response strategy for any firm.

Proofs of (1), (2a) and (2b) show that the strategy 'optimal waste reduction' of firms $j = \{1 \dots F\}$, and that the strategy 'market exit' $\varepsilon_j^0 = \varepsilon_j^* = 0$ of firms $j = \{F+1 \dots M\}$ are iterated strict dominant strategies so that the optimal waste reduction is the unique Nash equilibrium. ■

Appendix B: Figures 1-3

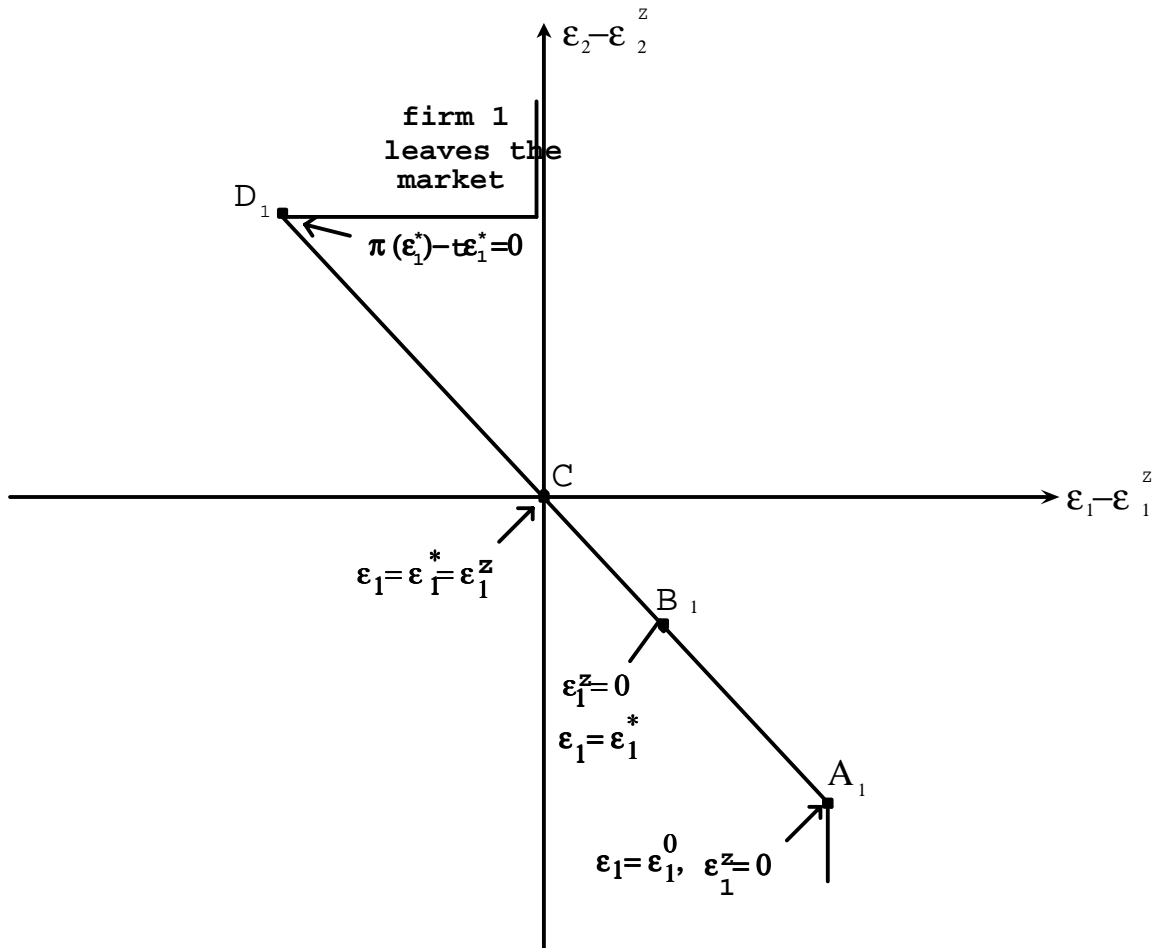


Figure 1a: Best-response function of an efficient firm 1 showing its set of best response strategies of pollution ε_1 and of tax payments ε_1^z on any amount of pollution and of tax payment by firm 2.

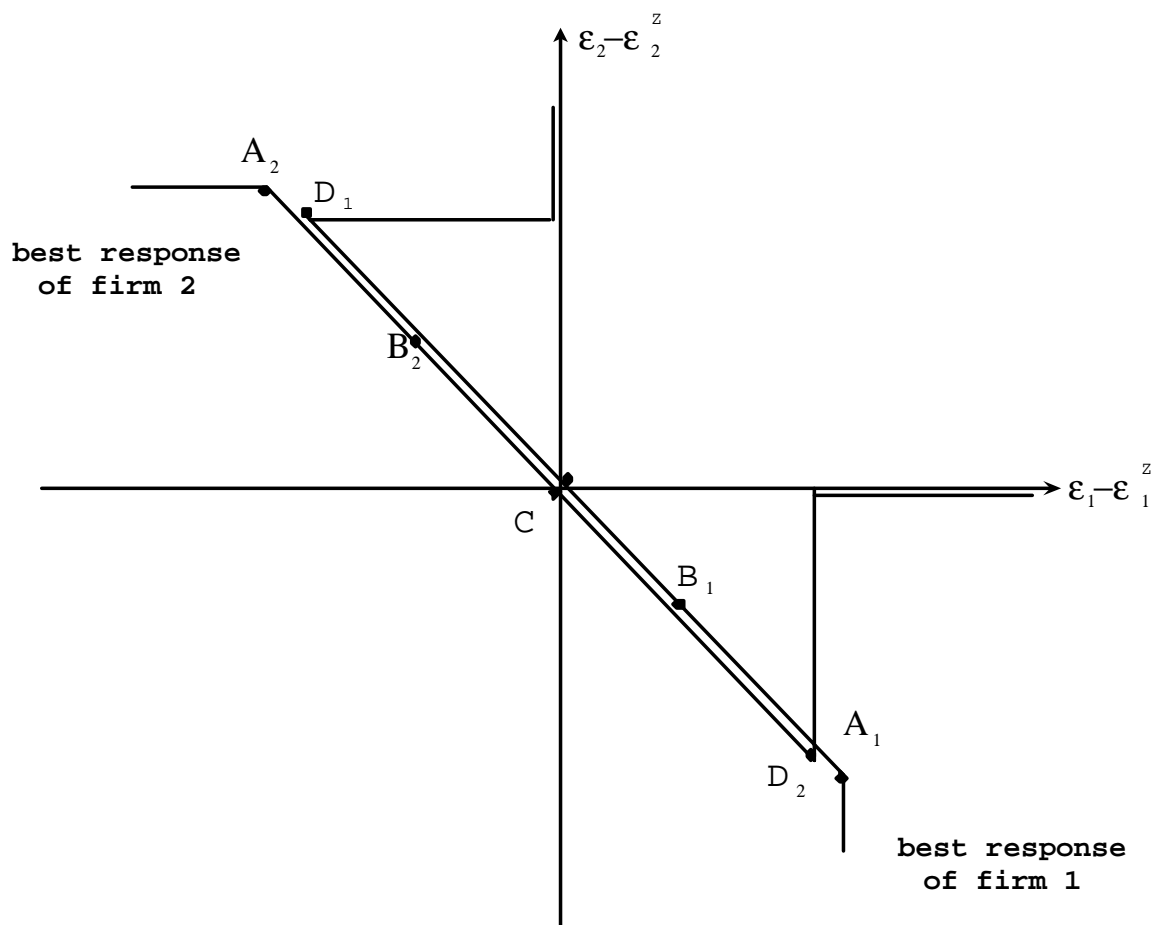


Figure 1b: Multiple Equilibria of a two firm game when both players are efficient firms.

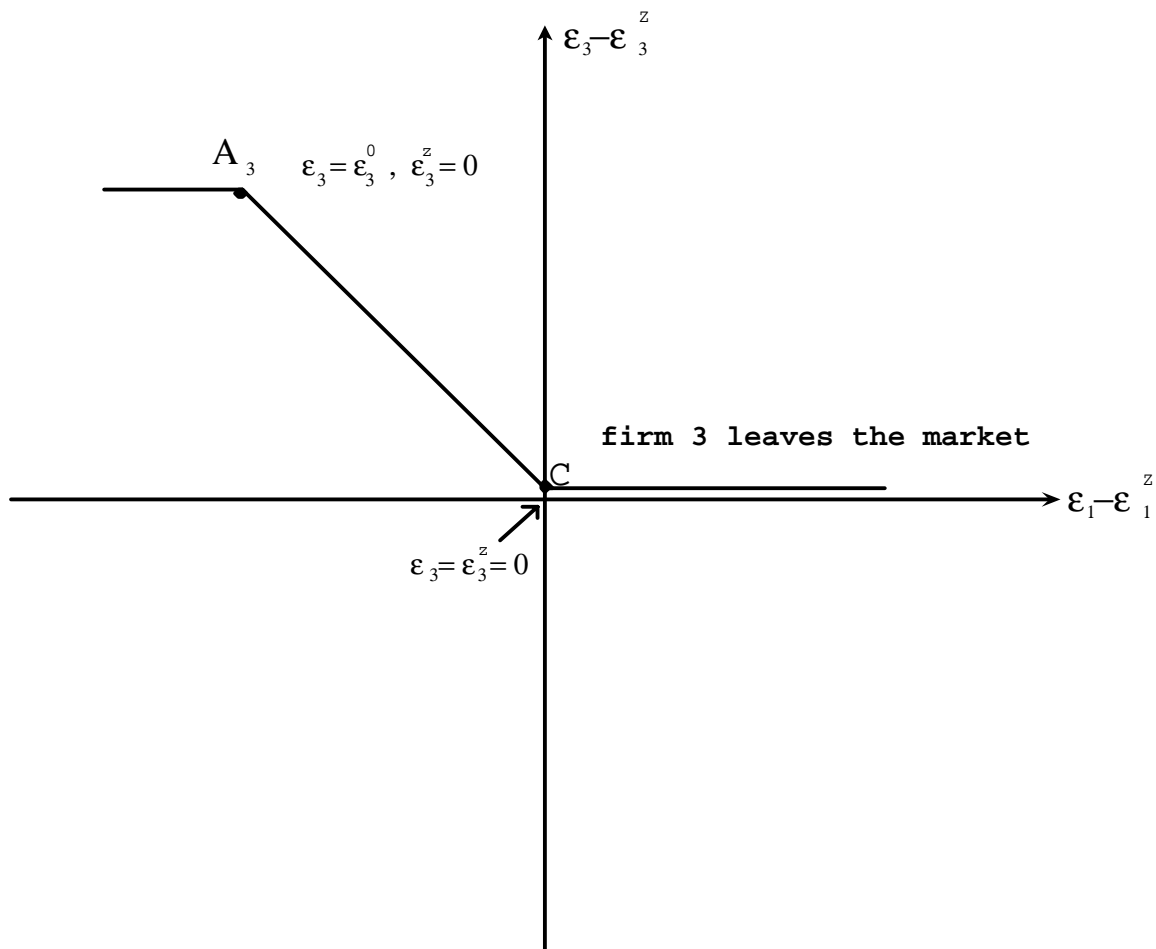


Figure 2a: Best-response function of the inefficient firm 3 for any strategy of an efficient firm.

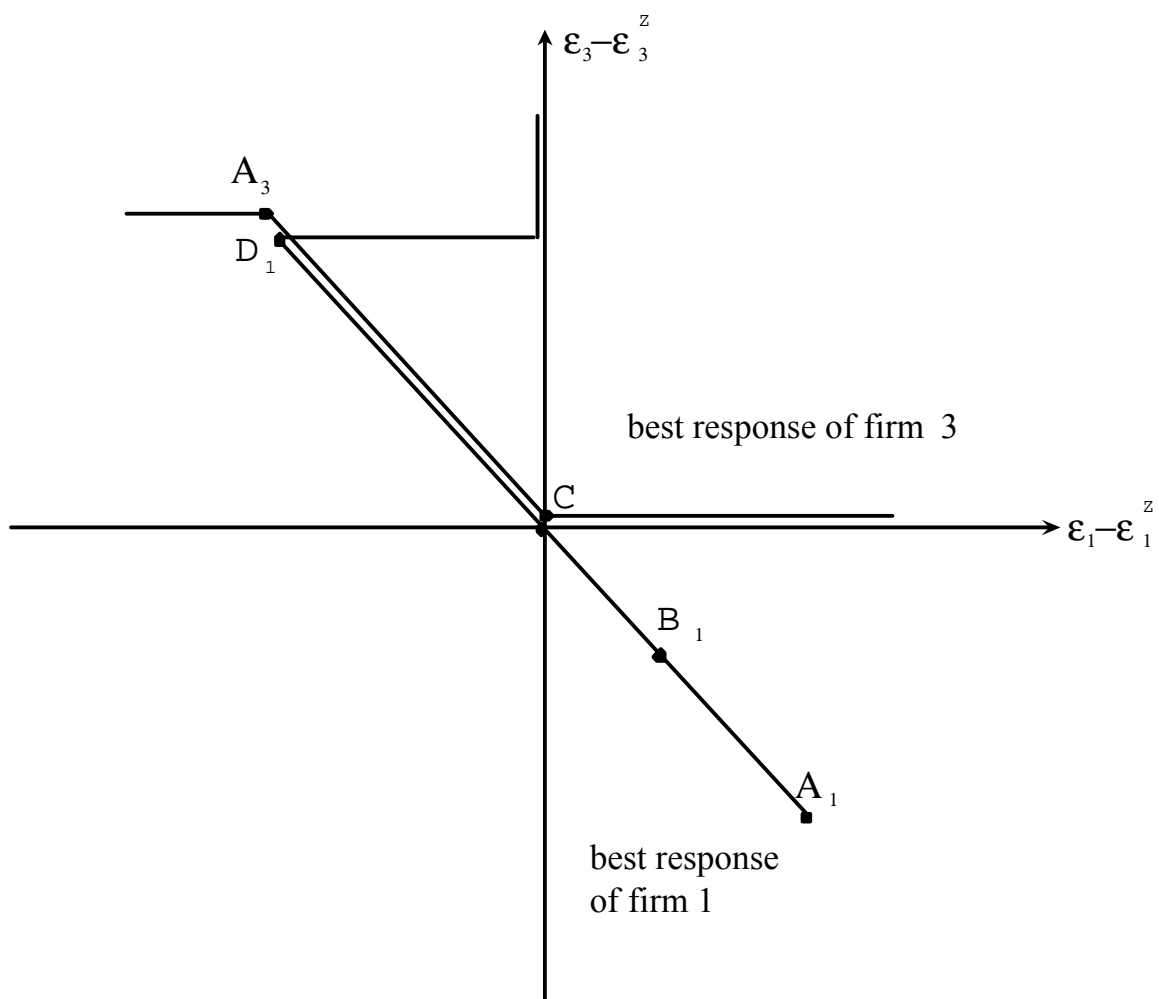


Figure 2b: Multiple equilibria of a two firm game for an efficient firm and an inefficient firm.

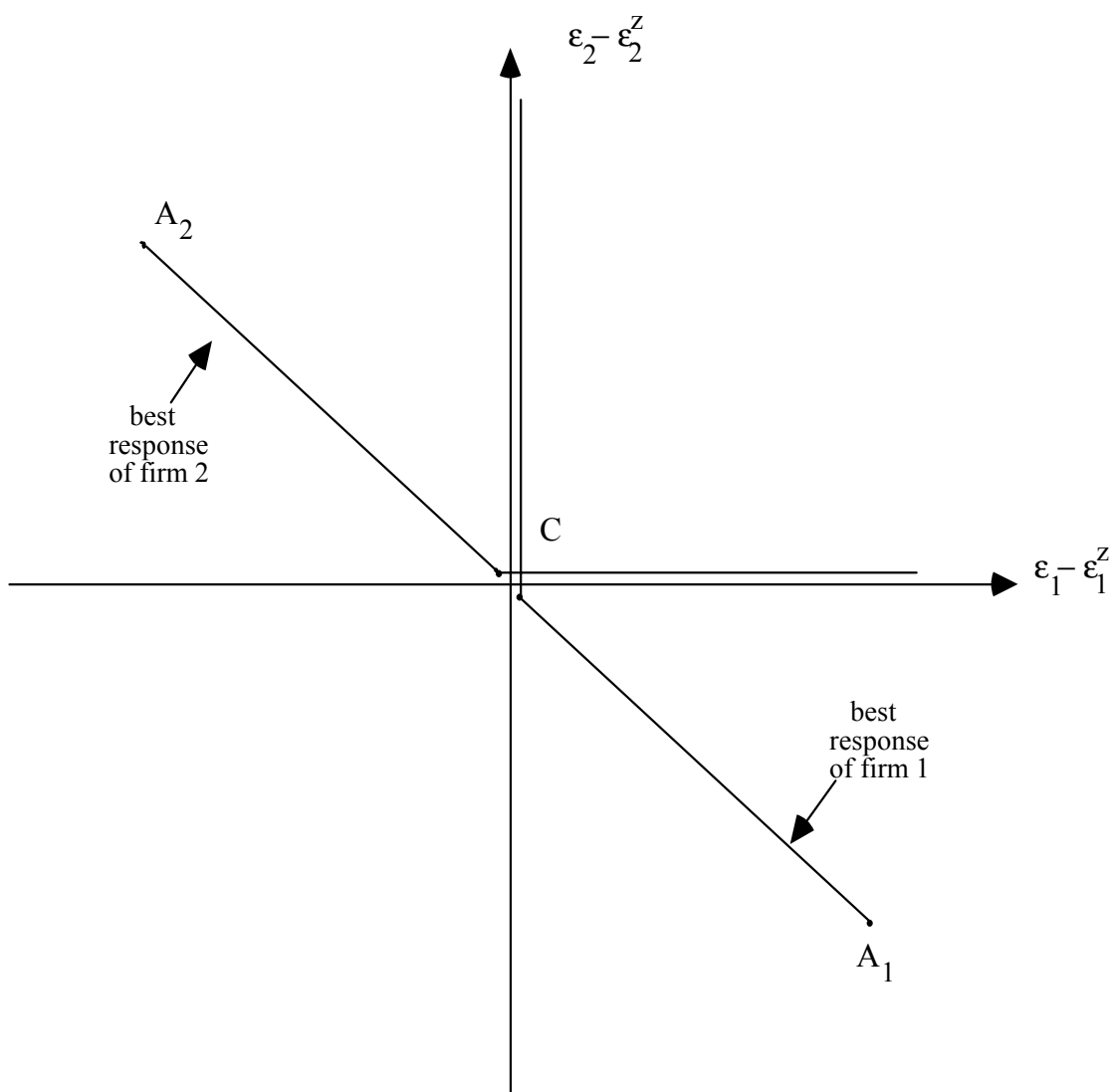


Figure 3: Unique equilibrium of the two firm game under the combined mechanism.