A complete implementation of the efficient allocation of pollution

By

Nava Kahana[a,b,*] Yosef Mealem[c] and Shmuel Nitzan[a]

Abstract

This paper presents a simple twofold mechanism that attains a *complete* implementation of the efficient allocation of pollution. The first component is adopted from Duggan and Roberts (2002). The second new component takes care of the moral hazard problem.

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[a] Department of Economics, Bar-Ilan University, 52900 Ramat-Gan, Israel

[b] IZA, Bonn, Germany

[c] Netanya Academic College, The School of Banking & Finance, Netanya, Israel

* Corresponding author, Tel: +972 3 531 8689, Fax: +972 3 7384034 E-mail: kahanan@mail.biu.ac.il

1. Introduction

One class of solutions to the problem of externalities involves the setting up of a market for the externality (Arrow (1970)). If firms produce pollution that is harmful to others, then a competitive market for pollution permits may bring forth an efficient outcome. However, in contrast to markets of ordinary private goods, in a market for pollution rights the amount purchased from this good (permission to pollute) is not necessarily the amount ‘consumed’ (in fact, the actual level of emission). In other words, the nature of the good accounts for the moral hazard problem. Kwerel (1977) suggests a mixed pollution control plan that combines a competitive market for licenses with effluent charges. English and Yates (2007) consider the possibility that both polluters and those exposed to pollution are allowed to purchase permits and modify Kwerel's mechanism to the minimum-price mechanism. Both of the proposed schemes are based on the assumption that the actual levels of emissions do not exceed the licensed quantities, that is, firms comply with the law. Lewis and Sappington (1995) also assume that the number of units consumed by each firm is equal to the number of allowances it holds. Duggan and Roberts (2002) present a mechanism that replicates a competitive market for pollution rights and implements the efficient allocation of pollution. In their setting, the successful implementation of the efficient allocation also hinges on the implicit assumption that the firms behave honestly. In their study the solution of the moral hazard problem associated with the asymmetric information between the firms and the regulator is based on two assumptions; first, the regulator is able to observe all the firms and, second, this ability is sufficient to induce honest behavior. [1]

A competitive market for pollution permits suffers then from a clear weakness; it implements the efficient allocation, provided that the purchase of the pollution rights is a binding commitment, namely, the firms’ purchased and actual quantities of pollution are equal, i.e., the firms comply with the law. Our objective is to suggest a simple mechanism that attains a *complete* implementation of the efficient allocation of pollution that takes into account the possibility of dishonest behavior by the firms. The proposed mechanism has two components. The first component that takes care of the adverse selection problem is the mechanism proposed by Duggan and Roberts (2002). The second new component of the mechanism takes care of the moral hazard

[1] Duggan and Roberts (2002) mention, however that although beyond the scope of their work, the moral hazard problem merits further consideration.

problem by inducing honest behavior by all the firms i.e., ensuring that the firms actually produce the purchased quantities of pollution. The mechanism is especially simple compared to the mechanisms proposed in the implementation literature. The main drawback of the mechanism is its possible impracticability under some circumstances due to its requirement of firms' complete information. However, the same weakness also applies to the first component of the mechanism proposed by Duggan and Roberts (2002) and to that studied by Varian (1994). For many cases, nevertheless, this assumption may be plausible. See, Moore and Repullo (1988), and Maskin (1985) for further discussion of this issue.

2. The model

The first component of the mechanism was proposed by Duggan and Roberts (2002) and is briefly described below, adopting their notation.[2] Consider a population that consists of $n \geq 2$ profit-maximizing firms. The level of pollution of firm i and its resulting profit are denoted, respectively, by Q_i and $B_i(Q_i)$.[3] Let $C(Q_1, \dots, Q_n)$ be the social cost, measured in monetary terms, imposed on society by the firms' pollution.[4] Without environmental regulation, the maximum profit of firm i, B_i^o, is achieved by producing a pollution level of Q_i^o. In general, these pollution quantities are inefficient, since the firms ignore the social cost they impose on society. The regulator's objective is to implement the socially optimal allocation of pollution. The social optimum, $Q^* = (Q_1^*, \dots, Q_n^*)$, is characterized by the condition that each firm's marginal benefit equals the marginal social cost of pollution:

$$\frac{dB_i}{dQ_i}(Q_i^*) = \frac{\partial C}{\partial Q_i}(Q_1^*, \dots, Q_n^*), \quad \forall i. \tag{1}$$

Let P_i be the price per unit of pollution set by the regulator for each firm *i*. Assuming that each firm maximizes $B_i(Q_i) - P_i Q_i$, optimality could be achieved if:

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[2] For a more detailed description of the mechanism, see Duggan and Roberts (2002).

[3] Our results also hold in the more general case, where the profit of each firm depends not only on its own emission but also on that of all the other firms.

[4] Hal R. Varian (1994) describes a compensation mechanism that is appropriate for a "bilateral" information structure: agent *i* imposes costs on agent j , both *i* and *j* know the magnitude of these costs. Our mechanism fits a "multilateral" information structure with differential social impact of pollution, as in Dasgupta et al. (1980).

$$P_i = \frac{\partial C}{\partial Q_i}(Q_1^*, \ldots, Q_n^*), \quad \forall i. \tag{2}$$

However, this requires knowledge of the social optimum itself or familiarity with the firms' benefit functions that the regulator lacks.[5]

We assume like Duggan and Roberts that the benefit and cost functions are common knowledge among the firms, while the regulator knows only the form of the cost function. However, while Duggan and Roberts assume that the regulator observes pollution emissions of each firm, we assume that only the firms observe the pollution outputs of the firms.[6]

3. The first component of the twofold mechanism

The first component of the twofold mechanism is defined as follows. Firm i purchases a quantity $\hat{Q}_i \in [0, K]$ for itself and reports a quantity $\overline{Q}_{i-1} \in [0, K]$ for its "neighbor", firm ($i-1$), where n is assumed to be firm 1's neighbor. The bound K imposed by the regulator is assumed to be larger than the efficient pollution output. Each firm i faces a price P_i per unit of pollution that depends on the purchased quantities of the other firms and on the report of its neighbor firm ($i+1$) (i.e., the price is independent of the firm's own actions) and is equal to:

$$P_i = \frac{\partial C}{\partial Q_i}(\hat{Q}_1, \ldots, \hat{Q}_{i-1}, \overline{Q}_i, \hat{Q}_{i+1}, \ldots, \hat{Q}_n). \tag{3}$$

In addition, firm i pays a fixed penalty $\left|\overline{Q}_{i-1} - \hat{Q}_{i-1}\right|$ for misrepresenting the demand of its neighbor.[7] In the presence of the moral hazard problem associated with the asymmetric information between the firms and the regulator, it is optimal for firm i to purchase an amount of pollution as small as possible (actually zero), to produce

[5] We assume that the regulator is concerned about the public welfare only. Otherwise, creating a competitive market, by setting individual prices, as well as levying Pigovian taxes would give rise to rent-seeking activities, independent of the informational structure.

[6] Notice that this strong informational requirement can be substituted by a weaker assumption, namely that each firm observes the pollution outputs of its neighbors. Under this informational assumption, the firms have to be partitioned into neighboring groups (at least two firms in each group) and the second component of the twofold mechanism should be separately applied in each of these groups.

[7] Notice that $\left|\overline{Q}_{i-1} - \hat{Q}_{i-1}\right|$ is measured in monetary terms i.e., the price of one unit of deviation is normalized to 1.

the amount that maximizes its profits, Q_i^o, and to report a quantity, $\overline{Q}_{i-1} = 0$ for its neighbor $(i-1)$. However, if we induce the firms to buy the amount of pollution that they intend to produce, it is straightforward to verify that they will actually emit the socially optimal amounts of pollution, $(Q_1^*, \ldots, Q_n^*)$.[8] Thus, one should supplement the first component of the mechanism with a second element that ensures that the firms produce the amounts $\tilde{Q}$ that are equal to the purchased amounts $\hat{Q}$. This will allow the complete twofold mechanism to effectively implement the efficient pollution allocation, that is, guarantee that $\tilde{Q} = \hat{Q} = Q^*$.

4. The second component of the twofold mechanism[9]

Our proposed simple sequential second component of the mechanism, that induces polluters' compliance with the regulator's objective without actually having to monitor the action of even a single polluter, is based on the assumption that the regulator is able to observe the pollution output of any single firm. The ability to observe the pollution emission of a single firm can be costly. However, carrying out such a single inspection is usually feasible. We also add the plausible assumption that although the regulator does not know the firms' profit functions, he has information on an upper bound π of the maximum profit of the firms (under no regulation), such that $B_i^o < \pi$, $\forall i$. The objective of our proposed supplementing mechanism is reached by designing incentives for the firms to monitor each other.

The sequential mechanism is defined as follows. *Stage 0*: Two firms, the informer a and the controller b are selected randomly.

The announcement stage – Stage1: Firm a announces the pollution emissions of the firms, $\breve{Q} = (\breve{Q}_1, \ldots, \breve{Q}_n)$.[10]

The control stage – Stage 2: Firm b either approves or disapproves a's report. If the report is approved, a fine F_i, $F_i = \pi$, is imposed on the deviating firms for which $\breve{Q}_i \neq \hat{Q}_i$. If firm b disapproves the report, it has to present supporting evidence,

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[8] The uniqueness of this equilibrium is established in Proposition 1 in Duggan and Roberts (2002).

[9] The second component of the mechanism can be viewed as being complementary to the mechanisms of Kwerel (1977), Duggan and Roberts (2002), English and Yates (2007) or to other mechanisms that are based on a competitive market for pollution rights.

[10] Notice that firm a is requested to report the actual emission quantities, but it need not make a truthful announcement.

i.e., choose one firm indexed j, $j \in \{1, \dots, b, \dots, n\}$ to be inspected by the regulator. If the observed pollution quantity of firm j is found equal to the reported quantity, $\breve{Q}_j = \tilde{Q}_j$, then a fine F_b, $F_b = \pi + \varepsilon$, $\varepsilon > 0$ is levied on firm b. However, if $\breve{Q}_j \neq \tilde{Q}_j$, then firm a pays the fine $F_a = \pi + \varepsilon$, whereas firm b receives the reward ε.[11] Notice that firm b receives the net reward ε even if $j = b$.

The sequential mechanism is based on a system of rewards and punishments that (i) induces *b* to truthfully control *a* (ii) induces *a to* report truthfully, when it takes into account the incentives of b (iii) induces all the firms (including *a* and *b*) to abide by their commitments.

How does this sequential mechanism exactly work? To determine the subgame-perfect Nash equilibrium, let us work backwards through the game.[12] We start by solving for the optimal choice of the last mover; firm b, at the approval stage, for each possible situation it might face, then work backwards to compute the optimal choice of firm a at the announcement stage and, finally, determine the resulting optimal choice of all the firms (including a and b).

At the announcement stage, firm a might either report truthfully, $\breve{Q} = \tilde{Q}$, or misreport, $\breve{Q} \neq \tilde{Q}$. In the former case, it is optimal for firm b to approve the report, in which case its profit is at least equal to $B_b(\tilde{Q}_b) - \pi$ (this happens in the worst case when $\breve{Q}_b \neq \hat{Q}_b$), whereas, if it disapproves the report its profit is reduced to $B_b(\tilde{Q}_b) - \pi - \varepsilon$. This occurs because *b* cannot find a firm j such that $\breve{Q}_j \neq \tilde{Q}_j$ and thus, has to pay a fine of $\pi + \varepsilon$. Given that firm b approves the true report of a, the profit of firm a is at least $B_a(\tilde{Q}_a) - \pi$ (this happens in the worst case when $\breve{Q}_a \neq \hat{Q}_a$).

In the latter case, where firm a announces a false report, $\breve{Q} \neq \tilde{Q}$, it is optimal for firm b to disapprove, in which case its profit is at least $B_b(\tilde{Q}_b) + \varepsilon$. This is the

[11] Notice that all firms, including a and b, are assumed to observe the pollution output of all the firms and, therefore, the information provided by a and approved by b can be used as testimony in the court. Moreover, if the accused firm denies the accusation, by assumption, the regulator is able to inspect it and provide sufficient evidence in the court. In any case, as is shown latter, in equilibrium no firm is brought to court and fined.

[12] Hal R. Varian (1994) also uses the refinement of subgame-perfect equilibrium to implement the efficient allocation of pollution. However, the implementation is based on a compensation mechanism.

outcome because it can find a firm j, such that $\breve{Q}_j \neq \tilde{Q}_j$ and, consequently, be rewarded the amount ε, whereas, if it approves the report its profit is at most $B_b(\tilde{Q}_b)$ (this happens when $\breve{Q}_b = \hat{Q}_b$). Thus, for firm b, the strategy "to disapprove" dominates the strategy "to approve". Given that firm b disapproves**,** the profit of firm a, if it makes a false report, $\breve{Q} \neq \tilde{Q}$, is $B_a(\tilde{Q}_a) - \pi - \varepsilon$.

Taking into account the optimal behavior of firm b in the approval stage, firm a will choose to make a truthful report in the announcement stage, $\breve{Q} = \tilde{Q}$, in which case its profit is at least $B_a(\tilde{Q}_a) - \pi$, which is larger (by ε) relative to its profit if it makes a false report in the announcement stage, $\breve{Q} \neq \tilde{Q}$.

Given that firm a reports truthfully, i.e., $\breve{Q} = \tilde{Q}$, and firm b approves, in a subgame-perfect Nash equilibrium, the optimal strategy of each firm (including a and b) is to buy and produce the desired pollution emissions, $\tilde{Q}_i = \hat{Q}_i = Q_i^*$, in which case no fine is imposed and therefore, the profit of firm i is $B_i(\hat{Q}_i) \geq 0$, which is larger than the negative profit associated with deviation from the purchased pollution quantity, $\tilde{Q}_i \neq \hat{Q}_i$, a deviation that results in a fine π.

The twofold mechanism thus ensures that the firms purchase the efficient pollution quantities, $\hat{Q} = Q^*$, and produce the amounts of pollution that they purchase, $\tilde{Q} = \hat{Q}$. This results in the implementation of the efficient allocation of pollution as an equilibrium outcome, $\tilde{Q} = \hat{Q} = Q^*$.

5. Conclusion

The resolution of the problem of inefficient levels of pollution is partly based on the replication of competitive markets for pollution rights. However, in contrast to markets of ordinary private goods, the purchased amount of pollution rights is not necessarily the amount 'consumed' (in fact, produced). In other words, the nature of the good accounts for a serious moral hazard problem. Previously, this problem has been either disregarded, as in Kwerel (1977) among others, or resolved by resorting to questionable assumptions. In particular, in Duggan and Roberts (2002), this problem is bypassed by assuming that the regulator is apparently able to observe the produced pollution quantities of all the firms and that this ability is sufficient to induce honest behavior. In the present paper, this problem of likely dishonest behavior is at the focus and is resolved by relying on the success of the simple second component of the twofold mechanism to induce honest behavior by all the players. This second component can be viewed as being complementary not only to the mechanism of Duggan and Roberts (2002), but also to other mechanisms that are based on a competitive market for pollution rights.

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