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Pigou and Clarke join hands*

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Abstract. This paper develops a simple, incentive compatible, allocation mechanism by means of which both polluters and pollutees will reveal their preferences so that the government can determine the Pareto optimal pollution level. The mechanism involves a combination of the Pigou tax and the Clarke tax. The two taxes are complementary and together provide a practical solution to the environment problem. The mechanism is applied to the problem of finding the optimal quality of river water which serves both as a waste disposal and as a source of drinking water.

1. The problem

Competitive markets for private goods are incentive compatible. Both individual consumers and producers optimize their trades under given market prices, and no one has any incentive to misrepresent his technologies or preferences. The invisible hand steers the economy towards Pareto optimality.

In the presence of public goods and environmental problems, the virtues of competitive markets are more limited, to say the least. It is true that the price mechanism inspired Pigou (1920) to propagate government-imposed tax prices for waste discharges as a means of controlling environmental damages and, indeed, the Pigou tax has important virtues. It makes polluters reduce their waste discharges in a way which ensures that the resulting environmental quality standard is reached at minimal cost. However, the Pigou tax does not incorporate the pollutees' preferences in any meaningful way. The appropriate level of the tax rate and the environmental quality level at which the government should aim are unknown and remain unknown even if the tax prices are paid out to the pollutees to enhance the analogy with the market mechanism. The non-separability of the environmental quality among the pollutees – the public goods property – makes it impossible to design a pure price mechanism that fully solves the environmental problem.

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The alternative to a price mechanism are demand revealing survey procedures as proposed by Clarke (1971), Groves and Ledyard (1977), Loeb (1977), Suchanek (1979), and others. These procedures define sophisticated payment rules which induce the pollutees and (in some cases) the polluters to correctly reveal their preferences or technologies so that the government is able to calculate the Pareto optimal pollution levels. No one hides or misrepresents his own private information since, by doing so, he would hurt himself. The demand revealing mechanisms of Clarke, Groves, et al. share the private markets' property of incentive compatibility. They establish an invisible hand for public goods.

While the existing demand revealing survey procedures are perfectly general and theoretically attractive, they are much more complicated than the price mechanism or the Pigou tax. In recent years, environmental problems have become increasingly urgent, but the solutions offered by the literature have become increasingly abstract. They concentrate on general equilibrium refinements rather than implementation advantages, and, so far, the policy makers have not been convinced.

This paper attempts to reduce the widening gap between the practical problems and the theoretical solutions by combining the Clarke and Pigou taxes.[1] The two taxes are complementary in that the former induces the pollutees, and the latter the polluters, to reveal their private information. From a purely theoretical perspective the solution offered has no advantages over the approaches of Loeb and Suchanek which also solve the revelation problem for both sides of the market. However, it is simpler and therefore easier to implement. It does not replace the well-known and widely accepted Pigou tax but complements it where necessary to overcome the public goods problem.[2] Two invisible hands join in solving the environmental problem.

To make the discussion more lucid, it is phrased in terms of a water supply problem. Water can, in some circumstances, be seen as a private good whose properties permit a market solution to be found. This is the case for drinking water of a given quality, where marginal supply costs are positive and where the quantity can be increased by progressively expanding the water catchment area. No public goods problem exists here. It is quite a different matter, however, where the aim is to choose quality rather than quantity. In this case we are dealing with a public good from which all users benefit simultaneously. Water quality cannot be chosen separately for individual users and an efficient level of supply cannot be achieved by way of the price mechanism.

There are many other aspects of the environment which are of a similar nature and for which market arrangements do not lead to the economically efficient use of resources. Included among these are the quality of the ocean water, the air we breathe, the infrastructure, protection against noise pollution, and the ozone layer. In all of these cases quality must be enjoyed simultaneously by a large number of people, and incentive compatible mechanisms are needed to determine the optimal quality level.

2. Optimal environmental quality

The problem arising from the indivisible nature of quality can be illustrated by way of a river whose water is used for many different purposes by a large number of economic agents. On the one hand, upstream industrial firms and municipalities discharge the wastes from their treatment plants into the river, while on the other hand numerous downstream waterworks supply water from the river to the residential areas along its banks. Expenditure on filtration installations make it possible for treatment plants to improve the quality of the river water, relative to its quality when untreated wastes are discharged. The treatment plants are polluters, but, in their efforts to reduce the waste discharge, are also suppliers of the pubic good "water quality" in the economic if not the legal sense. The waterworks, as representatives of the end users, are both the parties damaged by pollution – the "pollutees" – and, at the same time, consumers of the good "water quality." The individual treatment plants can decide on their own levels of waste discharge, but, because of the self-mixing property of water, all the water taken from the river by the waterworks is of the same indivisible quality. Water quality as a good is divisible between the polluters but not between the pollutees. Let y_i, $i = 1, \ldots, n$ be the individual polluters' waste discharge levels and $y = \Sigma_{i=1}^{n} y_i$ the aggregate waste discharge from which the pollutees suffer jointly. For the time being it is assumed that there are only two polluters ($n = 2$) and two pollutees.

In terms of the individual discharge of wastes, y_i, the polluters have falling marginal benefit curves $B_i(y_i)$ and the pollutees have rising marginal cost curves $C_j(y)$ with regard to the aggregate waste discharge level y. These show respectively the maximum willingness-to-pay, and the minimum compensation required, for an extra unit of waste discharge. The marginal benefit can also be interpreted as the marginal value product of the factor waste discharge, used to produce the service "waste absorbtion," for an onsite sewage system of a city or industrial plant. In the opposite direction, it can be interpreted as the marginal cost of reduction in waste discharge or of enhancing the quality of the river water. The marginal cost curves of the waterworks, C_1 and C_2, represent the marginal cost of river pollution incurred by transforming river water into drinking water, and they can also be interpreted as demand curves for water quality.

Figure 1 shows the marginal benefit and cost curves for the two treatment plants and two waterworks. The diagram in the top right hand corner shows the aggregated curves. Because divisibility is different for the treatment plants and the waterworks, the marginal benefit curves are aggregated horizontally and the marginal cost curves are aggregated vertically. The Pareto optimal level of aggregate waste discharge, $\tilde{y}$, is given by the Samuelson-Lindahl solution (see Samuelson, 1955; and Lindahl, 1919). In the figure, this is the intersection

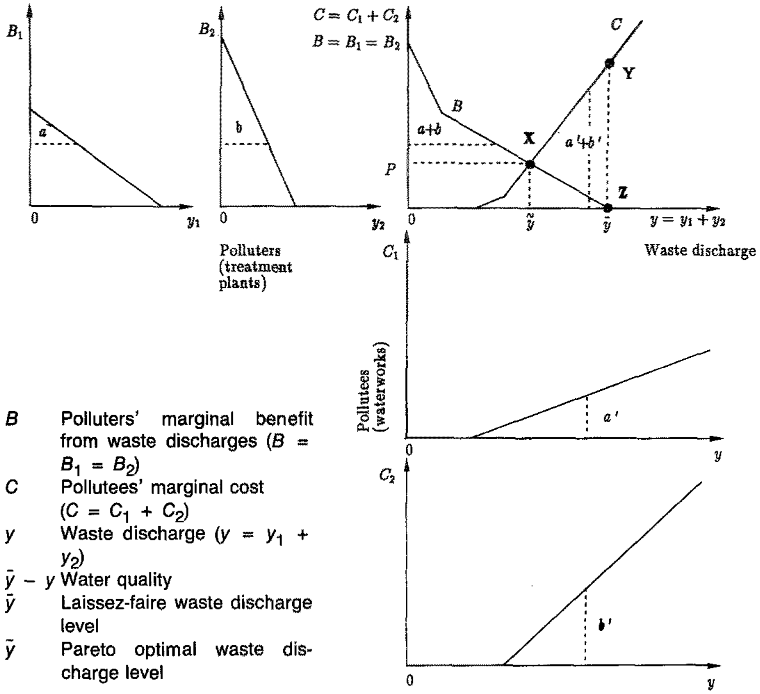

Figure 1. The Pareto optimal pollution level (Samuelson-Lindahl solution)

of the marginal benefit and cost curves B and C. The amount all pollutees, *taken together*, are prepared to pay for an extra unit less of pollution is equal to the marginal cost *each single* polluter has to incur to remove one unit.

A good example illustrating the problem considered is the river Rhine which is polluted by upstream production plants in Switzerland, France, and Germany, and which provides drinking water for downstream cities in Germany and the Netherlands. Enormous purification costs and quality reductions have to be borne by these cities. Dutch authorities have even planned to lay a fresh water pipeline in the river-bed to collect cleaner water from more distant upstream locations.

Related examples refer to water basins such as the Baltic Sea or Lake Constance. These basins are used both for waste discharge and for purposes that require clean water such as fishing or, again, the supply of clean drinking water. Another problem covered by the approach includes the issue of air pollution. Sulphur, nitric oxide, dust, and even carbon dioxide are among the substances which are difficult to avoid in industrial production processes, but which create serious disadvantages for a great number of people. Air pollution may also occur in the figurative sense that some people produce noise which disturbs others. In all of these cases the polluting activities add up to an aggregate pollution level which is simultaneously and inseparably suffered by a great number of people. Invariably, therefore, Pareto optimality can be defined in terms of the Samuelson-Lindahl solution.

3. An incentive compatible allocation mechanism

The Samuelson-Lindahl solution is difficult to implement. It is certainly possible to imagine an authority that could ask both the polluters and pollutees, in this case the treatment plants and the waterworks, to disclose their technologies and preferences and, on the basis of these, calculate the optimal level of pollution. However, it is well known that it is frequently in the parties' interests to provide the authority with false information. Lindahl's (1919) proposal to adjust individual cost shares iterately until all pollutees vote for the same pollution level would result in Pareto optimality if everyone believed that his vote is unable to affect his cost share in consecutive iteration steps. However rational voters know that this is not true. Even if the single voter is one among many he exhibits substantial influence on his ultimate cost share and is able to seize a monopsony rent by underrepresenting his own preference for waste reductions.

A policy tool which is often recommended is the distribution of tradeable pollution certificates. This method has virtues similar to those of the Pigou tax but, like it, is only a partial solution to the environmental problem. Trading the certificates can achieve an efficient distribution of a given amount of aggregate waste discharge among the polluters when the authority has predetermined this amount by fixing the number of certificates. However, the optimal number of certificates itself cannot endogenously be found since, from the point of view of the pollutees, the certificates are a public good. When the pollutees are given the right to issue or buy certificates, the free rider problem leaves little hope that they will keep or buy enough of them to enable an optimal solution to be reached.[3] Where both the number of pollutees and the number of certificates are large enough, the likely result will be the laissez-faire solution shown in the diagram as $\bar{y}$. In this solution the marginal benefit obtained by the polluter from increasing the waste discharge is zero, and there is a welfare loss in terms of excessive overall production costs of drinking water which equals the triangle XYZ.

This section describes a way in which the implementation problem can be overcome and the welfare loss can be avoided.

What is required is an authority which can impose charges, pay subsidies, and regulate the amount of pollution. The authority is directed to enforce the Pareto optimal level of waste discharged and it complies. The questions of whether such a direction can be arrived at as a result of a political process and whether the authority is able to comply with it should certainly be discussed. Nevertheless, the present paper abstracts from these questions. This does not mean, however, that the authority is assumed to have perfect knowledge. Indeed the problem of the incentive compatibility of the allocation arises precisely because the authority does not know the marginal benefit and cost curves and can only discover them by the use of survey methods. The effectiveness of the method presented does not depend on assumptions about the participants' moral attitudes. It can be compared to Adam Smith's invisible hand which brings about a Pareto optimal allocation of private goods in competitive markets although the participants' actions are based only on their own self-interest.

It is assumed here that both polluters and pollutees are self-interested rent maximizers, and that the conditions necessary to ensure that income effects do not affect marginal benefit and cost curves are met. It is also assumed that the number of actors, at least of the polluters, is large enough to ensure that a market solution would approximate closely the competitive equilibrium for private goods. Let n be the number of polluters and m the number of pollutees. What is being sought is a method for allocating public goods that works as well as the market does for allocating private ones. For the sake of keeping the mechanism simple more than this is not demanded.

All parties know the allocation process, which consists of five steps.

(1) The authority asks the individual polluters and pollutees to reveal their marginal benefit and cost functions $B_i(y_i)$ and $C_j(y)$, where $i = 1, \ldots, n$; $j = 1, \ldots, m$; and $y \equiv \sum_{i=1}^{n} y_i$. It uses this information to calculate the Pareto optimal individual and aggregate waste discharge levels $\tilde{y}_i$, $i = 1, \ldots, n$, and $\tilde{y}$, $\tilde{y} \equiv \sum_{i=1}^{n} \tilde{y}_i$, according to the method described in the last section. The Pareto optimum is defined such that $B_1(\tilde{y}_1) = \ldots = B_n(\tilde{y}_n) = B(\tilde{y}) = C(\tilde{y}) = \sum_{j=1}^{m} C_j(\tilde{y})$ where B and C are the aggregate marginal benefit and cost functions. The authority also calculates a Pigou tax rate P by equating this rate to the Pareto optimal level of the aggregate marginal benefit and cost as revealed by the survey: $P = B(\tilde{y}) = C(\tilde{y})$.

(2) Before the survey is carried out, specific "critical" discharge levels y_i^*, $i = 1, \ldots, n$, are irrevocably assigned to the single polluters and these levels are made public. After the survey and the calculation of the Pareto optimal discharge levels, each polluter i must pay the Pigou tax rate (or price) P for all units discharged that exceed the critical level $(\tilde{y}_i - y_i^*)$. Analogously, the authority pays the polluter the same amount P for all "unused" pollution units $(y_i^* - \tilde{y}_i)$. The critical discharge levels y_i^* are arbitrary and can be determined on equity grounds or with regard to the government's revenue requirements. The optimal discharge levels $\tilde{y}_i$ are prescribed for the individual polluters. The single polluter can indirectly influence these levels when he reveals his marginal benefit function, but once the authority has received the function, the polluter has no further room for manoeuvre.

(3) Before the survey, positive cost shares α_j are irrevocably assigned to the individual pollutees j, $j = 1, \ldots, m$, and these shares are made public. The cost shares can be chosen arbitrarily but they must sum to 100%. After the survey pollutee j pays the authority the share α_j of the aggregate costs (reduced benefits) incurred by the polluters when they reduce the amount of waste from the laissez-faire level $\bar{y}$ to the Pareto optimal level $\tilde{y}$, i.e., he pays the amount $\alpha_j \cdot \int_{\tilde{y}}^{\bar{y}} B(y)\mathrm{d}y$. The costs are calculated on the basis of the marginal benefit curves as revealed by the polluters.

(4) After the survey, the authority calculates a level of total waste discharge y_j' for each pollutee j that would be Pareto optimal in terms of the revealed marginal benefit and cost curves of the other participants, if this pollutee's cost share α_j were paid but his preferences disregarded. Formally, y_j' is defined by the condition $(1 - \alpha_j)\, B(y_j') = \Sigma_{k=1, k \neq j}^{m}\, C_k(y_j')$ for all $j = 1, \ldots, m$. Pollutee j thus pays the authority an amount that, combined with his payment described in (3), is just sufficient to cover the net disadvantage of all other agents which results when the total level of waste discharge is changed from the "anti-j" Pareto optimum y_j' to the true Pareto optimum $\tilde{y}$. In addition to the payment described under (3) he thus pays the amount $\int_{\tilde{y}}^{y_j'} [(1 - \alpha_j)B(y) - \Sigma_{k=1, k \neq j}^{m}\, C_k(y)]\mathrm{d}y$. This amount is the Clarke tax. Again, all calculations are made on the basis of the revealed benefit and cost curves rather than the unobservable true benefit and cost curves.

(5) The authority's budget is balanced by means of transfers from or to the overall government budget. The transfers are chosen such that neither polluters nor pollutees are perceptibly advantaged or disadvantaged.

4. The polluter's decision problem

The allocation process just described motivates the participants to declare their true marginal benefit or cost curves. Thus it becomes possible for the authority to actually determine the Pareto optimal discharge levels for the individual polluters. The next two sections explain why this is so.

Consider first the situation of the polluter, in this case the water treatment plant. Each individual treatment plant faces a decision problem similar to that of a buyer or seller in a competitive market, and therefore has an incentive to reveal its true marginal benefit curve.

The decision problem of the treatment plant is shown in Figure 2. The authority receives the information on the individual marginal benefit and cost curves and calculates the price P of waste discharge, the Pigou tax, as described under (1). Given this price it allocates the discharge level $\tilde{y}_i$ to polluter i. The

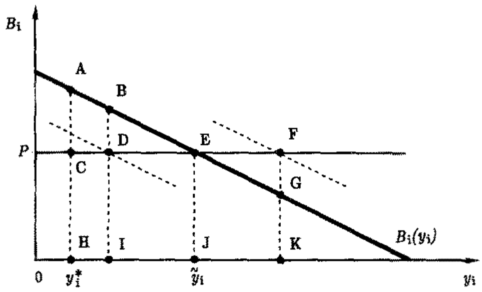

Figure 2. The polluter's decision (treatment plant).

magnitude of this discharge level satisfies the equation $B_i(\tilde{y}_i) = P$ where $B_i(y_i)$ is the marginal benefit function revealed. The authority receives the amount $P \cdot (\tilde{y}_i - y_i^*)$, or CEJH in the figure, from the polluter, where the predetermined variable y_i^* may or may not fall short of $\tilde{y}_i$.

The discharge level $\tilde{y}_i$ and the resulting payment to the authority are not exogenous for the treatment plant. It can choose them indirectly by announcing its marginal benefit curve B_i. Only the price P is exogenous from the point of view of the individual treatment plant because of the competitive assumption. The plant is not forced by anyone to disclose its genuine B_i curve but it does so nevertheless. If it were to lie and specified, for example, the dotted curve passing through D, it would only be harming itself. Because the prescribed discharge level would fall by DE, the Pigou tax burden would be reduced by DEJI. However, the true treatment costs would increase by BEJI leaving a net disadvantage of BED. Disclosing a curve further to the right, for example the one through F, would not be worthwile either. The shift from E to F would increase the Pigou tax burden by the amount EFKJ but the reduction in treatment costs EGKJ (the increase in the benefits from pollution) would be smaller and would fall short of the additional payment by EFG.

Naturally when treatment plant i declares its marginal benefit curve it does not know which pollution price P the authority will set. However, it does not care because the above considerations hold for any level of price. Whatever this level is, it is never worthwile for the polluter to disclose a false marginal benefit curve. For the same reason the polluter does not have to know whether or not P is at the level which produces a Pareto optimum.

The critical discharge level y_i^* set by the authority does not matter either. It can easily be shown, by varying Figure 2, that the best strategy for the individual treatment plant is to declare its correct marginal benefit curve even when $y_i^* \geq \tilde{y}$, that is when the polluter receives a payment from the authority. Even if the polluter receives a subsidy for "unused" discharge units, it is still better to go to point E where marginal benefit and price are equal.

Only if it is assumed that the Pigou tax rate P can be affected by the preferences revealed, would it be worthwile making a false declaration aimed at gaining a monopoly or monopsony profit. This is ruled out here by the assumption that the number of polluters is large. With a large number of polluters the single polluters's market share is small, too small to affect P significantly through his own actions.

If in some particular situation this assumption is not justified, the allocation mechanism described will appear less attractive. This does not mean, however, that it is quite useless. Without competition among the polluters the mechanism certainly does not ensure that the aggregate pollution level will be adjusted until the Pareto optimum is reached. However, the adjusted discharge level can be expected to be closer to the Pareto optimum than the previously fixed discharge level y_i^*.[4] When there are only a few polluters the authority should try to bring the critical level y_i^* as close as it can to the Pareto optimal level and leave the fine-tuning to the allocation mechanism. This method would in any case be better than simply setting prescribed levels of pollution.

5. The pollutee's decision problem

The real difficulty in constructing an incentive compatible allocation mechanism comes from the side of the pollutees, for a change in the pollution level is an indivisible economic activity only from their point of view. As mentioned above, the Lindahl mechanism, in which the cost shares are varied until all waterworks want the same level of pollution, is not appropriate. Each waterworks would try to hide its own true preferences in order to make the others pay a larger share of the costs, and the incentives to lie do not vanish when the number of participants increases. The case is fundamentally different from that of the polluter and a differend kind of mechanism for revealing preferences is therefore needed.

Figure 3 illustrates the mechanism for revealing preferences where there are two pollutees, i.e., two waterworks. The calculations are made for waterworks 1. Its preferences are shown by the curve C_1 and its previously fixed share of costs determines the position of the curve $\alpha_1 B$.

The fictive Pareto optimum that would exist if waterworks 1 could be made to pay without considering its preferences is characterized by $B - \alpha_1 B = C_2$ or, equivalently $B - C_2 = \alpha_1 B$. In the diagram the condition is met at y_i', since the curve $B - C_2$ cuts the cost share curve $\alpha_1 B$ of waterworks 1 here.

By way of contrast, the true Pareto optimum is at $\tilde{y}$ where the curve C_1 cuts the $B - C_2$ curve. Here, the marginal benefit of the treatment plants equals the sum of the marginal costs of the waterworks. If all participants disclose their true preferences, $\tilde{y}$ is reached, and waterworks 1 pays two kinds of

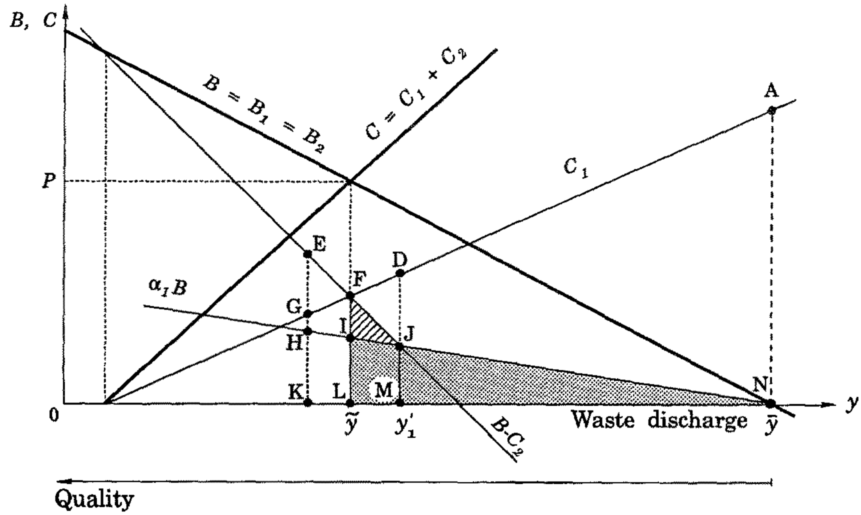

Figure 3. The pollutee's decision (waterworks).

charges. The first results from the previously set cost share α_1 and is shown by the dotted area INL. The second is the Clarke tax. It is imposed on the transition from $y_1{}'$ to $\tilde{y}$, and is assessed in a way that ensures that, combined with the increase in the first kind of charge brought about by the transition, it is sufficient to compensate for the decline in net benefits of the other waterworks and the treatment plants. In the example given in Figure 3, the Clarke tax is represented by the hatched area FJI, since the decline in net benefits equals the area FJML under the curve $B - C_2$ and the additional cost contribution of waterworks 1 resulting from the predetermined cost share α_1 is given by the area IJML. The total amount paid by waterworks 1 to the authority is FJNL. According to its true preferences, this is less than the maximum amount FANL that it would have been prepared to pay to reduce the waste discharge by LN. The waterworks therefore gets a rent equal to FANJ.

It must now be shown that it would not be worthwhile for the waterworks to lie because a misrepresentation of the marginal cost curve C_1 would result in a smaller rent. Consider first the case where waterworks 1 understates its true preference for water quality and assume that its revealed marginal cost curve intersects the curve $B - C_2$ at point J and not at point F. In this case, the discharge level would have been higher by LM and waterworks 1 would have saved taxes amounting to FJML. However, its cost increase resulting from the higher level of pollution would have been FDML so that its rent would have been smaller by FDJ. Overstating its preferences for water quality would also not have been worthwile. If, for example, the waterworks had disclosed a curve C_1 passing through E, the discharge level would have been lower than the

Pareto optimum by KL. Given the true marginal cost curve, it would have been prepared to pay an additional amount GFLK, but in fact it would have had to pay the additional amount EFLK. By exaggerating its preferences for water quality the waterworks therefore incurs a net loss of EFG. This completes the proof that the pollutee can obtain his maximum rent only when he is honest.

As with the process of revealing the polluter's preferences, incentive compatibility does not require that, when the pollutee discloses his preferences, he must know what the other actors' preferences are, nor must it be assumed that the preferences revealed are the true ones. Nothing in the pollutee's decision calculation just described depends on an assumption that other actors' preferences are correctly declared. Because the procedure to be followed is compulsory and known in advance, each agent is aware that a true disclosure of his marginal cost curve is always to his own advantage. Finally, it is of course not necessary for there to be only two pollutees. If there are m pollutees, as assumed in Section 3, the above calculation is still appropriate for each individual decision maker, $j, j = 1, \ldots, m$, if $a_1, y_1{}'$, and C_1 are replaced by $a_j, y_j{}'$, and C_j and if C_2 is replaced by $\Sigma_{k=1, k \neq j}^{n} C_k$.

6. Concluding remarks

The allocation mechanism presented in this paper is an incentive compatible solution to typical environment problems, where pollution affecting a public medium is individually caused but collectively borne. The solution results from joining the invisible hands which the Pigou and Clarke taxes activate. Its strength is its simplicity which gives it higher chances of being implemented in practical decision problems than other theoretically attractive solutions.

The mechanism is able to generate substantial revenues. Pollutees pay to the government an amount that covers the waste reduction costs of the polluters plus the Clarke tax. (Though the latter may be negligible when there are many pollutees; see Tideman and Tullock, 1976, 1977; and Sinn, 1986). Polluters, on the other hand, can be made to pay substantially more than the pollutees' costs if the critical discharge levels y_i^* are chosen small enough, perhaps even set equal to zero. Some authors would see such a surplus as a disadvantage, claiming that the government's budget should be balanced with regard to all payments resulting from the allocation mechanism. In fact, however, the revenue raising capacity is an advantage. It helps reduce the distortionary taxes on efficient market transactions on which governments otherwise must rely. Good "eco-taxes" in the Pigovian tradition are good revenue raisers, good eco-taxes of the Pigou-Clarke variety are even better revenue raisers.

Despite certain advantages, the solution offered is, of course, not immune to the criticisms of incentive mechanisms that occasionally appear in the literature, and it shares the weaknesses pointed out by the critics. As in the market for private goods, collusion between the actors can distort the allocative results and as with decision making generally, the question of whether it is individually rational to bear the costs of disclosing preferences arises. On the other hand, the mechanism cannot be criticized for not meeting exaggerated demands. One can agree with those who point to government failure and claim more tolerence for market failure but the reverse proposition can also be made. To demand a level of efficiency from a governmental allocation process for public goods that the market cannot even approximate with private goods would be utopian. Even the public choice school cannot demand Nirvana here on earth. Despite the theoretical elegance of the Coase theorem it is quite clear that markets have failed miserably when it comes to dealing with environmental problems. It may be high time to seek practical alternatives, and perhaps the combination of the Pigou and Clarke taxes is one.

Notes

1. The paper has been developed from an earlier paper (Sinn, 1988) which the author published in German.
2. Suchanek (1979) proves a duality result according to which an incentive compatible allocation mechanism based on emission quotas can be substituted by one based on emission charges. However, his emission charges involve individually tailored tax rates and have few similarities with Pigou taxes.
3. The free rider problem can also be avoided by majority voting with predetermined cost shares. However majority voting singles out the median voter's decision which does not, in general, coincide with Pareto optimality.
4. This follows from Sinn and Schmoltzi's (1981) analysis of the Coase theorem in the presence of market power. Market power in the sense of a monopoly or monopsony position implies that the equilibrium allocation of a scarce resource is being biased from the Pareto optimum towards the resource endowments. However, the equilibrium allocation always deviates less from the Pareto optimum than the endowments do. Trade always pushes the allocation in the direction of the Pareto optimum.

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