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Innovation in Pollution Control

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I. INTRODUCTION

Comparisons of the various institutional arrangements for controlling pollutant emissions from individual sources—effluent fees, effluent control subsidies, marketable permits, and direct ("command and control") regulation—have usually focused on their static efficiency properties and institutional feasibility (e.g., Dales, 1968; Zerbe, 1970; Baumol and Oates, 1975; Kneese and Schultze, 1975; Marin, 1978; Mills and White, 1978; Spence and Weitzman, 1978; Russell, 1979). A relatively neglected area has been the study of how each arrangement influences *innovation* in pollution control. A few studies (e.g., Kneese and Schultze, 1975; Marin, 1978; Mills and White, 1978; Russell, 1979) have casually claimed that the control methods that rely on economic incentives provide superior incentives for innovation. But there have been few systematic studies of the question.[1]

This paper provides a simple model of pollution control innovation by a profit-maximizing polluter who is subject to the various control methods.[2] The consequences of the methods will be explored in three major contexts: First, we assume that the polluter (and the innovation) is a small enough part of the overall pollution problem so that none of the important marginal conditions are changed by the innovation. Second, we assume that the polluter (and the innovation) are important enough so that marginal conditions are changed by the innovations, but that the governmental authority determining pollution control incentives or levels fails to make the appropriate adjustments. Third, we again assume that the innovation causes marginal conditions to change, but in this case the governmental authority makes the appropriate adjustments. (We use the term "ratcheting" to describe this last phenomenon.) In all cases, we assume that the innovating polluter correctly predicts the reactions of the governmental authority and bases his innovation decisions on that prediction.

A profit-maximizing entrepreneur would normally be expected to adopt any innovation that promised gains (present discounted value) to him in excess of initial

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[1]See Zerbe (1970), Wenders (1975), Magat (1978, 1979).

[2]The model provided here is somewhat similar to that provided by Wenders (1975). But the model here stresses conclusions to a greater extent and also includes marketable permits, which Wenders neglects.

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investment costs. He would pursue innovations at the margin up to the point at which the marginal gains to him are equal to the marginal costs of innovation. By contrast, the proper social criteria are that innovations should be adopted only if social benefits (present discounted value) exceed social costs and that innovations should be pursued only to the point at which marginal social benefits equal marginal social costs. In the analysis that follows, we will assume that private innovation costs are identical with social costs, so no conflicts in criteria occur on that account. But, as we shall argue, the private and social benefits from innovation can differ under the various institutional control arrangements, and, hence, conflicts are possible.

Among the points covered in this paper, we find that when the innovation does not change marginal conditions, the methods relying on economic incentives encourage the socially proper amount of innovation, while direct regulation encourages too little. When innovation changes marginal conditions, however, no method encourages just the right amount of innovation, regardless of whether the control authority ratchets or not. Some methods overencourage; others underencourage. The private gains or losses on inframarginal units appear to be the source of the differential between private motives and the socially optimal outcome.[3]

II. CONTROL COSTS AND INNOVATION

The costs of controlling emissions from a source typically increase at an increasing rate. For our purposes we will employ a cost function that represents the present value of all costs over the planning period, except that the costs of "investment" in innovation (if any) are excluded. Such a cost curve for emission reductions (MC_{ER}), stated in terms of the marginal costs of percentage removal of emmisions, is presented in Fig. 1.

An innovation is a discovery that will reduce the costs of controlling emmisions. It normally involves an initial cost or investment (e.g., research and development expenses) and then a subsequent cost reduction or savings if the innovation is employed.

The cost savings from innovations can take several forms. It is possible to develop an innovation that reduces costs on inframarginal units of control but leaves MC_{ER} unchanged at the current level of control. Such an innovation does not change marginal conditions and, thus, would not ordinarily be expected to result in a change in a percentage removal for the source. There are several other types of innovation. Costs could be higher (lower) for some inframarginal units but lower (higher) for marginal units. The innovation which is more commonly discussed is one where both inframarginal and marginal units are less costly than the original cost function (MC'_{ER} in Fig. 1). It is this last type of innovation that will be the focus of our analysis.

In all cases, for purposes of simplicity we will assume that the innovation is specific to the innovating polluter and cannot be transferred to any other polluter.[4]

[3] Our findings with respect to inframarginal units are similar to those found, in somewhat different contexts, by Rose-Ackerman (1973) and Collinge and Oates (1982).

[4] We leave the cases of an inovation by one polluter that can be sold or licensed to other polluters, or innovations by supplier firms, to others to analyze.

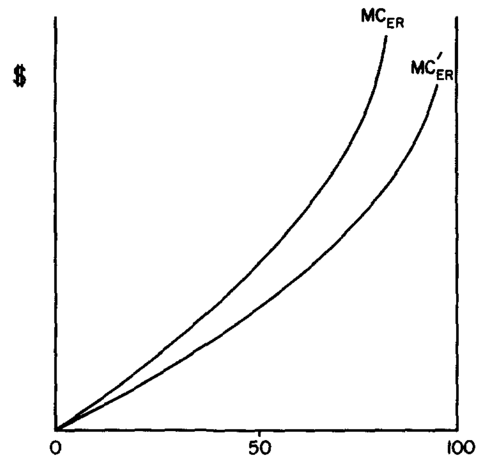

FIGURE 1

III. INCENTIVES TO INNOVATE

In the following analysis, we will assume that a polluter currently operates along a pollution control marginal cost function characterized by MC_{ER} in Fig. 2. The units of emissions along the horizontal axes have been arbitrarily redefined so that 100 units of pollutants would be emitted in the absence of any controls. The governmental pollution control authority (depending on the institutional method employed) currently levies an effluent fee of P_1 per unit of pollutant emission, provides an effluent control subsidy of P_1 per unit, issues marketable permits for emissions of

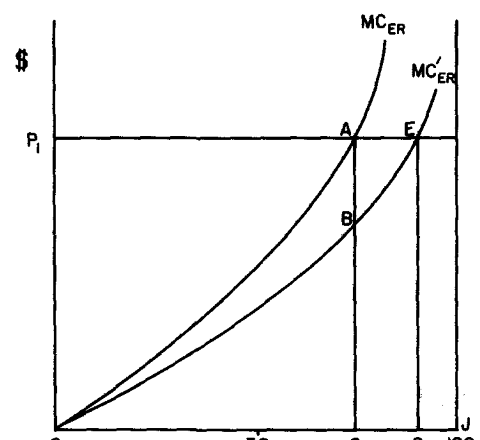

FIGURE 2

only CJ units per time period (which clear the market at a price of P_1 per unit), or issues regulations that allow only CJ units to be emitted per time period (enforced by a prohibitive penalty substantially above P_1 per unit). If the polluter behaves in a cost-minimizing or profit-maximizing fashion, all of these policy efforts will cause the polluter to control his emissions by OC units and to continue to emit CJ units. If P_1 represents the marginal social benefits accompanying a reduction (from current levels) of one unit of emissions and if MC_{ER} also represents the social costs of emissions control, the level of emissions control achieved is socially optimal. We will assume that all of these conditons hold.

We now assume that an innovation in pollution control is possible. The innovation promises that pollution control cost curve MC'_{ER} will prevail in the future. But the innovation requires an initial investment of X dollars. In the subsequent analysis we compare the behavior of a profit-maximizing polluter, both in his decision as to whether to adopt the innovation and in the amount of emission control that occurs, under the various institutional control arrangements. In addition we will compare these outcomes with the socially optimal ones.

A. The Change in Emissions is Small—No Change in Marginal Conditions

We assume that the polluter in question is just one among a large number of emitters of the pollutant so that any reduction in this polluter's emissions can be valued at the existing social value of emissions reductions and the social marginal benefit from reductions remains unchanged.

1. The socially optimal outcome. Since the change in emissions is small, social optimality still calls for control to be pursued up to the point where the social marginal costs of control are equal to P_1 (the social marginal benefits). Thus, control would increase by CD units—i.e., overall control would be OD units, and only DJ units of emissions would continue to occur.

With this new level of control, the social benefits from the innovation can be seen to be composed of two parts: the decrease in pollution control costs at the previous level of control (i.e., cost savings of OAB); and the added social benefits from the decrease in emissions ($AEDC$), less the extra costs incurred to achieve that decrease ($BEDC$), or a net benefit of AEB. The sum of the two parts is represented by area OAE.

Thus, the innovation is socially worthwhile and should be adopted if the initial costs X are less OAE, and conversely.[5]

2. The outcome under an effluent fee system. A profit-maximizing polluter, contemplating emissions control after the innovation, would pursue control to the point at which the marginal costs of control per unit equals the effluent fee per unit—i.e., a control level of OD. At that point, the gains to the polluter from the innovation are the sum of the cost reduction at the previous control level (OAB), plus the reduction in effluent fee payment ($AEDC$), less the extra control costs incurred ($BEDC$). Thus, the net gains to him are area OAE—exactly the same amount as the social benefits from the innovation.[6]

[5] Similarly, any pursuit of extra innovation should continue until the marginal increase in initial costs (ΔX) equals the marginal increase in area OAE (ΔOAE).

[6] And, similarly, it can be shown that he will pursue innovation to the point of $\Delta X = \Delta OAE$.

Thus, the profit-maximizing polluter's incentives to adopt an innovation (and the level of control achieved) are identical with the socially optimal criteria.

3. The outcome-under emissions control subsidies. A profit-maximizing polluter, contemplating emissions control after the innovation, would pursue control up to the point at which the marginal costs of control equals the subsidy per unit—i.e., control level *OD*. At that point, the gains to the polluter from the innovation are the cost savings *OAB*, plus the extra subsidy to be earned (*AEDC*), less the extra costs of control (*BEDC*). Thus, again, the profit-maximizing polluter's gains from the innovation would be identical to the social benefits, and the polluter's innovation (and pollution control) decisions would again be socially optimal.[7]

4. The outcome under marketable permits. We assume that the number of marketable permits the innovating polluter receives remains at *CJ* (i.e., we are assuming that the time frame over which benefits are contemplated is shorter than the time period for which the marketable permits have been issued). The profit-maximizing polluter, contemplating pollution control after the innovation, would pursue control to the point at which the marginal costs of control equal the price at which a permit could be sold—i.e., a control level of *DJ*. Again, the gains to the innovating polluter would be the cost of savings *OAB*, plus the revenue from the sale of excess permits (*AEDC*), less the extra costs of control (*BEDC*). Thus, again, the profit-maximizing polluter's gains from innovation are identical to the social benefits, and the socially optimal decisions with respect to innovation and control levels will occur.[8]

5. Outcome under direct regulation. The profit-maximizing polluter, contemplating pollution control after the innovation, would have no incentive to increase the level of control, as long as the regulatory level of allowed emissions does not change. Thus, emissions would remain at the level *CJ*, and the gains to the polluter from the innovation would be only the cost savings at the existing level of control, *OAB*. Since the private gains in this case, *OAB*, are less than the social benefits, *OAE*, there will be instances—those in which $OAB < X < OAE$—when the profit maximizing polluter will fail to adopt innovations that are socially desirable.[9] And control levels, regardless of whether an innovation is or is not adopted, will remain too low.

6. Conclusions when marginal conditions are unchanged. If the change in emissions is small enough so that the marginal social benefit of emissions reduction is not affected, the institutional control methods that rely on economic incentives—effluent fees, emissions control subsidies, and marketable permits—all provide the socially optimal incentives for innovation and control. Direct regulation provides too low a level of incentives, so that some socially appropriate innovations do not occur and too little control occurs.[10]

[7] Emissions control subsidies, though, are likely to encourage more entry (and, possibly, innovation with it) into the underlying industry than will other control methods. See Mumey (1971) and Jaffee (1975).

[8] The same point as in footnote 6 also applies. Further, the same basic propositions hold if the pollution control authority auctions the requisite number of permits (i.e., the property right is initially held by the government rather than the polluter). For discussion of transformation functions and problems with marketable permits, see Tietenberg (1980).

[9] Similarly, the firm under direct regulation will only pursue extra innovation to the point where $\Delta X = \Delta OAB < \Delta OAE$.

[10] Magat's (1979) model yields the result that effluent fees and direct regultion have the same incentive effect on innovation. He gets this result by having the control authority reduce the effluent fee by an appropriate amount, so that no change in emissions occurs as a consequence of the innovation. But we

B. The Innovation Changes Marginal Conditions, but the Control Authority Fails to Adjust

We now assume that there is only a single emitter of the pollutant in question and the emissions reduction likely to be achieved by the innovation is nontrivial, so the social marginal benefit from emissions reduction will be affected. The principle of declining marginal utility indicates that the social marginal benefit from subsequent emissions reduction is likely to decline as control increases.

1. The socially optimal outcome. In Fig. 3, curve *AF* traces the schedule of social marginal benefits from emissions reductions. The proper social criterion for control is still to extend control to the point at which social marginal benefits equal social marginal costs. In the presence of the innovation, the appropriate level of control is *OG*. It is easy to show that the net social gains from the innovation are now encompassed by area *OAF*. Area *OAF* is less than *OAE* because subsequent emissions reductions are worth less to society.

Thus, the innovation is socially worthwhile if its initial costs *X* are less than *OAF*. And emissions should be reduced to a level of *GJ*.

2. The outcomes under the various control methods. If the control authority does not adjust the control instruments, the reasoning of Section A still holds. The methods relying on economic incentives again yield net gains for the profit-maximizing polluter of *OAE*, which is greater than *OAF*. The method of direct regulation again yields net private gains of only *OAB*, which is less than *OAF*. The only possible exception to this statement involves marketable permits. If there is only one polluter receiving the permits, their "marketable" nature disappears. (On the other hand, if the polluter has to "buy" the permits from the authority at a set price, the net effect is the same as that under an effluent fee.) To allow analytic comparisons, the marketable permits case is best considered in the context of a polluter who is one among a few polluters, so a market in permits does exist. A nontrivial innovation is likely to reduce the innovator's demand for permits—i.e., it releases some of his permits for sale. Unfortunately, without knowing more about the other polluters' demands for permits, one cannot tell whether the price of permits will fall only slightly below price P_2 (in which case the innovator reduces emissions almost to *DJ* and his net gain is almost *OAE*) or will fall almost to zero (in which case the innovator will control only a small amount of emissions and the net gain from the innovation—if the price fall is accurately forecasted—is also small, well below *OAB*).

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can see no reason for the control authority to behave in this manner. If the change in pollution is truly marginal, no change in fee is called for, and the polluter will (and should) pollute less. If the change in pollution is nonmarginal, a lower fee is called for (see Secs. B and C below), but the innovator will still pollute less. Insisting that the innovator be induced by a fee decrease to return to the original pollution level, just for the purposes of comparison, has little behavioral or nomative justification. If the regulator somehow discovers that the innovation has been made, the tendency toward too little innovation is exacerbated. In this case the regulator's response would be to tighten the standard to allow only *DJ* units to be emitted, and the potential innovator would then subtract the anticipated extra costs *BECD* from the anticipated savings *OAB*. This result is analogous to our "ratcheting" result in Section C below. But see also the discussion in footnote 17.

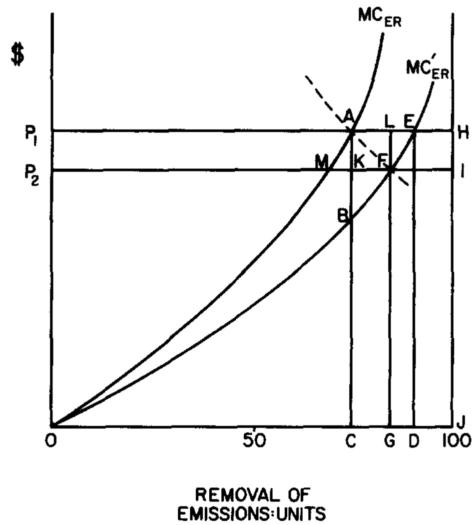

FIGURE 3

3. Conclusions when marginal conditions are changed but the control authority fails to react.[11] If a major polluter contemplates a nontrivial innovation and pollution control authority is nonreactive, the control methods relying on economic incentives (with the possible exception of marketable permits) encourage too much innovation; the excess occurs whenever $OAF < X < OAE$. And whenever innovation occurs, too much emissions control results. On the other hand, direct regulation encourages too little innovation; this deficiency occurs whenever $OAB < X < OAF$. And despite any innovations that do occur, too little control occurs.[12]

Accordingly, deadweight loss occurs regardless of the control method employed. The extent of the deadweight loss depends on the elasticities of the social benefit schedule and of the marginal cost schedule yielded by the innovation. An increase in the former elasticity causes a smaller deadweight loss from the excessive innovation encouraged by the economic incentive methods and a larger deadweight loss from the deficient innovation caused by direct regulation. A decrease in the elasticity of the marginal cost schedule causes the deadweight loss from all methods to decline.

Finally, many economists would argue that there frequently are positive social externalities from innovation that innovators cannot fully capture. Hence, the direct rewards to innovators do not adequately reflect the social gains from innovation.[13] To the extent that our analysis ignores these socially beneficial spillovers, the deadweight loss from the economic incentive methods is reduced (and the deadweight loss from direct regulation is increased).

[11]The results of this section can be interpreted in a slightly different context: If all polluters are considering the adoption of an innovation, the sum of their actions will change the marginal conditions, and the control authority may react properly. But each firm may well believe that its individual actions will not change the marginal conditions, and, hence, each firm perceives its incentives to be those discussed in this section.

[12]Again, incentives for innovation at the margin suffer the same problems as before, for all methods.

[13]But see Hirschleifer and Reilly (1979) for a summary of a contrary view.

C. The Innovation Changes Marginal Conditions and the Control Authority Adjusts Properly (Ratcheting)

Again, we assume a single (sole) emitter, but this time the pollution control authority makes the socially appropriate adjustments. Thus, the effluent fee or emissions reduction subsidy is lowered from P_1 to P_2 or the number of marketable permits or the regulated amount of emissions is reduced to *GJ*.

1. The socially optimal outcome. The socially optimal outcome is the same as in Section B. After the innovation, emisssions should be reduced to *GJ*, and the innovation should occur if the initial investment costs *X* are less than *OAF*.

2. The outcome under effluent fees. A profit-maximizing polluter, contemplating pollution control after the innovation and after the adjustment in the effluent fee, would choose a level of control of *OG*. The gains to the polluter from the innovation are represented by area *OAHIF*. This can be broken down as follows: a cost savings of *OAB* on the existing level of control, a reduction in effluent fee payments of *ALGC* on the additional *CG* of emissions reductions, less *BFGC* of extra costs involved in the extra control, plus a reduction in effluent fee payments on the remaining emissions of *LHIF*.

Thus, the innovator achieves the proper level of control, but the effluent fee adjustment causes an excessive amount of innovation; this excess occurs whenever $OAF < X < OAHIF$. Also, it is worth noting that $OAHIF > OAE$, so excessive innovation and the likely deadweight loss from it will be yet greater if effluent fees are adjusted than if they are not. The excessive incentive arises because the decreases in *inframarginal* effluent fee payments are transfers from a social perspective but provide an incentive for the innovator.

A qualification should be added to this result. Suppose that the innovator is just one among a few polluters, but that he is large enough so that the innovation changes marginal conditions. When the control authorities reduce the effluent fee appropriately, the other (noninnovating) polluters enjoy a gain. Most of this gain represents a pure transfer from the pollution control authority to the other polluters (the reduction in fees on the previous emissions). But part of this gain occurs through the decrease in their emissions control occasioned by the decrease in the fee level: the decrease in control costs, less the extra fees paid on the additional emissions. This latter gain, comparable to area *AKM* in Fig. 3, is a real resource gain from the innovation. But the innovator does not benefit from this latter gain. Hence, the excess incentive for innovation is muted somewhat, although it is unlikely to be eliminated.

3. The outcome under emissions control subsidies. Again, after the innovation and subsidy adjustment, the innovator would choose the socially optimal control level *OG*. The gains to the innovator are composed of the cost savings on the previous level of control (*OAB*); plus the additional subsidy on the additional control (*KFGC*) less the additional costs of the additional control (*BFGC*), or *KFB* net; *less the reduction in subsidy on the previous control,* P_1AKP_2. Thus, the net gain to the innovator must be smaller than the social benefits (*OAF*), and, if the reduction in subsidy is large enough, the innovator may suffer a net loss rather than a gain, even before the investment costs *X* are included.

Thus, the emissions control subsidy method clearly encourages too little innovation.

4. The outcome under marketable permits. The innovation reduces the polluter's demand for permits. The appropriate adjustment for the contol authority is to reduce the supply of permits to *GJ*. For purposes of analytic comparison, we assume that the net effect of the reduced demand and reduced supply is to cause the price of permits to fall from P_1 to P_2. (Again, in a context of a single polluter, such an assumption is wholy arbitrary. It is best considered in the context of the innovator as one among a small group of polluters.)

The polluter again chooses the socially optimal level of control, *OG*. The gains to the innovator depend on who absorbs the reduction in the allocation of permits by the control authority.[14] If the other polluters have to absorb the reduction, whereas the innovator's allocation remains unchanged, the innovator achieves gains *OAB*, plus the sale of *CG* permits worth *KFGC*, less the cost of extra control *BFGC*; thus, the net gain is *OAB* plus *KFB*, which is less than the social gain of *OAF*. On the other hand, if the innovator has to absorb the entire reduction in the supply of permits, then both the pre- and postinnovation situations involve no net sales (or purchases) of permits, so the net gain is simply *OAB* less *BFGC*.[15] Again, this area is less than the social gain, *OAF*, and it could conceivably be negative.

Thus, in either case the marketable permits method provides too little encouragement for innovation. In the first case, the deficiency occurs because of inframarginal effects. In the second case it occurs because the ratcheting effectively converts the marketable permits system into a direct regulation system: Under direct regulation, the polluter bears no costs (faces no incentives) with respect to the remaining inframarginal pollution that is allowed under direct regulation; consequently, the ratcheting only imposes the extra control costs on the innovator without providing him with the reflection of the social gains from the reduced pollution.

5. The outcome under direct regulation. After the innovation and regulatory adjustment, the polluter again chooses the socially optimal level of control, *OG*. And the net gain to the innovator is identical to that which occurs under the second version of the marketable permits method: cost savings *OAB* less the extra costs *BFGC*. Again, direct regulation provides inadequate incentives for innovation. And, again, the deficiency arises because of the inadequate reflection of the social gains from emissions reduction in the incentive structure of the polluter subject to direct regulation. It is worth noting that reactive regulation of this kind provides even less incentive for innovation than does the nonreactive regulation of Sections A and B.

6. Conclusions when marginal conditions change and ratcheting occurs. adjustments by pollution control authorities to changed marginal conditions does succeed in achieving the socially appropriate level of emissions control, if innovation does occur. But the various control methods have very different effects on the incentives for innovation when this ratcheting occurs. An effluent fee system provides excessive incentives for innovation, while the other methods provide varying degrees of inadequate incentives for innovation.

An additional comment on ratcheting is warranted. We have assumed that the innovator accurately forecasts the ratcheting that would occur but that only one

[14] If the polluter had to buy his permits from the control authority, then the reduction in outlay has the same effect on incentives as the effluent fee system.

[15] An interesting question is whether the polluter thinks of the permits as an asset with value. If so, then the innovation suffers a loss in asset value of *AHGC* less *FIJC*. But if ratcheting is always rapid and accurate—if the polluter is always going to receive exactly the "correct" number of permits, and he knows it—it appears better to treat this case as analogous to direct regulation.

level of innovation (represented by MC'_{ER}) is possible. Suppose instead that multiple levels of innovation (represented by successive clockwise rotations of MC'_{ER}) are possible, at successively higher initial investment costs, but the inovator still accurately forecasts the ratcheting that will occur. The socially appropriate criterion is that inovative effort should be extended until the extra investment costs involved in the extra innovation just equal the extra social benefits (which can be represented by the addition to area OAF as MC'_{ER} rotates clockwise). But, if the innovator anticipates the ratcheting, private decisions will not meet this criterion, and distortions similar to those discussed above occur. Under an effluent fee system, the innovator will anticipate the decrease in effluent fees that occurs on all inframarginal units and will include in his marginal calculations the elasticity of fee decreases (which are transfers) to innovative efforts; thus he will have an incentive to extend his innovative efforts too far. Similarly, under an emissions control subsidy system, the innovator would include in his marginal calculations the elasticity of subsidy reductions on inframarginal units (again, a transfer) to innovative efforts, and he will have an inadequate incentive to extend his innovative efforts to the socially optimal level.[16] And under the marketable permits and direct regulation systems, the innovator would include in his marginal calculations the elasticity of tighter controls (and their consequent costs) to innovative efforts; and, again, the innovator would have inadequate incentives to extend his innovative efforts to the socially optimal level.

We have assumed here that the control authority has perfect information about the benefits and costs of improving environmental quality and about the relationship betwen emissions and environmental quality. Furthermore, we have assumed that under ratcheting the authority reacts immediately to the new innovation and the source fully expects this reaction. In a real world situation, this perfection is unlikely to occur. Slow and imperfect reactions tend to increase the incentive of a source to innovate. We can use direct regulation as an example. The slower the authority is at ratcheting, the more distant is the additional control cost ($BFGC$). Therefore, some innovations which would not pay under instantaneous adjustment will pay with a slowly reacting authority. If less than the efficient level of control is chosen by the authority (below OG), then there is additional stimulus to inovation. There are equivalent arguments for other institutional forms.[17]

IV. CONCLUSIONS

The effects on innovation of the four methods of pollution control discussed in this paper, under the three reaction scenarios, are summarized in Table I. The

[16]If the governmental control authority could set a perfectly discriminating tax or subsidy schedule—i.e., one that tracked curve AF—the distortions would be eliminated, and the polluter would face the socially optimal incentives for innovation and control.

[17]Also, at least in the short-run, "technology-forcing" regultion may increase the incentive to innovate. If the control authority learns of an innovation that lowers marginal costs to MC'_{ER} and that has initial costs $X < OAF$, it simply tightens the emissions standard to GJ. The gains to the polluter *then* to adopt the innovation is in excess of $OALF$. But, in the long run, technology-forcing regulation reduces the incentives of the regulated firms to reveal information about innovation to the control authority (Kwerel, 1977), and, hence, the pace of innovation may be slowed. Also, many observers believe that, empirically, control authorities tend to overestimate the net benefits of innovation (i.e., exaggerate OAF) and underestimate the initial costs (X) (see White, 1981).

TABLE I

Incentives for Innovation under Various Pollution Control Arrangements

	Effluent fees	Subsidies	Marketable permits	Direct regulation
No change in marginal conditions:	Optimal	Optimal	Optimal	Deficient
Change in marginal conditions, no ratcheting:	Excessive	Excessive	Indeterminate	Deficient
Change in marginal conditions, ratcheting:	Excessive	Deficient	Deficient	Deficient

TABLE II

Emissions Levels under Various Pollution Control Arrangements

	Effluent fees	Subsidies	Marketable permits	Direct regulation
No change in marginal conditions:	Optimal	Optimal	Optimal	Too high
Change in marginal conditions, no ratcheting:	Too low	Too low	Indeterminate	Too high
Change in marginal conditions, ratcheting:	Optimal	Optimal	Optimal	Optimal

consequences for emissions control are summarized in Table II. Clearly, the details of any particular emissions and innovation problem would need to be known before one could be confident about the likely consequences for innovation of any of the control systems. It is worth noting, however, that an effluent fee system never provides inadequate incentives. If one believes that innovation is inadequate in our economy (because of positive externalities of knowledge creation that cannot be captured), this last point argues in favor of effluent fees over the other control methods.

We conclude by offering a few remarks on recent innovations in *regulatory policy* by the U.S. Environmental Protection Agency and their effects on innovation in *emissions control*:

A "bubble policy" allows a polluter who has multiple emissions sources of the same pollutant at a single geographic site to have a single regulatory standard on the aggregate of his emissions from the site, rather than having separate standards apply to each source. A bubble policy reduces somewhat the inadequate incentives for the innovation under direct regulation, since the polluter who can innovate at one emissions source can capture (through reduction in emissions control and the consequent reduction in costs at the other sources) more of the social gains than occurs if regulation is on a source-by-source basis. Thus, in addition to their favorable effects on static efficiency, bubble policies should be favored for their positive effects on innovation.

Offset policies allow new industrial producers, who may also be pollutant emitters, to establish themselves in geographic areas that are in violation of EPA's national ambient air quality standards, if they can induce a current polluter to reduce his emissions by more than the predicted emissions of the new establishment (Liroff, 1980). The offset policy thus creates a rudimentary market in tradable emissions rights. Accordingly, economic incentives for innovation come into play with respect to innovation.

A crucial question for offset policy is the implicit or explicit price for a unit of emissions reduction that is established in the market. If a price is established that is close to the value yielded by the intersection of the social marginal benefits and social marginal costs curves, the analysis applied to marketable permits would apply here (with the caveat that for innovations that affect marginal conditions—i.e., that change the market price—the incentives are comparable to those for effluent fees if the inovator is a net buyer of permits). If the market price is substantially above or below the socially appropriate level, the analysis would need to be modified appropriately.

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