JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT 3, 178–188 (1976)

# Uncertainty and the Choice of Pollution Control Instruments

ZVI ADAR

*Department of Economics, Tel Aviv University, Tel Aviv, Israel*

AND

JAMES M. GRIFFIN

*Department of Economics, University of Pennsylvania, Philadelphia, Pennsylvania 19174*

Received January 12, 1976

This paper compares the relative efficiencies of pollution taxes, pollution standards, and the auctioning of pollution rights when the marginal damage function or marginal control cost are subject to uncertainty. In the first case, we find that all instruments yield the same expected social surplus. In the latter case, the choice of the optimal instrument depends, in general, on the relative elasticities of the marginal damage and marginal expected cost functions, on the way in which uncertainty enters the model, and on the distribution of the error term. Policy conclusions are derived.

## I. INTRODUCTION

The choice between alternative pollution control instruments typically centers on comparisons of transaction costs, and administrative and policy costs.[1] While such cost comparisons are no doubt important, we question why the role of uncertainty is generally omitted in welfare calculations. Practitioners in the field of environmental quality recognize that uncertainty concerning the nature of the marginal damage function and the marginal control cost function are major stumbling blocks to selecting Pareto-efficient policies.[2] Perhaps the omission of uncertainty in the instrument choice discussion is due to an implicit assumption that uncertainty, while pervasive, is simply neutral to the instrument choice question. A notable exception is Lerner [6] who recognized that the relative slopes of the marginal damage and control cost functions should affect the choice between price and quantity controls.

As an extension to Lerner's conjecture, this paper delimits the circumstances under which uncertainty does and does not affect the choice between the following three policy instruments: taxes (a flat excise tax per unit of pollution); standards (quantitative controls on the amount of pollution generated by each source or firm[3]); and the Dale's proposal [3] for the auctioning of a fixed quantity of transferable pollution

[1] For example, see [3, 5].

[2] For an example concerning $SO_2$ taxes, see [4], where major uncertainty about the availability of flue-gas desulphurization is a problem.

[3] Note that throughout, we assume standards are set such that the marginal cost of abatement is equalized across firms, i.e., they are Pareto-efficient. Later, we return to this assumption.

rights. This paper shows that certain types of uncertainty can affect our choice between the three instruments while other types should not.

In order to delimit the circumstances under which uncertainty matters, it is necessary to distinguish the types and sources of uncertainty. Uncertainty permeates environmental policy-making in terms of the calculations of both marginal damages and marginal control costs. Uncertainty can manifest itself to the individual firm's decision makers and/or to the pollution control agency. At the firm level, uncertainty enters through the firm's marginal control cost function and through uncertainty induced by the control agency. Uncertainty concerning the firm's marginal cost function for pollution abatement is partially technology-induced as the control technology may be unproven or so new that future cost reductions due to potential scale economies, learning-curve phenomena, or technology diffusion rates are uncertain. In addition, uncertainty about future input prices introduces added uncertainty to the firm's marginal control cost function. As firms are well aware, the actions of the control agency can introduce an added source of disturbance. Examples include frequent changes in the pollution tax rate, changes in the pollution standards, or variations in the auction price for tickets.

Uncertainty at the level of the pollution control agency includes many of the same phenomena facing the firm, such as the uncertainty attached to the firm's marginal cost functions which in turn imparts uncertainty to the aggregate marginal control cost function facing the agency (society). Technologic and input price uncertainties prevail at either level of dissaggregation. While the agency is presumably free of the uncertainty it confers on the firm through policy changes, it faces two additional sources of uncertainty. First, even if the firm's marginal cost functions are known, the marginal control cost function facing the agency may not be known. Baumol [1] has considered these uncertainties and found them so pervasive that he favors policies which effectively disregard Pareto-efficiency criteria.[4]

A second and perhaps the most perplexing form of additional uncertainty is that the agencies have only vague ideas about the social marginal damage function. The standard errors attached to estimates of health and real estate costs of air pollution are indeed large. Thus a type of measurement uncertainty is connected with the marginal damage function owing to the difficulties of measuring social damage from pollution. Even with correctly measured marginal damage functions, a stochastic component would still enter through ambient air conditions which change continuously depending on climatic conditions. In the case of air pollution, factors varying daily, such as wind velocity and direction, affect the social damage of a given pollutant discharge.

In opposition to Baumol's policy advice, this paper posits that the purpose of policy in the face of uncertainty is to maximize expected welfare. In Section II, we begin by examining uncertainty at the level of the control agency. First, we contrast the expected welfare losses of all three policy instruments when uncertainty enters the marginal damage function. Second, we contrast the three instruments assuming the marginal control cost function is subject to uncertainty. These exercises reveal a fundamental asymmetry in the effects of uncertainty. In Section III, we consider how uncertainty combined with risk aversion by firms might change the previous results. Section IV explores differential uncertainty effects between standards and auctions. In Section V, we recapitulate the major policy implications.

[4] Also see [2].

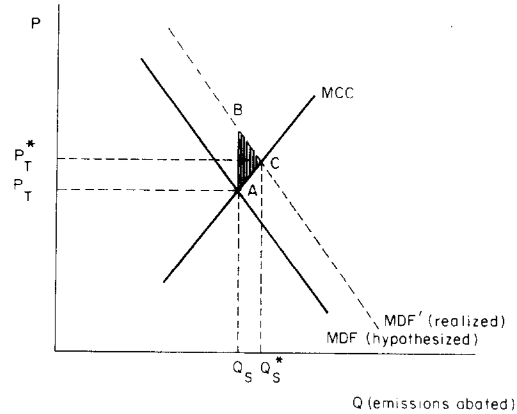


FIG. 1. Uncertain marginal damage function.

## II. UNCERTAINTY AT THE AGENCY LEVEL

This section illustrates that there is a basic asymmetry in the effects of uncertainty associated with the marginal damage function *vis-à-vis* the marginal control cost function on the choice between taxes, standards, and auctions. First, consider the case where the marginal control cost function (MCC) is known, and only the marginal damage function (MDF) is subject to uncertainty. In Fig. 1, we measure along the quantity axis, the pollution abated; corresponding to the origin of 0 reductions is the uncontrolled discharge of $Q_{max}$. Policies based on the hypothesized marginal damage function would result in a tax of $P_T$, the abatement of $Q_S$ units under a standards policy, or the auction of $Q_{max} - Q_S$ tickets. Due to uncertainty, the realized marginal damage function (MDF) deviated from the hypothesized MDF function in Fig. 1. Equivalent welfare losses will occur under a tax, standards, or an auction. With a tax policy, where the tax is set at $P_T$, emissions abated will only be $Q_S$ and the welfare loss from a tax is given by the shaded area *ABC*. Under a standards or auction policy, the emissions abated are again only $Q_S$, while the optimal reduction is $Q_S$*. Likewise, the welfare loss associated with these policies is the area *ABC*. Thus all three policies yield similar welfare losses. The explanation for this equivalency is that the quantities discharged, irrespective of the instrument, depend solely on the marginal control cost function, which is certain in this case, thereby resulting in identical quantities discharged, irrespective of the policy instrument. Thus the introduction of uncertainty in the damage function has nothing to say about the choice of policy instruments.

While intuition might suggest that similar results hold for the case in which the marginal control cost function is uncertain, this is not the case. Figure 2 illustrates a case in which the optimal tax, $P_T$, and the equivalent optimal quantity, $Q_S$, are assigned based upon the hypothesized shape of the marginal control cost function (MCC). However, the actual marginal control cost function turns out to be MCC′ as marginal costs are much higher than anticipated.

With a tax of $P_T$, only $Q'$ emissions were abated, even though at $Q'$ the marginal damage rate ($Q'B$) exceeds the marginal costs ($Q'A$). An optimal tax, $P_T$*, would have provided for emission abatement of $Q_S$* and would have avoided the welfare loss given by the shaded area (*ABC*).

With perfect hindsight, the optimal standard would have been $Q_S$*. The resulting welfare loss from a standards policy is given by the shaded area *CDE*. Similarly, since for an auction only $Q_{\max} - Q_S$ tickets would be auctioned, the level of pollution is reduced to $Q_S$ and the welfare loss is equivalent to that of a standards policy ($CDE$). As Fig. 2 illustrates for the case depicted, the welfare loss from a tax clearly exceeds the welfare loss for either a standards or auction policy. Therefore, we observe a fundamental asymmetry between uncertainty in the MDF, which leads to equivalent welfare losses, and uncertainty in the MCC curve which produces dichotomous results between taxes and quantitative restrictions (either in the form of an auction or standards). The explanation is that in the former case the MCC is known, thus price or quantitative controls are equivalent, while, with a stochastic marginal control cost functions, this uniqueness between prices and quantities no longer holds since quantity under a tax varies with shifts in MCC.

Clearly, the welfare loss, $CDE$ is not equal to the welfare loss $ABC$. In the case plotted in Fig. 2, the former is smaller, indicating the superiority of quantity restrictions. This, of course, is not a general result; the welfare loss from setting the tax $P_T$ can be approximated by the area of the triangle $ABE$ less the area $ACE$, and can be expressed by

$$WL_T - ACE = \tfrac{1}{2}\Delta P_T \Delta Q_T, \tag{1}$$

where

$$\Delta P_T = AB \quad \text{and} \quad \Delta Q_T = Q_S - Q'.$$

Substituting the elasticity ($e_d$) of the MDF curve, (1) can be also written as

$$WL_T - ACE = -(\tfrac{1}{2})(P/Q)(\Delta Q_T)^2(1/e_d). \tag{2}$$

The welfare loss associated with a quantitative restriction can be viewed graphically in Fig. 2 as the triangle $ADE$ less the area $ACE$. The new welfare loss can be approximated as

$$WL_q - ACE = \tfrac{1}{2}\Delta P_S \Delta Q_S, \quad \text{where} \quad \Delta P_S = DE \quad \text{and} \quad \Delta Q_S = Q_S - Q'. \tag{3}$$

Equation (3) can be restated in terms of price, quantity, and the elasticity of the control cost function ($e_c$).

$$WL_q - ACE = (\tfrac{1}{2})(P/Q)(\Delta Q_s)^2(1/e_c). \tag{4}$$

Combining Eqs. (2) and (4), and using the fact that $\Delta Q_s = \Delta Q_T$, yields

$$WL_T - WL_q = -(\tfrac{1}{2})(P/Q)(\Delta Q)^2[(1/e_d) + (1/e_c)]. \tag{5}$$

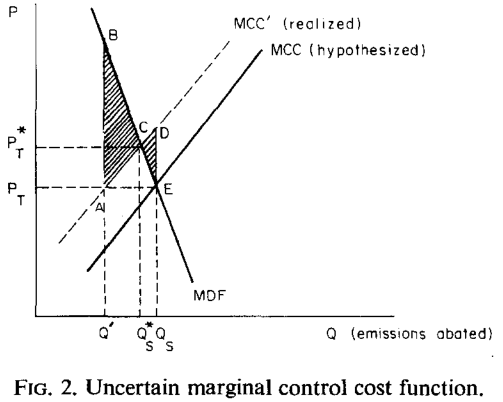


FIG. 2. Uncertain marginal control cost function.

Equation (5) suggests that tax and standards policies will have identical welfare loss properties only when (a) the damage and control cost elasticities are equal in absolute value, or (b) $\Delta Q = 0$, i.e., actual equals the hypothesized marginal control cost function implying zero welfare losses. An important implication of (5) is that standards are preferable when $e_d$ approaches zero and a tax policy is preferable when $e_c$ approaches zero, *ceteris paribus*.

This result suggests a fundamental asymmetry between the uncertainty in the damage function and in the control cost function on the relative effectiveness of tax, standards, and auction policies of abating pollution. When MDF deviates from its hypothesized value, all policies will generate the same deadweight loss. With (vertical) variations in MCC, we should expect welfare losses which depend on the slopes, or elasticities of the MDF and MCC curves. The marginal control cost function forms a behavioral relation for the firm under a tax. If MCC is known, taxes and quantitative instruments yield equivalent reductions in pollution, irrespective of movements in the marginal damage function. In contrast, the actual, as opposed to the hypothesized, marginal damage function, evinces no quantitative response irrespective of the instrument. Thus variations in MDF produce no dichotomy between price (tax) and quantitative (standards or auction) policies.

This asymmetry between uncertainty in the damage and control cost functions carries over to the problem of selecting the optimal policy instrument as well as the level of control under uncertainty.

First, consider the case where MDF is random, and the goal of the agency is to maximize *expected* welfare (i.e., minimizing the expected area *ABC* in Fig. 2).

Let MDF be given by the relationship

$$\mathrm{MDF}(q, u), \tag{6}$$

where $q$ is the quantity abated and $u$ is a random variable with known density $dF(u)$. By assumption, MCC is a known function depending only on the level of abatement

$$\mathrm{MCC}(q), \tag{7}$$

with quantitative restrictions of either a standards or auction type. An agency attempting to maximize the expected welfare gain will set $Q_S$ such that expected consumers' and producers' surplus is maximized as follows.

$$\mathop{\mathrm{E}}_{u} \int_0^{Q_s} [\mathrm{MDF}(q, u) - \mathrm{MCC}(q)]dq. \tag{8}$$

Under a tax policy, the agency will again set a tax, $P$, so as to maximize the expected consumers' and producers' surplus

$$\mathop{\mathrm{E}}_{u} \int_0^{Q_s(P)} [\mathrm{MDF}(q, u) - \mathrm{MCC}(q)]dq. \tag{9}$$

Since $Q_s(P)$ is the single valued relation $Q_s = \mathrm{MCC}^{-1}(P)$, which is known with certainty, maximizing (8) with respect to $Q$ is equivalent to maximizing (9) with respect to $P_T$. The optimal quantity corresponding to $P^*$ (i.e., $Q_S{}^*$ or $Q_s(P^*)$] is given by the first-order condition

$$\mathrm{E}\,\mathrm{MDF}(Q_S{}^*, u) = \mathrm{MCC}(Q_S{}^*). \tag{10}$$

The second-order condition invariably holds since we assume a negatively sloped MDF curve and a positively sloped MCC. Substituting optimal $Q_s^*$ into (8) we can find the value of the maximized expected welfare gain. In the linear case with an additive error term shown in Fig. 2, where

$$\text{MDF} = a - bq + u, \tag{11}$$

where $\text{E}(u) = 0$ and

$$\text{MCC} = \alpha + \beta q_s. \tag{12}$$

Note that (10) reduces to

$$Q_s^* = (a - \alpha)/(b + \beta) \quad \text{and} \quad P^* = \alpha + \beta(a - \alpha)/(b + \beta). \tag{13}$$

The expected welfare gain (EWG) depends only on the parameters $a$, $\alpha$, $b$, and $\beta$, and is independent of the distribution of $u$.

$$\text{EWG} = \frac{1}{2}\frac{(a - \alpha)^2}{(b + \beta)}. \tag{14}$$

We conclude that when MDF is uncertain and the agency is risk neutral, expected MDF should be used in the selection of optimal control levels. Moreover, taxes, standards, and auctions have the same resulting performance.[5]

Next, consider the case where MDF is known with certainty, but MCC is subject to a stochastic disturbance as given by

$$\text{MCC}(q, u), \tag{15}$$

where again $u$ has known density of $dF(u)$. With quantitative controls, we obtain results similar to the previous case. Maximizing with respect to $Q_s$ the expectation

$$\underset{u}{\text{E}} \int_0^{Q_s} [\text{MDF}(q) - \text{MCC}(q, u)]dq = \underset{u}{\text{E}}\,(\tilde{z}), \tag{16}$$

we conclude that the risk neutral agency should again select $Q_s^*$ to satisfy

$$\text{E}[\text{MDF}(Q_s^*) - \text{MCC}(Q_s^*, u)] = 0, \tag{17}$$

i.e., that $Q_s^*$ where MDF equals expected MCC. This result is independent of $dF(u)$ and of the particular form of uncertainty in MCC.

When a tax policy is used, the quantity of pollution abated with a given tax rate $P_{\text{T}}$ is a random variable

$$\tilde{Q}_s = \text{MCC}^{-1}(P_{\text{T}}, u). \tag{18}$$

Writing the expression for expected welfare gain

$$\text{EWG} = \underset{u}{\text{E}} \int_0^{\text{MCC}^{-1}(P_{\text{T}},\, u)} [\text{MDF}(q) - \text{MCC}(q, u)]dq, \tag{19}$$

we realize that this source of uncertainty compounds the uncertainty of producer surplus for a given $Q_s$, and that in general the frequency distribution of $u$ and the form in which it enters MCC will affect both the optimal tax, $P_{\text{T}}^*$, and the expected welfare gain, EWG. To illustrate this conclusion, consider first the generalization of Fig. 3, which depicts a linear MDF and MCC, and $u$ enters MCC additively. While an additive

[5] This is not to say they are equivalent in other respects.

stochastic error term facilitates the exposition, it has considerable economic content since factor price variations in inputs subject to a Leontief production technology would produce additive errors. Specifically, we assume

$$\text{MCC} = \alpha + \beta Q_s + u, \qquad \text{E}(u) = 0. \tag{20}$$

Optimal $P_{\text{T}}$ can be derived by solving

$$\frac{d}{dP}\mathop{\text{E}}_{u}\int_0^{\tilde{Q}(P)} [(a - bq) - (\alpha + \beta q + u)]dq = \frac{d}{dP}\mathop{\text{E}}_{u}(\tilde{\tilde{z}}) = 0, \tag{21}$$

where

$$\tilde{Q}(P) = (1/\beta)[P - \alpha - u]. \tag{22}$$

Differentiating, and substituting (22) into (21) we find the optimum condition to be

$$(P^* - \alpha)/\beta = \mathop{\text{E}}_{u}\tilde{Q}(P^*, u) = (a - \alpha)/(b + \beta), \tag{23}$$

which means that $P^*$ should be selected such that MDF equals *expected* MCC at the optimal level of abatement. Note the similarity to our general result for quantity (i.e., standards/auction) setting policy, but note also a difference: substituting into (16) an MCC with an additive error term, the expected welfare gain for the optimal standards or auction policy is

$$\text{E}(\tilde{z}) = \frac{1}{2}\frac{(a - \alpha)^2}{b + \beta}. \tag{24}$$

Substituting (23) into the expectation in (21), we find that with a tax policy, the expected welfare gain for a tax $[\text{E}(\tilde{\tilde{z}})]$ is

$$\begin{aligned}\text{E}(\tilde{\tilde{z}}) &= (a - \alpha)\mathop{\text{E}}_{u}\tilde{Q} - \left(\frac{b + \beta}{2}\right)\mathop{\text{E}}_{u}\tilde{Q}^2 - \mathop{\text{E}}_{u}u\tilde{Q}, \\ &= \frac{1}{2}\frac{(a - \alpha)^2}{(b + \beta)} - \frac{b - \beta}{2\beta^2}\mathop{\text{E}}_{u}u^2,\end{aligned} \tag{25}$$

and since $\mathop{\text{E}}_{u}\tilde{Q}(P^*, u)$ for the tax policy equals $Q^*$ for the standards policy,

$$\text{E}(\tilde{z}) - \text{E}(\tilde{\tilde{z}}) = \text{E}\,u^2[(b - \beta)/2\beta^2]. \tag{26}$$

This is a generalization of the result in (5). It indicates that when the slope of the expected MCC is steeper than MDF, a tax policy is preferred to quantity restrictions, and vice versa. Note that for given MCC and MDF, the difference in performance between the two policies is proportional to the variance of $u$,[6] but the choice of optimal policy is independent of it.

A multiplicative disturbance term in the marginal control cost function is interesting to contemplate since, like a heteroscedastic error term, its variance increases with marginal costs. This is not unrealistic as technology for high cost, low abatement technology is no doubt subject to greater uncertainty. When MCC contains a multi-

[6] If MCC were nonlinear, it would depend on higher moments of $dF(u)$ as well.

plicative error term, i.e.,

$$\begin{aligned} \tilde{MCC} &= (\alpha + \beta q)u, \qquad E(u) = 1, \\ \tilde{C}(q) &= \alpha uq + \tfrac{1}{2}(\beta u)^2 q^2, \end{aligned} \tag{27}$$

our conclusions change. The expected welfare gain of standards or an auction is

$$\mathop{E}_{u}(\tilde{z}) = \mathop{E}_{u} \int_0^Q [(a - bq) - (\alpha + \beta q)u]dq, \tag{28}$$

and maximizing $\mathop{E}_{u}(\tilde{z})$ with respect to $Q$ still yields the familiar first-order condition

$$Q_s^* = (a - \alpha)/(b + \beta). \tag{29}$$

Again, the quantity should be selected where MDF equals *expected* MCC.

However, when a tax policy is used, this result should be modified. Differentiating (28) with respect to $P$ where the upper bound of the integral is

$$\tilde{\tilde{Q}}(P, u) = (P - u\alpha)/u\beta \tag{30}$$

yields the first-order condition

$$\mathop{E}_{u}[(a/u) - \alpha] = \mathop{E}_{u}\{\tilde{Q}(P, u)[(b/u) + \beta]\}, \tag{31}$$

or

$$\mathop{E}_{u} \frac{\partial Q}{\partial P} \mathrm{MDF}(Q) = \mathop{E}_{u} \frac{\partial Q}{\partial P} \mathrm{MCC}(\tilde{Q}, u), \tag{32}$$

which is different, of course, from the quantity conditions. Nevertheless, we can still maintain that the economic meaning of the optimal condition is equating *expected* marginal damage to *expected* marginal cost, but in this case, with respect to price rather than quantity.

In a manner similar to the additive case, we can now compare the maximized expected welfare gain under a tax policy and a standards/auction policy. Not surprisingly, the result depends again on parameters of MCC and MDF,

$$\mathop{E}_{u}(\tilde{\tilde{z}}) - \mathop{E}_{u}(\tilde{z}) = \frac{a\beta + \alpha b}{2\beta}\left[\mathop{E}_{u}\tilde{Q} - \frac{a - \alpha}{b + \beta}\right] = \frac{a\beta + \alpha b}{2\beta}[\mathop{E}_{u}\tilde{Q} - Q^*], \tag{33}$$

where $E_u\tilde{Q}$ is expected quantity abated under the optimal tax, and $Q^*$ is the optimal quantity abated under a standards/auction scheme. Since $\tilde{Q} = (P - \alpha u)/\beta u$, the choice of optimal policy depends on $dF(u)$.

We conclude that when MCC is random, the effects of taxes and quantity controls of pollution will differ, and that the choice of the optimal instrument depends on (a) the parameters of MDF and *expected* MCC, (b) the particular way in which the random element $u$ enters the MCC, and (c) the frequency distribution of $u$.

Admittedly, the difference in the expected welfare gains is more cumbersome to calculate for policy analysis than the simple case where the disturbance is additive and we need only measure the relative elasticities, or slopes and the variance of $u$. Nevertheless, we believe such calculations are possible and instructive. Policy analysts definitely have some knowledge about the parameters of MDF and MCC [point (a)], since this is presumably the basis for current decision making. By the types of economic rationales offered here for additive and multiplicative disturbance terms, we feel that policy analysts can distinguish the types of uncertainty [point (b)] most relevant to the case at hand. Finally, as for the frequency distribution of $u$ [point (c)], our suggestion is simply to test for sensitivity using several alternative distributions as the policy implications may turn out to be quite robust with respect to distributional changes in $u$.

## III. UNCERTAINTY AT THE FIRM LEVEL AND RISK AVERSION

The results of the previous section hold for cases in which (1) uncertainty exists only at the agency level or (2) uncertainty exists both at the agency and firm level and firms are risk neutral. The first situation is obvious, but the second involves the critical question of whether the expected marginal control cost function evinces a behavioral relationship as well as the social costs of abatement. Throughout this paper, we treat the private and social costs of abatement as equivalent. If the expected MCC does in fact measure private abatement costs, we will face the question of whether it describes a behavioral relation. For the risk neutral firm, it is well known that decisions are based on expected marginal costs. Therefore, under risk neutrality, the expected marginal control cost curve facing the agency is nothing more than the summation of firms' expected marginal cost functions for abatement.

For the risk averse firm, the agency's expected marginal control cost curve describes the relevant expected social costs; however, it does not represent a behavioral relationship. The introduction of risk aversion in firm behavior complicates our results and adds another interesting asymmetry. We introduce risk aversion in the firm's behavior by hypothesizing that firms behave as if they possess a well-behaved utility of profits function, $U(\pi)$ with $U'(\pi) > 0$, $U''(\pi) < 0$, and act to maximize the mathematical expectation of utility.[7] Thus, when the firm knows only the frequency distribution of $P_{\mathrm{T}}$ when making its pollution decision it is assumed to maximize with respect to $Q$ the following expected utility of profits:

$$\mathop{\mathrm{E}}_{\tilde{P}_{\mathrm{T}}} U[\tilde{P}_{\mathrm{T}}Q - C(Q)]. \tag{34}$$

When $P_{\mathrm{T}}$ is certain but $C(Q)$ is uncertain, we replace $C(Q)$ by the random cost relationship $C(Q, u)$. The firm maximizes

$$\mathop{\mathrm{E}}_{u} U[P_{\mathrm{T}}Q - C(Q, u)]. \tag{35}$$

Analysis of the first- and second-order conditions of these maximization problems usually reveals that the firm will not operate where its expected marginal cost equals the expected price as we established for the risk neutral firm.

When $P_{\mathrm{T}}$ is uncertain, Sandmo has shown that the firm will produce the output, where $\bar{P}_{\mathrm{T}} > C'(Q)$. In a similar manner, when marginal costs are stochastic, the first-order condition

$$\mathrm{E}U'(\tilde{\pi})[P_{\mathrm{T}} - C'(Q, u)] = 0, \qquad \tilde{\pi} = P_{\mathrm{T}}Q - C(Q, u), \tag{36}$$

implies that under risk aversion,

$$P_{\mathrm{T}} > \mathop{\mathrm{E}}_{u} C'(Q, u). \tag{37}$$

[7] See [7] for a model of the competitive firm facing an uncertain price. This assumption has been widely used in other studies of the economics of the firm under uncertainty.

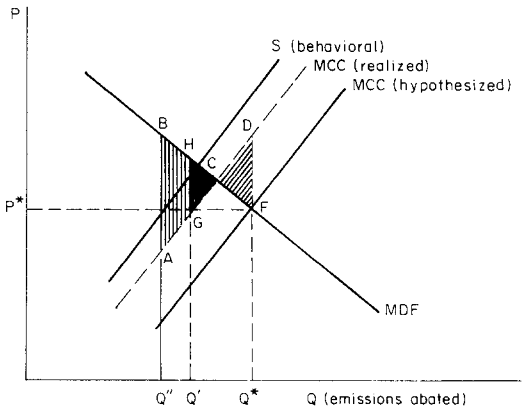


FIG. 3. Uncertain marginal control costs and risk aversion.

As a consequence of the fact that $P > C'(Q, u)$ and $\bar{P} > C'(Q)$, we can no longer use the expected MCC curve to evaluate both the social cost of pollution abatement and to determine the supply response of the polluting firm to a given policy.

For example, in Fig. 3, MDF and the expected MCC curve still have the same normative meaning as in Section II above, but now we represent the firm's behavior by the "supply" curve $S$. In order to maximize the expected welfare, the agency concludes that price $P^*$ and quantity $Q^*$ are optimal. Following the exposition in Fig. 2, we assume that the actual MCC differs from the expected MCC. Under risk neutrality, the tax $P^*$ would have resulted in the abatement of $Q'$ with welfare loss of $CHG$; however, risk aversion lead to a reduction of $Q''$ and a welfare loss of $ABC$. Note however, that the quantitative restriction (either standards or an auction) resulted in a loss of $CDF$, the same loss as under risk neutrality. In sum, the asymmetry between taxes and quantitative restrictions for uncertain MCC still holds. The expected welfare loss in Eq. (26) between taxes and quantitative standards would, however, need to be altered for the effects of risk aversion.

## IV. SOME CAVEATS AND ADDITIONAL INSIGHTS

Up until now the careful reader might ask why the analysis has been concluded in terms of three policy instruments when the affects of uncertainty have so far fallen into two dichotomous groups—price controls (taxes) and quantity controls (standards and auctions). The answer is that despite the above, standards and auctions are not identical with respect to uncertainty. One of the primary motivations for auctions in place of standards is that they reduce the information requirements of the agency since for standards to be applied efficiently, the agency must know the individual firm's expected marginal cost function for abatement. Obviously, the auction reveals this information in a much cheaper manner to the agency. As a consequence, the auction avoids the uncertainty attendant to the more complex informational requirements of standards.

While auctions have less informational uncertainty attached to them than standards, it is conceivable that under certain conditions some offsetting welfare effects may exist. In the case where the sole source of uncertainty is being induced by the auction via large price variation, the expected auction price will lie above the expected marginal control costs for the risk averse firms. If the difference between the auction price and marginal control costs (a type of risk premium) is merely a pecuniary payment to risk, then expected MCC continues to measure expected social abatement costs and the auction generates no attendant welfare loss. However, if the firm expends real resources to avoid this risk premium,[8] then social costs may be increased in an auction relative to more certain government policies such as taxes or standards. We feel that in most cases the welfare effects induced by the auction's uncertain price are likely to be small relative to the greater informational uncertainty attached to standards. On the other hand, the welfare effects of large variations in the auction price would appear to offer some explanation for why auctions could not replace standards on offshore oil production, nuclear reactor design, and other cases where the price for tickets might be subject to large variations.

## V. SUMMARY AND POLICY IMPLICATIONS

This paper reaches the following three major conclusions regarding differential welfare effects between taxes, standards, and auctions.

(1) Uncertainty in the marginal damage function has absolutely no effect on the choice between the three policy instruments.

(2) Uncertainty in the marginal control cost function will yield different expected welfare losses between taxes or quantitative restrictions (standards or auctions) depending on the variance of the stochastic error term and the slopes or elasticities of the MDF and MCC functions.

(3) Even under risk aversion, this asymmetry still holds, however, now the welfare loss also depends on the degree of risk aversion.

In conclusion, in situations of uncertain marginal control costs where the marginal damage function tends to be very price elastic, such as believed to occur for $SO_2$ emissions, a strong case can be made for taxes. On the other hand, where the marginal damage function is very inelastic, quantitative restrictions of an auction or standards type appear desirable.

In cases where quantity restrictions are appropriate, auctions and standards are not equivalent. Unlike auctions, standards introduce added informational uncertainty, which seems likely to dominate possible welfare losses due to wide variations in the auction price.

## REFERENCES

1. W. J. Baumol, On taxation and the control of externalities, *Amer. Econ. Rev.* **62**, 307–322 (1972).
2. W. J. Baumol and W. E. Oates, The use of standards and pricing for protection of the environment, *Swed. J. Econ.* **73**, 42–54 (1971).
3. J. H. Dales, "Pollution, Property and Prices," Univ. of Tronto Press, Toronto (1968).
4. J. M. Griffin, An econometric evaluation of sulphur taxes, *J. Polit. Econ.* **82**, 669–688 (1974).
5. A. V. Kneese and B. T. Bower, "Managing Water Quality: Economics, Technology, Institutions," Johns Hopkins Press, Baltimore (1968).
6. Abba P. Lerner, The 1971 report of the President's Council of Economic Advisers: Priorities and efficiency, *Amer. Econ. Rev.* **61**, 527–530 (1971).
7. Agnar Sandmo, On the theory of the competitive firm under price uncertainty, *Amer. Econ. Rev.* **61**, 65–73 (1971).

[8] For example, to avoid the losses associated with wide variations in ticket prices, the firm might install more flexible abatement equipment providing a flatter short-run cost function over a wider range. Such a technology may not, however, be of least cost at the abatement level corresponding to the standard.