

On the Superiority of Corrective Taxes to Quantity Regulation

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The traditional view of economists has been that corrective taxes are superior to direct regulation of harmful externalities when the state's information about control costs is incomplete. In recent years, however, many economists seem to have adopted a different view—that either corrective taxes or quantity regulation could be superior to the other. We emphasize that one argument for this newer view, identified with Weitzman (1974), holds only if the state is constrained to use a fixed tax rate (a linear tax schedule) even when harm is nonlinear. But if—as seems more plausible—the state can impose a nonlinear tax equal to the schedule of harm or can adjust the tax rate upon learning that it diverges from marginal harm, then corrective taxes are superior to quantity regulation. Another argument favoring quantity regulation is that it gains appeal when the state is uncertain about the harm caused by an externality. In this case, however, a corrective tax schedule (equal to the expected harm schedule) is superior to quantity regulation.

The consensus view of economists used to be that corrective taxes are superior to quantity regulation as a means of controlling harmful externalities. However, this belief has changed in recent years. Due in large part to the influence of Weitzman (1974) and Baumol and Oates (1971, 1988)

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economists now commonly state that either instrument, corrective taxes or quantity regulation, could be superior to the other. This newer view is presented in textbooks and surveys on environmental economics (Bohm and Russel, 1985; Cropper and Oates, 1992; Pearce and Turner, 1990; Tietenberg, 1996) as well as in general undergraduate textbooks (Pindyck and Rubinfeld, 1995; Rosen, 1992).

Our purpose here is to explain why, in fact, the traditional notion of the superiority of corrective taxes should continue to be a benchmark for economists' thinking about the control of externalities. Our discussion and analysis involve to a substantial extent an assessment of the relevance of different models and the plausibility of their assumptions rather than derivation of new theoretical results.¹

We first consider the standard context of a single externality-producing firm and review the conventional argument that corrective taxes are superior to quantity regulation. We observe that the contrary claim in Weitzman (1974) and related literature depends entirely upon the assumption that the corrective tax is constrained to be fixed and linear even when harm is nonlinear. The rationale for this restriction on taxes, though, is not evident, and we suggest that it is generally inappropriate. We next consider the idea that quantity regulation may be desirable when the state is uncertain about the magnitude of harm. We show that corrective taxes (equal to expected harm) remain superior to quantity regulation even when harm is uncertain.

We also examine the choice between corrective taxes and quantity regulation (and permit schemes) in situations in which multiple firms jointly create an externality. Although our discussion of this case relies in part on informal judgments, it suggests that corrective taxes (and modified permit schemes) possess the same basic advantage over quantity regulation as in the single-firm case: they harness firms' information about control costs, making possible a result in which the level of the externality is optimal (or more nearly so).

1. Our emphasis on the advantages of nonlinear taxes is in the spirit of Roberts and Spence (1976).

1. Single Firm: Control Costs Unknown to the State

1.1. The Traditional View of the Superiority of Corrective Taxes

We begin with the classic problem of a harmful externality generated by a single firm. In this case, we make the usual assumption that the schedule of harm as a function of the level of the externality is known to the state, whereas the firm's control cost schedule is known only to the firm.² We also presume that the marginal harm schedule rises with the level of the externality. This is illustrated in Figure 1, where e is the level of the externality, $MH(e)$ is the marginal harm schedule, and $MC_H(e)$ and $MC_L(e)$ are two possible marginal control cost schedules.

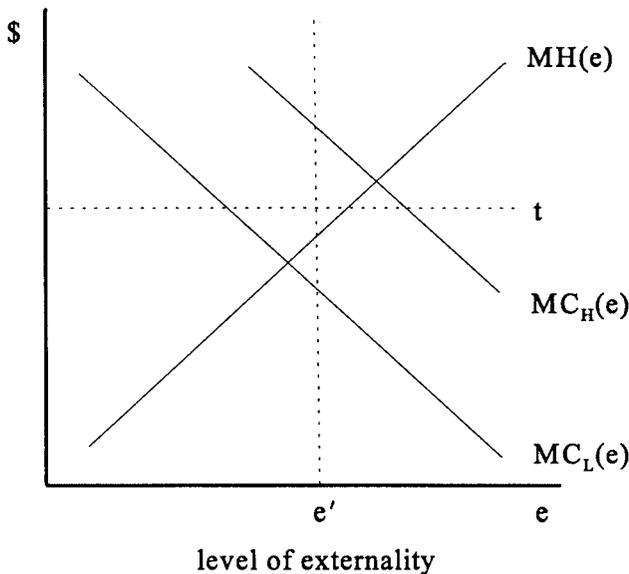


Figure 1. Regulating externalities when control costs are unknown.

The traditional view of externalities and corrective taxes, due to Pigou (1932), is that imposing a tax equal to the magnitude of the harm caused by the externality will induce efficient behavior because, under such a

2. Control costs should be interpreted as including not only direct expenditures made to abate the level of the externality, but also forgone profits from reduction of output. (In some literature on externalities, the control cost schedule is referred to as the benefit schedule because firms benefit from not having to control pollution.)

scheme, the firm will bear the full social cost of its behavior. In the present context, this means that the state should set the corrective tax schedule equal to the harm schedule. In other words, the marginal tax rate should equal $MH(e)$. Then, the first-best outcome will always be achieved. The reason is that the firm will choose the level of externality where its marginal control cost—whether $MC_H(e)$ or $MC_L(e)$ —equals the marginal tax rate, which by construction equals the marginal harm.³

However, the first-best outcome generally will not result under quantity regulation. Under quantity regulation, the state announces a limit on the level of the externality, say, e' .⁴ But because the control cost schedule is not known to the state, it cannot calculate the optimal level of the externality for the firm, and it typically will make a suboptimal choice. For example, if the marginal control cost schedule is $MC_H(e)$, e' will be suboptimal because the marginal control cost will exceed the marginal harm.

The reason that the corrective tax is superior to quantity regulation is evident. The corrective tax effectively harnesses the firm's information about its control costs. Although the firm does not directly reveal its information about control costs under the corrective tax, it does choose the level of the externality at which its actual marginal control cost equals the marginal tax rate, which in turn equals the marginal harm, and thus it behaves optimally.

1.2. The Weitzman Argument that Quantity Regulation May Be Superior to Corrective Taxes

In Weitzman (1974) and related literature, it is assumed that, when the state employs a corrective tax, it must use a linear tax schedule—a

3. This straightforward point about how to internalize externalities underlies Roberts and Spence's (1976) demonstration that schemes which mix linear taxes and quantity regulation are superior to either alone.

4. Quantity regulation as described in the text can be viewed as a special case of a more general regulatory scheme under which the state offers the firm a menu of different quantity levels, each having an associated fee. (The quantity regulation scheme in the text may be interpreted as a menu such that the fee for any quantity less than or equal to e' is zero and that for any greater quantity is infinite.) Such schemes would allow for any relationship whatever to hold between the level of the externality and the firm's payment to the state, which, of course, is just what is allowed under nonlinear corrective taxes. In this article, however, we will follow convention by limiting the term "quantity regulation" to the state's setting a specific quantity that cannot be exceeded.

fixed tax rate—even though harm may be nonlinear, in which case the optimal corrective tax, equal to harm, is nonlinear.⁵ In general, a linear tax schedule leads to a suboptimal result. For example, suppose that the state chooses the tax rate t (see Figure 1) and the control costs are $MC_H(e)$. Then, the marginal harm exceeds the marginal control cost at the level of the externality chosen by the firm.

Because the use of linear corrective taxes, like the use of quantity regulation, involves error, either corrective taxes or quantity regulation may be superior. As shown by Weitzman (1974) and others, under certain conditions, corrective taxes are superior when marginal control cost schedules are steeper than the marginal harm schedule, and quantity regulation is superior in the converse case.

Somewhat surprisingly, the assumption that taxes must be linear either is only casually motivated or is not even mentioned in the relevant literature.⁶ Moreover, imposing nonlinear corrective taxes seems straightforward. All that the state has to do is announce its nonlinear tax schedule, and all that the firm has to do is compute its taxes from the schedule (or read its taxes from a table, as taxpayers actually do with our nonlinear personal income tax). Thus, the state should be able to achieve the first-best outcome with corrective taxes.

We also note that the state needs less information to impose the optimal nonlinear corrective tax than it needs to implement either a linear tax or quantity regulation. To determine the nonlinear tax schedule, the state needs to know only the harm schedule. (We discuss below the situation in which the state does not know the harm schedule, in which case the state needs to know only the expected harm schedule.) In contrast, to determine the optimal linear tax or the optimal quantity—even though each is just a single number—the state must know more: not only the harm schedule, but also the distribution of possible marginal control cost schedules. In

5. Results similar to Weitzman's were developed by Adar and Griffin (1976), Fishelson (1976), Roberts and Spence (1976), and Rose-Ackerman (1973).

6. For example, Weitzman (1974, p. 481) briefly justifies limiting his analysis to linear prices on the ground that they are "simple messages, easily comprehended, traditionally employed, and frequently contrasted." Myles's (1995) graduate text refers to the "considerable administrative difficulties" of a nonlinear scheme but does not identify them. Cropper and Oates's (1992) survey presents Weitzman's argument without mentioning the assumed restrictions on the state.

addition, the state must make calculations to determine the (second-best) optimal linear tax rate or quantity level.

Finally, suppose that for some reason the state is constrained to choose between using a linear tax and quantity regulation. In such a case, we note, a linear tax may be more attractive than has been suggested by our discussion thus far. Realistically, firms usually cause externalities over time. When the state collects taxes from a firm, the state learns the level of the externality and thus can make inferences about the firm's marginal cost schedule. Using this information, the state can adjust the tax rate, allowing a higher level of welfare to be achieved.⁷

1.3. Criticisms of Corrective Taxes when Conditions Change

It has been suggested that changes in control costs or in harm pose problems for corrective taxes. See, for example, Butler and Maher (1982) and Rose-Ackerman (1973). If control costs change, however, a preexisting optimal nonlinear tax would automatically produce an optimum: the firm would choose a different but efficient level of the externality because the firm would continue to equate its (now different) marginal control cost to the marginal harm. We note, by contrast, that under quantity regulation the permitted level of the externality would have to be altered when control costs change.

If the harm schedule changes, a new tax schedule equal to the new harm schedule would produce the optimum. Note that the state would also have to change the allowed level of the externality under quantity regulation.

In the latter case of changes in the harm schedule, the state would wish to adjust taxes immediately, yet this may not always be possible. Some take the potential difficulty of adjusting taxes quickly to be an argument favoring quantity regulation. Weitzman (1974) and Baumol and Oates (1988), for example, cite emergencies as prototypical situations in which rapid adjustment of taxes might be impractical, and thus in which quantity regulation may constitute a superior approach. But rapid adjustment of quantities also will be difficult in emergencies. If there is, say,

7. The firm will behave strategically, anticipating the effect of its choice of e on the level of the tax, and the state's optimal adjustment strategy should take this into account. Accordingly, it will not generally be possible to achieve the first-best outcome, as can be done with a nonlinear tax.

a sudden atmospheric inversion that makes emissions unusually harmful on a particular day, it is not clear why instructing firms to reduce their emissions by a given amount could be done more quickly than informing firms of a higher tax on emissions.

2. Single Firm: Harm and Control Costs Unknown to the State

The superiority of corrective taxes to quantity regulation has also been questioned on account of the state's having only imperfect information about the harm caused by an externality. If the harm schedule associated with an externality is uncertain, the state cannot set the tax schedule equal to the schedule of actual harm. Therefore, it is often suggested that quantity regulation gains appeal, a view with which Baumol and Oates (1971, 1988) are associated.⁸ We surmise that another motivation for this view (which seems to be part of our folklore) is that quantity regulation provides better protection against the risk of a large harm.

However, the notion that uncertainty about harm somehow favors quantity regulation is mistaken. The basic logic favoring corrective taxes—that they harness a firm's information about its control costs—remains true when the schedule of harm (as well as the control cost schedule) is unknown to the state. In this case, the corrective tax schedule should equal the *expected* harm schedule. Of course, the outcome under corrective taxes can no longer be first best: if marginal harm is in fact greater than its expected value, the level of the externality will be too high, and conversely if marginal harm is lower than its expected value. A corrective tax equal to expected harm is, however, second best (that is, best given that harm is uncertain), and it is superior to quantity regulation.

To demonstrate that a corrective tax equal to expected harm is second best, consider the following standard formulation of the state's planning

8. Baumol and Oates generally advocate achieving a target quantity of pollution. (In reaching the quantity target, they favor permit schemes or iterated linear taxes in the multiple firm setting rather than command and control regulation.) Their primary motivation for aiming at quantity targets is that it would be difficult to measure harm at different levels of emissions, that is, uncertainty over harm. They do not, however, consider the possibility of setting taxes equal to expected harm.

problem.⁹ The state knows that the harm caused by the externality is given by the function $h(e, \eta)$, which depends upon the level of the externality, e , and an unobservable parameter η , which has density $f(\eta)$. The level of the externality, $e(x, \theta)$, depends upon a firm's expenditures to control the externality, x , and a parameter θ , which has density $g(\theta)$; θ might correspond to the efficiency of expenditures x in reducing the level of the externality. The firm observes θ before it chooses x , but the state does not observe θ .

The state chooses a tax schedule $t(e)$ that may depend only on the level of the externality, because the state cannot observe η or θ . Given the tax schedule, the firm selects x to minimize its total costs (control cost plus tax obligation),

$$x + t(e(x, \theta)). \quad (1)$$

Thus, the firm's choice, denoted $x(\theta, t)$, is a function of θ and the tax schedule t . The state will select the tax schedule t to minimize expected social costs (the sum of control costs and harm),

$$\int [x(\theta, t) + \int h(e, \eta) f(\eta) d\eta] g(\theta) d\theta, \quad (2)$$

where the state takes into account that e depends on θ and on x (which the firm is known to choose after it observes θ).

Clearly, the state can do no better than could a benevolent dictator who observes θ and then commands the firm to choose an x . Since such a dictator knows θ , he would choose x to minimize

$$x + \int h(e(x, \theta), \eta) f(\eta) d\eta, \quad (3)$$

the sum of the control cost and the expected harm. But the state (without knowing θ) can induce the firm to choose this same x . The state can do so by setting the corrective tax schedule $t(e)$ equal to the expected harm schedule:

$$t(e) = \int h(e, \eta) f(\eta) d\eta. \quad (4)$$

9. Kaplow and Shavell (1996) establish essentially the same result in demonstrating that the optimal liability rule when harm is uncertain is one under which injurers pay the expected harm. In addition, implicit in Ireland (1977) is the result that a corrective tax equal to expected harm dominates quantity regulation; he does not, however, show that such a tax is second-best optimal. Also, White and Wittman (1983) prove a related result that strict tort liability for harm is superior to a linear tax or quantity regulation when harm is uncertain.

Then the firm, whose problem as expressed above is to choose x to minimize $x + t(e(x, \theta))$, will be led to minimize

$$x + \int h(e(x, \theta), \eta) f(\eta) d\eta, \quad (5)$$

which is exactly the dictator's problem. Thus, setting the tax schedule equal to the expected harm schedule achieves the second-best optimum.

This analysis reveals that the intuition from the certainty case—that a corrective tax allows the state to harness the firm's information about control costs—is applicable to the case in which harm is uncertain. The only differences here are that the optimal corrective tax equals expected harm and that the outcome is second best rather than first best.

The result that the optimal corrective tax equals expected harm implies that quantity regulation is inferior to this corrective tax. The reason is that quantity regulation is equivalent to a particular nonlinear tax, one that equals zero for all levels of the externality below some stipulated quantity and infinity (i.e., some prohibitive amount) for levels above that quantity.¹⁰ Given the extent to which quantity regulation diverges from a tax equal to expected harm, one would expect quantity regulation to be substantially worse than the optimal corrective tax. Thus, there is no basis for the view that quantity regulation may be desirable when uncertainty makes it impossible to set a tax schedule equal to actual harm.¹¹

The result that the optimal tax schedule equals the expected harm schedule depends on the assumption that harm and control costs are uncorrelated. If they were correlated, the optimal corrective tax schedule would be somewhat different, but would again be superior to quantity regulation.¹² Regardless, the assumption of no correlation usually seems

10. Roberts and Spence (1976) observe that quantity regulation is an instance of a nonlinear tax.

11. Those who cite Baumol and Oates (1988) for documenting the advantages of permit schemes (their preferred form of quantity regulation) over corrective taxes may not be aware that much of their case depends upon their use of a quantity target as a proxy social objective.

12. The optimal scheme would take into account that the firm's choice of e conveys information about its control costs, which in turn are now assumed to be correlated with harm and thus bear on the optimal marginal tax rate, and it would also reflect that the firm may behave strategically in choosing e . Stavins (1996) and Weitzman (1974), among others, show that positive correlation would tend to favor quantity regulation over a corrective tax, but their argument assumes that the corrective tax must be linear (and fixed over time).

appropriate: the factors that determine harm, such as how a pollutant affects the human body, would seem to have little connection with the factors that determine control costs, such as the feasibility of various abatement technologies.

3. Multiple Firms

Here we discuss situations involving multiple firms that jointly create an externality, such that harm is a function of the aggregate quantity of the firms' externality-generating activity. For example, when many firms in a city discharge sulfur dioxide, the total quantity of emissions may determine pollution harm. In this setting we consider corrective taxes versus quantity regulation, as well as corrective taxes versus permit schemes, which constitute a form of quantity regulation. We assume that control costs are unknown to the state but that harm is known. (Our conclusions would be similar were we also to allow for uncertainty about harm, for essentially the reasons given in the single-firm case.)

3.1. Corrective Taxes versus Quantity Regulation

Corrective taxes of the type that we have discussed cannot implement the first-best outcome in the present setting.¹³ To do so, the state would have to confront each firm with a tax schedule under which the marginal tax rate equals the marginal harm, which now depends on the total level of the externality. That is, each firm's tax schedule would have to depend on the other firms' actions. (To illustrate, when there are many small firms, each firm would essentially face a linear tax, with a rate equal to the marginal harm at the total level of the externality.)

The difficulty with such a scheme, of course, is that, at the moment when any particular firm makes its decision about the level of the externality to generate, it does not know the total because the total will depend

13. The case of multiple firms has received some attention in the literature comparing corrective taxes and quantity regulation. Mendelsohn (1984) suggests that the presence of many firms might complicate the use of nonlinear taxes, but he does not explore the problem. Karp and Yohe's (1979) model of the multiple-firm case assumes linear, fixed taxes. Weitzman (1978) examines fixed nonlinear taxes, but he requires that each firm's tax be independent of other firms' actions. We will explain that, in practice, these assumptions limit the benefits from corrective taxes.

on the decisions of all the other firms.¹⁴ The firm will learn this information only when all firms' quantities are reported to the state at the end of, say, a one-week period and these quantities are summed to determine the marginal harm and thus the tax rate. In other words, firms would not know the precise marginal tax rate until the end of the period.¹⁵ Nevertheless, we suggest that, as a practical matter, corrective taxes equal to marginal harm retain their general advantage over quantity regulation. Although firms do not know their actual tax obligation until the end of each period, it seems plausible that, after a modest number of periods, firms would be able to make reasonably accurate estimates of their tax obligations.¹⁶ (Economists believe, after all, that firms generally are able to make reasonably good estimates of next week's input prices, even though these prices will depend on the input demands of other firms.) Thus, one might conjecture that, in short order, firms' behavior should usually be close to the first best.

A similar result could be achieved by the state's announcing a tax rate (a linear tax) at the outset of each period (using information obtained from prior periods' reports). In this case, because the tax rate is fixed in

14. In stating that firms will not know this total, we are assuming that firms do not observe other firms' decisions (until the end of the tax reporting period) and that firms do not have complete information about other firms' control costs (if they did, they could infer others' behavior).

15. We note, however, that there does exist a mechanism that would solve the problem of firms' not knowing the marginal tax rate at the time they choose their level of the externality. Specifically, suppose that each firm initially submits a demand schedule indicating its level of externality as a function of the tax rate. The state aggregates these schedules, determines the proper marginal tax rate, and thereby tells each firm its level of externality and its tax bill—all in advance of firms' actions. This mechanism works nearly perfectly if the number of firms is large. For a mechanism that induces truthful revelation even with a small number of firms, see Dasgupta, Hammond, and Maskin (1980).

16. Some authors have, however, informally suggested that, under schemes that modify the tax rate over time, the level of the externality would change only slowly because capacity and emission controls would not be adjusted immediately. See Roberts and Spence (1976) and Rose-Ackerman (1973). This is true, but whatever is the speed of firms' responses to changes in taxes, the responses will be optimal as long as the corrective tax is set so that, at every point in time, the tax rate equals the marginal harm. (To substitute, for example, a stricter quantity regulation in order to force a more rapid reduction in the level of the externality than would result under taxes would be inefficient because, in the stipulated scenario, the marginal control cost at the lower level of the externality would exceed marginal harm.)

advance, firms would know their exact tax obligations at the time they make their decisions; however, the induced level of the externality would typically be inefficient. But, as the state adjusted the tax rate each period, it seems likely that the tax rate would soon be close to the marginal harm at the prevailing total quantity, so that optimality would be approximately achieved.¹⁷

Now, contrast the case of quantity regulation. Not only will the level of the externality generally be suboptimal when it is chosen by the state, but also the state will not be able to correct its mistakes over time. This is because—unlike in the case with corrective taxes—the state cannot learn anything about firms’ control costs from their behavior: firms’ level of the externality is simply dictated by the state, so nothing can be inferred from it. Therefore, when one considers the extended periods over which most pollution control schemes operate—such as the decades since the passage of the Clean Air Act—it seems likely that the advantage of corrective taxes over quantity regulation would be substantial.

3.2. Corrective Taxes versus Permit Schemes

Under conventional tradeable permit schemes, the state issues a fixed quantity of permits, each one of which authorizes the holder to generate a stated amount of the externality; these permits may be traded among firms, giving rise to a market in the permits. Permit schemes are a form of quantity regulation because the total level of the externality is determined by the total quantity of permits issued by the state. As a result, permit schemes are likely to be inferior to corrective taxes for the reason we have emphasized throughout: under permit schemes, the state chooses the total level of the externality without knowing firms’ control costs, whereas under corrective taxes firms’ decisions determine the total level of the externality.

As an important aside, we note that, when control costs differ among firms, permit schemes do have a well-appreciated advantage over regulation of the externality at the level of the individual firm. Namely, the

17. With regard to the schemes just described, we note that firms would anticipate that adjustments would occur, which would affect the adjustment process. If the number of firms is small, they might act strategically, as we discussed in the single-firm case in note 7. See Morgan (1983). However, we observe that the second modified permit scheme described below would avoid problems of strategic behavior.

costs of achieving a given total level of the externality will be minimized because all firms face the same permit price and thus firms' marginal control costs are equated. Yet it remains true that this total level is stipulated by the state.

The state need not, however, be confined to using conventional permit schemes. In particular, the state can employ modified schemes that make use of the information contained in market prices for permits (the market price will equal each firm's marginal control costs). Under such modified schemes, the quantity of permits in use would be adjusted in light of the price at which permits trade. We now describe two types of modified permit schemes that possess the advantages of nonlinear corrective taxes. (It should not be surprising that modified permit schemes may have the advantages of nonlinear corrective taxes, for permit schemes in which the total level of the externality is made a function of the permit price are a kind of dual to nonlinear corrective taxes, namely, prices that are a function of the total level of the externality.)¹⁸

Under a straightforward modification of a conventional permit scheme, the state would alter the quantity of permits over time. Suppose that, given the currently issued quantity of permits, the equilibrium permit price exceeds marginal harm. Then, since the permit price equals the marginal control costs of firms, the state knows that marginal control costs exceed marginal harm. Therefore, it is desirable for the state to allow firms to increase the level of the externality. This can be done by issuing more permits.¹⁹ Conversely, if the equilibrium permit price is less than marginal harm, the state should reduce the number of permits. This process of adjustment in the number of permits will end when the permit price equals marginal harm, and optimality is thus achieved.²⁰

Under a rather different type of permit scheme, the state would issue tradeable permits with different "exercise" prices.²¹ In particular, permit 1 would have a usage fee—paid to the state—equal to the marginal harm

18. For a general discussion of quantity-dependent pricing, see Spence (1977).

19. Firms' anticipation of this possibility would affect the scheme. We comment on this issue as it arises with respect to tax rate adjustments in note 17.

20. A familiar complication, which we do not consider here, is that, if the harm schedule is not convex, a local optimum (reached through iteration) may not be the global optimum.

21. Such mechanisms are analyzed by Collinge and Oates (1982), Laffont and Tirole (1996), and Roberts and Spence (1976, appendix).

caused by the first unit of the externality; permit i would have a usage fee equal to the marginal harm caused by the i 'th unit of the externality. (Note, therefore, that the permit scheme embodies a nonlinear corrective tax equal to the marginal harm schedule.) In the equilibrium of the market for the permits, some quantity, q , of permits will be exercised. Each of these permits obviously must have the same effective price—market price plus usage fee—and permit q must have a market price of zero.²² This implies that all firms will equate their marginal control costs to the usage fee of permit q , which by design equals the marginal harm at the equilibrium level q of the externality. The permit scheme thus results in an equilibrium that is optimal.²³

4. Conclusion

Economists traditionally have favored the use of corrective taxes to reduce harmful externalities because taxes leave control decisions in the hands of individual firms, which have better knowledge of their own control costs than does the state. But economists have recently come to believe that either corrective taxes or quantity regulation could be superior to the other. One argument for this view rests on the assumption that corrective taxes must be linear and fixed, even when harm and thus the optimal corrective tax is nonlinear. However, as we discuss, nonlinear corrective taxes are often easy to impose, particularly in the case of externalities generated by a single firm. Furthermore, even if linear taxes are employed, it would seem that tax rates could be adjusted to improve welfare. Moreover, we explain that conventional permit schemes may be modified to simulate nonlinear corrective taxes.

We have also discussed the notion that quantity regulation might be superior to corrective taxes on account of uncertainty about the magnitude of harm. As we demonstrated (in the single-firm case), a nonlinear tax

22. Permits $i > q$ will be unexercised and worthless, and each permit i with $i < q$ will have a positive market price that equals the usage fee of permit q minus its own usage fee. Note that for this scheme to work, the state should issue a number of these different types of permits that is sufficiently large definitely to exceed the optimal level of the externality.

23. Other modifications of conventional permit schemes would also lead to optimality. See, for example, Kwerel (1977).

schedule equal to the expected harm schedule is (second-best) optimal, and quantity regulation is inferior.

Of course, there are a number of factors bearing on the problem of externalities that we have not considered, such as administrative costs and political considerations.²⁴ Nevertheless, we believe that the core intuition of economists' traditional view, indicating the superiority of corrective taxes to quantity regulation in controlling externalities to an optimal extent, is robust and provides the appropriate starting point for thinking about policy.

24. With regard to the latter, see Boyer and Laffont (1999) and Keohane, Revesz, and Stavins (1999).

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