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A TAX CUM SUBSIDY REGULATORY ALTERNATIVE FOR CONTROLLING POLLUTION
Insights from Thinking About Acid Rain

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A tax cum subsidy pollution control mechanism is proposed to mitigate against the potential efficiency losses caused by moral hazard in a self-reporting method that prescribes a best available technology and trusts, in the absense of expected cost penalties, that it will be employed fully.

1. Introduction

Problems of moral hazard, caused most fundamentally by asymmetric information, certainly arise in issues of environmental regulation where the sheer number of sources of any one pollutant usually eliminates any chance of exhaustive monitoring. Consider, for example, a firm's installation of the best available technology for reducing sulfur emissions. Even with the technology in place, sulfur emissions may not be reduced to the socially appropriate level. To believe that the correct level of emissions will be obtained, the regulatory authority must assume that the firm will willingly incur the cost of its operation and rely on the firm's monitoring and maintaining its operation at maximum efficacy. The firm can, however, be tempted by the higher profits that would be enjoyed if it did neither; and who would know if the regulatory authority relied exclusively on the firm to report its own actions?

The authority would not, of course, be so rash. Spot checks would surely be arranged to make sure that the firm was accurately reporting its behavior, and financial penalties could surely be imposed if the firm were caught cheating. The problem, of course, lies in determining the size of those penalties. If the firm were risk neutral, the expected penalty for cheating, including the probability of being subjected to a spot check, would have to match the 'gains to cheating' if the threat of being caught were to serve as an adequate deterrent. Enormous probabilistic penalties are not, however, likely to be imposed. Penalties are, instead, frequently adjusted to preserve the existence of the offending firm even at the very real expense of eroding the effectiveness of the entire system.

If assymetric information is the source of difficulty, though, then improvement lies in (1) making information easier to collect because of a more restricted number of sources and (2) providing the incentive for economic actors to tell the truth. Looking to sulfur emissions as a practical illustration, we propose a system that taxes the sulfur (pollutant) content of coal (material input) and subsidizes the removal of sulfur (again, pollutant) from industrial effluent. It is a system designed to achieve the same ideal level of efficiency as a probabilistic fine mechanism without encountering the same practical reluctance to implement.

2. The basic model and social optimum

Let some good y be produced from labor L, capital K_y, and a vector of possible grades of some raw material $\{m_1, \ldots, m_n\}$ according to a general production function

$$y = f\left(K_y,\ L,\ \sum \alpha_i m_i\right), \tag{1}$$

where the α_i are parameters that define the productive quality of the grade of the raw material employed. If one were to envision applying this formulation to an acid rain example, y might represent electricity generated from a coal burning plant, the $\{m_i\}$ might reflect various grades of coal ore, and the $\{\alpha_i\}$ might index the corresponding BTU contents of those grades. Let benefits derived from the consumption of y be denoted functionally by $B(y)$ and the supply costs of the various grades of material be reflected by $c_i(m_i)$. Suppose further that the various grades of the raw material also had some pollution content (e.g., sulfur content) reflected by a vector $\{\delta_1, \ldots, \delta_n\}$. The total polluting potential of the materials employed would be

$$z = \sum \delta_i m_i. \tag{2}$$

Let there exist a cleansing technology that removes z_c from the effluent according to a secondary 'translation' function

$$z_c = g[K_z,\ E,\ z] = g\left(K_z,\ E,\ \sum \delta_i m_i\right), \tag{3}$$

where K_z represents the capital which embodies the cleansing technology and E represents some additional input required to run that technology (e.g., E might reflect the additional energy required to run the scrubbers that are part of K_z). Total emissions from the production of y would then simply be by

$$z_E = z - z_c, \tag{4}$$

and their social cost can be captured by a social cost schedule $S[z_E]$.[1]

Setting the wage paid to labor equal to w, the price of either type of capital equal to r and the price of E equal to p, the first best optimum for this simplified model is a vector of input employment levels denoted $\{L^*,\ K_y^*,\ K_z^*,\ E^*,\ m_1^*, \ldots, m_n^*\}$ that maximizes

$$\left\{B(y) - rK_y - rK_z - wL - pE - \sum c_i(m_i) - S(z_E)\right\},$$

subject to eqs. (1) through (4) with respect to L, K_y, K_z, E, and the $\{m_i\}$. The solution vector, which also determines a vector of state variables $\{y^*,\ z^*,\ z_c^*,\ z_E^*\}$ through eqs. (1) through (4), can

[1] The social cost of emissions from any given source depends, of course, upon other parameters like location, the height of the smokestack, the humidity of the atmosphere, etcetera. The present analysis abstracts from the complications that these parameters introduce to the problem, but not entirely. Remarks that bring them back into play are found in the concluding comments of section 4.

therefore be characterized by a set of first-order conditions:

$$L: \quad B'[*]f_L[*] - w = 0; \tag{5a}$$
$$K_y: \quad B'[*]f_K[*] - r = 0; \tag{5b}$$
$$K_z: \quad S'[*]g_K[*] - r = 0; \tag{5c}$$
$$E: \quad S'[*]g_E[*] - p = 0; \quad \text{and} \tag{5d}$$
$$m_i: \quad B'[*]f_m[*]\alpha_i - c_i'[*] - \delta_i S'[*] + \delta_i S'[*]g_z = 0.^{2} \tag{5e}$$

Consider now a stylized representation of a regulatory scheme requiring the installation of the best available (emission reduction) technology; it is a control scheme frequently applied to limit the discharges of polluters in the United States. The regulatory authority is presumed, in the context of our model, to mandate the installation and operation of the technology summarized by eq. (3) with capital set to equal K_z^*. To guarantee that K_z^* is installed, the authority needs only inspect the firm once. To guarantee that the technology is operated appropriately, however, the authority must also specify that the polluter will face a pecuniary penalty if his or her emissions are observed to be greater than z_E^*. To capture this penalty phase in our analysis, the authority announces (1) that a tax set at some rate t will be imposed upon every unit of observed pollution above z_E^* and (2) that the probability of being monitored in a spot check against that target will be maintained at some appropriate π. The idea is for the authority to set t and π so that the vector $\{L^*, K_y^*, K_z^*, E^*, m_1^*, \dots, m_n^*\}$ maximizes the firm's expected profits; the authority's constraint is the practical impossibility of maintaining the constant surveillance required to set $\pi = 1$. Assume, therefore, that practicality dictates that $0 < \pi \ll 1$.

The long-run competitive equilibrium in the face of such a control scheme is a vector of employment levels that maximize the benefits derived from producing and consuming y net of both the private cost of production and the expected cost of being caught in violation of the emissions target; i.e., a vector that maximizes

$$\left\{ B(y) - rk_y - rK_z^* - wL - pE - \sum c_i(m_i) - \pi t\left[(z - z_c) - z_E\right] \right\},$$

subject to eqs. (1) through (4) with respect to L, K_y, E, and the $\{m_i\}$.[3]

The competitive equilibrium can be characterized by

$$L: \quad B'[\hat{\ }]f_L[\hat{\ }] - w = 0; \tag{6a}$$
$$K_y: \quad B'[\hat{\ }]f_K[\hat{\ }] - r = 0; \tag{6b}$$
$$K_z: \quad \text{not applicable } (K_z = k_z^*); \tag{6c}$$
$$E: \quad \pi t g_E[\hat{\ }] - p = 0; \quad \text{and} \tag{6d}$$
$$m_i: \quad B'[\hat{\ }]f_m[\hat{\ }]\alpha_i - c_i'[\hat{\ }] - \delta_i\pi t + \delta_i\pi t g_z[\hat{\ }] = 0. \tag{6e}$$

[2] In recording these conditions, the arguments of the various functions are denoted [*] to indicate that they are to be evaluated at the optimum; usual derivative notation is employed, as well.

[3] It is implicitly assumed, in this modeling, that the single firm being considered does not exert its monopoly power. Instead, the usual characterization of competitive equilibrium, that marginal benefit equals marginal cost, is employed. At this point in the analysis, allowing either for market power in an imperfectly competitive industry or for many firms in a competitive industry complicates the analysis without adding to generality.

For any π chosen for reasons of administrative practicality, conditions (6a) through (6e) will match conditions (5a) through (5e) only if

$$t = \left[S'(z_E^*)/\pi\right]. \tag{7}$$

Conversely, if the per unit penalty envisioned here were specified to satisfy eq. (7), then the competitive solution characterized by eqs. (6) would match the socially optimal vector $\{L^*, K_y^*, K_z^*, E^*, m_1^*, \ldots, m_n^*\}$, and $\{y^*, z^*, z_c^*, z_E^*\}$ would obtain.

Notice carefully that the specification of the appropriate tax is decidedly probabilistic. For a risk-neutral firm to completely internalize the anticipated cost of a penalty for being caught in violation of an emissions target, the per unit penalty must exceed the marginal social damages caused by emissions greater than z_c^* by the inverse of the probability of the firm's getting caught. Such a fine would, in all likelihood, be so large in many cases that it could not be imposed without destroying economically the polluting firm. To the extent that the regulatory authority or the judicial system is reluctant to impose such an economic 'death penalty' for an emissions violation, though, the ability of the entire scheme to adequately limit emissions is eroded. If, in particular, the expected penalty were perceived to be less than the prescribed $[S'(z_E^*)/\pi]$ either by design or by implementation, then the profit motivated firm would underuse E, underuse K_z^*, and emit too much pollution. The only mitigating factor working against this erosion would be any aversion to risk that the firm or its management might display.

3. A tax cum subsidy alternative

Now consider an alternative control mechanism that subsidizes the utilization of the cleansing technology so that the firm has the opposite incentive. Suppose, in particular, that the regulatory authority were to purchase the residue of the cleansing technology, z_c, at some price τ. Suppose, further, that these purchases would be financed by the taxing of the possible grades of material inputs, the $\{m_i\}$, at differential rates t_i. Could the policy vector $\{\tau, t_1, \ldots, t_n\}$ be specified so that the firm would choose the social optimum identified in section 2 in its own best interest? The competitive equilibrium in the face of the tax cum subsidy scheme would be a vector of employment levels that maximizes

$$\left\{B(y) - rK_y - rK_z - wL - pE - \sum c_i(m_i) - t_i m_i + \tau g(K_z, E, z)\right\},$$

again subject to eqs. (1) through (4) with respect to L, K_y, K_z, E, and the m_i. Equilibrium can therefore be characterized by

$$L: \quad B'(\tilde{\ })f_L(\tilde{\ }) - w = 0; \tag{8a}$$
$$K_y: \quad B'(\tilde{\ })f_K(\tilde{\ }) - r = 0; \tag{8b}$$
$$K_z: \quad \tau g_K(\tilde{\ }) - r = 0; \tag{8c}$$
$$E: \quad \tau g_E(\tilde{\ }) - p = 0; \quad \text{and} \tag{8d}$$
$$m_i: \quad B'(\tilde{\ })f_m(\tilde{\ })\alpha_i - c_i'(\tilde{\ }) - t_i + \tau\delta_i g_z(\tilde{\ }) = 0. \tag{8e}$$

Notice immediately that conditions (8a) through (8e) can duplicate the optimality conditions of eqs.

(5a) through (5e) if

$$\tau \equiv S'(z_E^*) \quad \text{and} \tag{9a}$$

$$t_i \equiv \delta_i \tau \quad \text{for} \quad \text{all } i = 1, \ldots, n. \tag{9b}$$

The appropriate subsidy is therefore the familiar marginal social cost of emissions. The tax on any grade of raw material would, meanwhile, depend critically upon only its pollution content and its potential marginal social damage. Quite reasonably, each grade would be taxed according to its potential social damage, and the employing firm would be rewarded according to its reduction of that potential.

With the tax and subsidy rates set appropriately, the tax cum subsidy scheme could provide the incentives for the firm to seek the optimal solution in its own best interest, and the moral hazard question on the emissions side of the firm's decisions could be eliminated. If the subsidy were operated as a 'payment upon receipt' enterprise, then firms would be paid only for the pollution that they removed from their effluent, and they would be inspired to remove and report precisely the correct amount.

On the input side of the decision-making process, however, the potential for a new moral hazard issue appears. Because there are fewer sources of any particular raw material than there are sources of any particular pollution, though (e.g., recall the coal example where we now count coal mines rather than coal burners), the informational difficulties should not be so severe. The number of observations required to completely monitor the system would, quite simply, be drastically reduced.

Arguably, then, the moral hazard issue would be significantly reduced if the tax cum subsidy scheme were adopted. But how much would it cost? Notice that the total tax paid by a firm purchasing $\{m_1^*, \ldots, m_n^*\}$ could never exceed the total subsidy that it would receive because

$$\text{total tax} = \sum t_i m_i^* = \tau \sum \delta_i m_i^* = \tau z^* \leq \tau z_c^* = \text{total subsidy}.$$

Properly specified, therefore, the system would do better than break even unless the firm cleaned every unit of pollution from its effluent. Even then, the net balance of the program would be no less than 0. Financing the subsidy should not, therefore, be an issue.

4. Some concluding remarks

A regulatory mechanism that taxes potential pollution on the way into a firm and subsidizes the removal of that pollution on the way out of a firm has been suggested on the basis of informational superiority. Compared with a mechanism that depends upon randomly monitored self reporting of costly activity and the threat of financial penalty for violation, the tax cum subsidy scheme was seen to have many potential advantages.

The analysis depended, to be sure, on a number of assumptions that may not be very realistic. The economic assumptions were fairly routine, if not realistic, and it is left to future work to determine the effect of economic generalization on the results; we suspect that the qualitative superiority result should survive those extensions. There is, however, one environmental assumption of particular concern. Recall that the social costs of pollution were expressed as a function of emissions, alone. The costs attributable to any single source should, of course, depend not only upon the level of emissions, but also upon such factors as location, local topography, height of the stack, and so on; and the introduction of these firm specific parameters should certainly undermine the notion that a common standard, penalty, tax, or subsidy applied to all sources of any given pollutant could achieve the first best optimum.

We maintain, however, that the information based superiority of the tax cum subsidy mechanism would still hold even if these site differentiating parameters were introduced into the analysis. For either method of regulation to achieve the first best optimum in that case, the regulatory authority would have to set firm specific controls requiring, for each, the very same site specific information. Were it possible to collect and process that information for any firm, then direct application of the preceding analysis with firm specific definition of $S'(z_E)$ would support all of the reported results. Were it impossible to incorporate all of that information, however, then neither control method could achieve the first best solution, and the two options would be reduced to trying to achieve the identical second best solution. Since the analysis presented here shows that to be possible, as well, introducing site specific information does not undermine the comparative results.

References

Arnott, R. and J. Stiglitz, 1985, The basic analytics of moral hazard, Mimeo. (Queens University, Kingston).

Arnott, R. and J. Stiglitz, 1986, The welfare economics of moral hazard, Mimeo. (Queens University, Kingston).

Greenwald, B. and R. Arnott, 1986, Externalities in economics with imperfect information and incomplete markets, Quarterly Journal of Economics 101, 229–264.

Marshall, J., 1976, Moral hazard, American Economic Review 10, 880–890.

Pauly, M., 1974, Overinsurance and public provision of insurance, Quarterly Journal of Economics 88, 44–62.

Yohe, G. and P. MacAvoy, 1986, The practical advantage of tax over regulatory policies in controlling industrial air pollution, Mimeo. (University of Rochester, Rochester, NY).