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MORE ON THE PROPERTIES OF A TAX CUM SUBSIDY POLLUTION CONTROL STRATEGY *

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A modification in a tax cum subsidy pollution control strategy proposed by Yohe and MacAvoy to mitigate against the effects of moral hazard on the effectiveness of self-reporting strategies is shown capable of eliminating the dead weight welfare loss of regulating the emissions of an imperfectly competitive polluter.

1. Introduction

In a note published in 1987, Yohe and MacAvoy (henceforth, Y–M) proposed a two-stage tax cum subsidy approach to pollution control designed specifically to reduce the likelihood that moral hazard would undermine the ability of environmental regulations to meet their welfare objectives [see Yohe and MacAvoy (1987)]. The Y–M proposal envisioned a control mechanism which would combat moral hazard by taxing firms for each unit of a specific pollutant contained in the materials that they employed in their production processes *and* subsidizing the same firms for each unit of the pollutant that they removed from their effluent. Working within a perfectly competitive model, Y–M showed that such a scheme (1) could achieve the social optimum, (2) would provide incentives for polluters to accurately report their effluent-cleansing activity (rather than hide their deficiencies in undertaking that activity), and (3) would never fail to break even operationally.

Left unresolved, though, was the relative efficacy of their proposed mechanism in confronting an imperfectly competitive polluter. It is widely known that taxing the emissions of a monopolistic polluter can do more harm than good. Why? Because increasing the marginal cost of an imperfect competitor causes output that is already too low to fall. The increased dead weight loss associated with this reaction can, under some circumstances, actually dominate the reduced social costs of lower emissions and produce a net social loss. Moreover, even if there is a net social gain, it will not be as large as it would be if it were not for the exercise of market power by the polluter. [1] This note will explore the ability of a Y–M type of two stage control strategy to mitigate against this second welfare leakage.

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[1] See, for further exploration of this point, Asch and Seneca (1976), Burrows (1981), Burrows and Yohe (1988), Greenwald and Arnott (1986), Misiolek (1980), and Russel (1986).

2. The model and the socially optimal benchmark

The output side of the Y–M model was characterized in the usual way. The production of some good X was summarized by a function of the form

$$X = F\left(K_x,\ L, \sum \alpha_i m_i\right), \tag{1}$$

where K_x and L represented capital and labor employed in the production process, respectively, $\{m_1, \ldots, m_n\}$ was a vector which cataloged the possible grades of a raw material m used in that process, and the α_i were parameters which defined the productive quality of the material grades m_i. Benefits derived from consuming X were reflected by schedule $B[X]$, the supply costs of the various m_i were quantified by schedules $C_i[m_i]$, labor was perfectly elastically supplied at wage w, and capital was available at a constant required return of r. All of the schedules were assumed to have the usual shapes.

The emissions side of the model was built upon the presumed pollution content of the various grades of the raw material. Denoting the pollution content of grade m_i by δ_i, the total polluting potential of any vector of material grades $\{m_1, \ldots, m_n\}$ was

$$Z \equiv \sum \delta_i m_i. \tag{2}$$

There existed an effluent cleansing pollution abating technology characterized by a secondary 'production function',

$$Z_c = G[K_z,\ E,\ Z] = G\left[K_z,\ E, \sum \delta_i m_i\right], \tag{3}$$

where K_z represented the capital which embodies the cleansing technology and E represented some additional input required to run that capital. The input E was available at a constant price P_E, and K_z matched K_x in its availablility at r. Total emissions from the production of X were then, quite simply

$$Z_E \equiv Z - Z_c = \sum \delta_i m_i - G\left[K_z,\ E, \sum \delta_i m_i\right]; \tag{4}$$

and their social costs were given by $S[Z_E]$. Again, all of the schedules assumed their customary shapes.

The first best optimum for this simple model was a vector of input employment levels $\{L^*,\ K_x^*,\ K_z^*,\ E^*,\ m_1^*, \ldots, m_n^*\}$ that maximized

$$\left\{B[X] - rK_x - rK_z - wL - P_E E - \sum C_i[m_i] - S[Z_E]\right\}$$

with respect to the vector of discretionary inputs available to the firm, $\{L,\ K_x,\ K_z,\ E,\ m_1, \ldots, m_n\}$, and subject to eqs. (1) through (4). The solution vector was characterized by the following set of first order conditions:

$$L: \quad B'[*]F_L[*] = w; \tag{5a}$$

$$K_x: \quad B'[*]F_K[*] = r; \tag{5b}$$

$$K_z: \quad S'[*]G_k[*] = r; \tag{5c}$$

$$E: \quad S'[*]G_E[*] = P_E; \quad \text{and} \tag{5d}$$

$$m_i: \quad B'[*]F_m[*]\alpha_i = C_i'[*] + (1 - G_z[*])\delta_i S'[*]. \tag{5e}$$

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

3. The equivalence between a simple tax and a tax cum subsidy alternative in application to a competitive firm [2]

It was easily argued that a firm in a competitive industry would respond to a tax t applied to emissions by maximizing

$$\left\{ B[X] - rK_x - rK_z - wL - P_E E - \sum C_i[m_i] - tZ_E \right\},$$

with respect to the same vector of discretionary inputs and again subject to eqs. (1) through (4). [3] Setting

$$t = S'[*] \tag{6}$$

then guaranteed that the first order conditions for this maximization would match the conditions of eq. (5); the social optimum could thus be attained, but only if the problems involved in monitoring and self reporting were overcome.

Turning then to consider a different sort of control mechanism considered – one designed to tax those things which were relatively easier to monitor, and subsidize those things which were relatively more difficult to monitor – an equivalence result was obtained. The idea was that a regulatory authority could announce that it stood ready to purchase the product of the effluent-cleansing technology at some unit price τ, financing those purchases with funds that it had raised by taxing the delivery of various grades of raw material at rates t_i set according to their pollution content. The competitive equilibrium which emerged in response to any such vector $\{\tau, t_i, \ldots, t_n\}$ maximized

$$\left\{ B[X] - rK_x - rK_z - wL - P_E E - \sum C_i[m_i] - \sum t_i m_i + \tau Z_c \right\}$$

with respect to the usual vector of inputs and subject to eqs. (1) through (4). A little algebra revealed that the conditions which characterize equilibrium here would match the optimality conditions of eq. (5) only if

$$\tau^* = S'[*] \quad \text{and} \quad t_1^* = \delta_i \tau^* \tag{7a), (7b}$$

for all $i = 1, \ldots, n$. Quite reasonably, equivalence in achieving the first best optimum was demonstrated if each grade of raw material were taxed upon delivery to the firm according to its potential for social damage, and the employing firm were rewarded according to its efforts to diminish that potential. [4]

[2] See Yohe and MacAvoy (1987) for a complete discussion.

[3] It was implicitly assumed that the single competitive firm would operate as a competitive industry, producing where marginal cost equals marginal benefit. Adding more firms to make it a conventional competitive model would simply confound the notation without contributing content. Moving to the monopoly extreme of imperfect competion will be accomplished in section 4.

[4] It should also be noted that equivalence does not depend upon optimality. Employment decisions in response to any charge t could be elicited by setting $\tau = t$ and $t_i = \delta_i t$ for all i.

4. Application of the alternatives to a monopoly firm

Turning now to the issue of regulating monopoly polluters, the equivalence between a single emissions tax and the two stage Y–M mechanism can be bad news. It means that monopoly power will undermine the efficacy of the two stage scheme in exactly the same way that it effects the simple tax.

To verify equivalence in the monopoly setting, note first that a monopolist would choose an input employment vector $\{L^m, K_x^m, K_z^m, E^m, m_i^m, \ldots, m_n^m\}$ in response to an arbitrary tax rate t applied to emissions by maximizing profits,

$$\{XP[X] - rK_x - rK_z - wL - P_E E - \sum C_i[m_i] - tZ_E\},$$

subject still to eqs. (1) through (4). The resulting first order conditons hold that

$$L: \quad MR[\sim_t]F_L[\sim_t] = w; \tag{8a}$$
$$K_x; \quad MR[\sim_t]F_K[\sim_t] = r; \tag{8b}$$
$$K_z: \quad tG_K[\sim_t] = r; \tag{8c}$$
$$E: \quad tG_E[\sim_t] = P_E: \text{ and} \tag{8d}$$
$$m_i: \quad MR[\sim_t]F_m[\sim_t]\alpha_i = C_i'[\sim_t] + \delta_i t(1 - G_z[\sim_t]). \tag{8e}$$

Notice that all of the employment levels lie below the socially optimal level as long as MR$[X] < P[X]$; i.e., as long as the firm has some discretionary power over price. Notice, too, that (8c) and (8d), as well as the second term on the right hand side of (8e), come into play only when $t > 0$. A positive tax reduces emissions by lowering the employment of the m_i, causing the cleansing technology to be employed, and thereby reducing output by increasing the marginal cost of production.

Now consider the monopolist's response to a subsidy/tax vector $\{\tau, t_1, \ldots, t_n\}$ of the Y–M type. Employment decisions would then be made by solving

$$L: \quad MR[\approx_\tau]F_L[\approx_\tau] = w; \tag{9a}$$
$$K_x: \quad MR[\approx_\tau]F_K[\approx_\tau] = r; \tag{9b}$$
$$K_z: \quad \tau G_K[\approx_\tau] = r; \tag{9c}$$
$$E: \quad \tau G_E[\approx_\tau] = P_E; \text{ and} \tag{9d}$$
$$m_i: \quad MR[\approx_\tau]F_m[\approx_\tau]\alpha_i = C_i'[\approx_\tau] + t_i - \tau\delta_i G_z[\approx_\tau]. \tag{9e}$$

The conditions in (8) and (9) match if, as was noted to define equivalence, $t = \tau$ and $t_i = \delta_i \tau$ for any t.

All is not lost, though. A two stage control mechanism provides at least two degrees of freedom. Suppose that the subsidy were offered along a schedule $\tau[X]$ whose value changed with the level of output; the source of concern in imposing either a tax or its equivalent two stage scheme on a firm with market power was, after all, found in the likelihood that such a firm would respond by lowering its output from an output that was already too low. The monopolist would respond to this sliding type of tax vector, $\{\tau[X], t_1, \ldots, t_n\}$, by solving first order conditons of the form

$$L: \quad \{MR[\hat{\ }] + \tau'[\hat{\ }]g[\hat{\ }]\}F_L[\hat{\ }] = w; \tag{10a}$$

$$K_x: \quad \{MR[\hat{\ }] + \tau'[\hat{\ }]g[\hat{\ }]\}F_K[\hat{\ }] = r; \tag{10b}$$

$$K_z: \quad \tau[\hat{\ }]G_k[\hat{\ }] = r; \tag{10c}$$

$$E: \quad \tau[\hat{\ }]G_E[\hat{\ }] = P_E E; \quad \text{and} \tag{10d}$$

$$m_i: \quad \{MR[\hat{\ }] + r'[\hat{\ }]g[\hat{\ }]\}F_m[\hat{\ }]\alpha_i = C_i'[\hat{\ }] + t_i - \tau[\hat{\ }]G_z[\hat{\ }]\delta_i. \tag{10e}$$

Recall now that $MR[X] = P[X]\{1 + (1/\epsilon[X])\} = B'[X]\{1 + (1/\epsilon[X])\}$ where $\epsilon[X] < 0$ is the price elasticity of demand facing the firm. After a little algebra, it becomes clear that the conditons given in (10) can be made to match the optimality conditions of (5), but if

$$\tau[X^*] = S'[Z_1^*], \tag{11a}$$

$$t_i = \tau[X^*] \quad \text{for all i, and} \tag{11b}$$

$$\tau'[X^*] = -P[X^*]/[g[K_z^*, E^*, Z^*]\epsilon[X^*]] > 0. \tag{11c}$$

Optimality can be achieved, therefore, even in the face of market power, if the solution $\{L^*, K_x^*, K_z^*, E^*, m_1^*, \ldots, m_n^*\}$ is the unique solution to (10) given the control specifications of (11). A monotonic $\tau[X]$ schedule satisfying (11a) and (11c) will do the trick.

Consider, for example, $\tau[X] = a + b[X^* - X]$ where $a \equiv S'[*]$ and $b \equiv -\{P[*]/G[*]\epsilon[*]\}$. Eqs. (11a) and (11c) are clearly satisfied, and the continuity of $\tau[X]$ combines with $\tau'[X] = -b > 0$ to assure monotonicity. Notice, too, that such a subsidy schedule would collapse to the appropriate $\tau^* = S'[*]$ if we approach the competitive situation of section 1 by letting $\epsilon[X]$ approach (negative) infinity.

For an arbitrarily targeted level of emission consistent with some effluent charge t but not necessarily supported by the optimality conditions, equivalence within a linear schedule could be achieved by setting

$$a = t, \; b = P/G\epsilon \quad \text{and} \quad t_1 = \delta_i t. \tag{12}$$

This would not be a first best solution, to be sure, but cast its implications into a world in which there are many sources of the same pollutant – some perfect competitors and some not. It would guarantee that the 'marginal net social product' of each grade of material at every firm would be set equal to each other; no rearrangement in the utilitization of the raw material could generate a Pareto improvement. It would mean that even imperfectly competitive firms would respond to the pollution control as perfect competitors. Given the constraint of an arbitrary target, second best efficiency would thus be attained. And how much would it cost? The total tax paid by any firm purchasing any combination of material grades $\{m_1, \ldots, m_n\}$ would never fall short of the the total subsidy that it might receive because $\Sigma t_i m_i = \tau\ \Sigma\delta_i m_i = \tau Z \leq \tau Z_c$ for any $\{\tau, t_1, \ldots, t_n\}$ satisfying (12).

5. Concluding remarks

Despite unanswered questions concerning information and efficacy under uncertainty, these results certainly suggest a means by which pollution control can avoid two significant sources of cost

– moral hazard and market power. Integrating the insight drawn here into the existing comparative control literature could thus pay dividends in matching regulatory initiatives with their broadly defined social objectives.

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