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PORTER'S COMBINATION TAX AND SUBSIDY FOR CONTROLLING POLLUTION

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ABSTRACT

Porter once proposed a combination tax and subsidy for controlling pollution, but then rejected it as impractical [1]. Upon further analysis, the concept now appears to have desirable properties. Mathematically, the Porter combination is equivalent to a single tax on emissions and, like the tax, fosters economic efficiency. The two sets of data on which Porter's scheme would be based are periodically updated and published by the U. S. Environmental Protection Agency. Because the polluting firm would prepare two reports, one for the operating tax and the other for the abatement subsidy, there is a cross-check on the data that would encourage more accurate reporting by firms.

Regulatory agencies typically control pollution by setting maximum emission rates per unit of particular inputs or outputs. An alternative to such emission standards would be to tax emissions at rates equal to the value of marginal damage inflicted. Economists advocate the taxing alternative because, in principle, the tax (i) induces optimal levels of abatement activities, (ii) correctly raises the prices of polluting goods, so that households shift some of their consumption to nonpolluting goods, and (iii) fosters the optimal level of pollution.[1]

A problem with the economist's approach, however, is the perverse incentive for firms to understate the quantity of emissions for which they should be taxed. This problem can be mitigated with higher fines [3, 4] and with strategic [5] and technologically innovative monitoring systems [6, pp. 24, 71-86], but these

[1] The economic case for emission taxes is reversed if the governmental transactions costs of administering and collecting the taxes is sufficiently larger than the transactions costs of enforcing emission standards as to offset these three efficiency benefits. The issue of transactions costs is examined in [2].

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augment the transactions costs of implementation. Economists have long recognized that subsidizing abatement is a market oriented alternative to the tax that is more likely to foster the honest cooperation of polluters [7], but the subsidy approach has been controversial. Initially it was argued [8] that subsidizing abatement would be equivalent, in its effect on resource allocation, to taxing emissions, but the debate has subsequently been won by economists [9-11] who have shown that subsidies increase the profitability of polluting industries, attracting an excessive number of new firms to those industries. Nevertheless, economists [7, 12] have continued to search for new mechanisms for subsidizing abatement that would have the advantage of fostering the cooperation of polluters without the disadvantage of attracting new firms to polluting industries.

A new possibility is based on an early paper of economist Richard C. Porter [1] in which each polluting firm must pay a "right to enter" tax each period that is based on the quantity of emissions it would emit if there were no abatement, then later receive a payment, called a subsidy, for the quantity of emissions that the firm actually abated during the period. Except to show that his combination tax and subsidy is efficient, that is, that it fosters the correct levels of abatement activities, has the optimal effect on relative prices, and does not attract new firms to the polluting industry, Porter [1, p. 416] dismissed his theory as having "no practical interest . . . since it is rare that industrial entrants must in fact buy the right to enter" an industry. In fact, a "right to enter" tax, better known as an operating franchise fee, is not only a well-argued concept in microeconomic analysis but, in some form or other, is almost universally imposed. Porter's combination entry tax and abatement subsidy could be readily implemented with the emission data researched and published by the U. S. Environmental Protection Service. Because the firm pays a franchise fee based on emissions in the absence of controls and then receives a payment for emissions abated, there is a double check on the accuracy of the firm's compliance. It therefore appears that Porter's combination tax and subsidy may have the desired properties of both fostering efficiency and discouraging inaccurate reporting by polluters. This view is now reinforced by several recent papers [13, p. 193; 14], apparently written without knowledge of the prior contribution of Porter [1], proposing that a tax on the pollution content of the inputs used by firms (which is a somewhat less general approach than that of Porter), in combination with subsidy payments for abatement, would be efficient and ". . . would provide incentives for polluters to accurately report their effluent-cleansing activity."

In Sections I and II of this article, the economist's simple model of a competitive market economy, in which pollution from one industry (the polluting industry) damages production in another industry (the receptor industry), is used to demonstrate that Porter's combination tax and subsidy promotes economic efficiency, that is, fosters a productive arrangement of the economy's resources such that it would be impossible, whether by reallocating inputs between firms or altering the scale at which individual firms operate, to produce more of any one good without also producing less of some other good. In the interest of generality, it is assumed that receptor firms can expend resources to reduce or avoid their exposure to pollution. The tax, subsidy, and competitive market pressures induce polluting firms to efficiently abate emissions and to operate at an efficient scale. Although firms in the receptor industry are neither taxed nor subsidized, it is remarkable that each firm responds to the optimal level of pollution and to competitive market pressures by choosing an efficient level of avoidance activity and scale of production. In addition to these efficiency properties, it is argued in Section III of the article that Porter's combination tax and subsidy would foster greater honesty by firms in reporting their emissions.

I. THE MODEL OF EFFICIENT PRODUCTION, ABATEMENT, AND AVOIDANCE

In this section, the mathematical model is formulated and then used to derive the marginal conditions for the efficient allocation of the economy's scarce resources. When these marginal conditions are met, which in theory they would be in a perfectly competitive market economy in which polluting firms pay the correct franchise fee to operate and receive the correct subsidy payment for their abatement of emissions, it would then be impossible to increase the output of any good in this economy without, at the same time, reducing the output of another good. Clearly, if the output of any good could be increased *without* decreasing the output of any other good, the economy would *not* be operating efficiently.

Consider a simple economy in which there are only two goods, whose quantities are x and y. The production of good y by m identical firms causes pollution that damages the productivity of n identical firms that produce good x. We may think of industry y as a sulfuric acid manufacturing or petroleum refining industry whose individual firms emit sulfur dioxide, and industry x as an agricultural industry, whose individual firms, in this case farmers, suffer damage to their crops because of the sulfur dioxide fumes. The assumption that firms in each industry are identical, which is often made in economic models for analytic convenience, is in many cases reasonably realistic. The output levels of the two industries are mathematically explained by the formulas,

$$x = nX(L_x, K_x, z), \qquad y = mY(L_y, K_y), \tag{1}$$

where the functions, $X(\cdot)$ and $Y(\cdot)$, are what economists call "production functions." The output levels of the two industries increase with the number of firms, n and m, and increase at an increasing and then decreasing rate with the quantities of labor and capital, L_i and K_i, used by each firm. The latter assumption generates the U-shaped unit costs curves so familiar to students of introductory economics, In the case of the receptor firms, output decreases as their level of exposure, z, to pollution increases.

The level of pollution exposure, z, depends upon the ambient pollution level, which is e, and the quantities of labor, L_v, and of capital, K_v, used for avoidance by the individual firm in industry x. The pollution level, e, is proportional to the total output of good y, although the constant of proportionality, E, better known as the emission factor, is itself a variable that depends upon the quantities of labor, L_b, and of capital, K_b, devoted to abatement by the individual polluting firm. In the context of our real world example, we may think of z and e as being concentrations of sulfur dioxide, measured in micrograms per cubic meter or parts per million. Abatement could be achieved by conversion to the double contact process in the case of sulfuric acid manufacturing [15, p. 61] or the alkaline treatment of by-product gases [15, p. 54] in the case of petroleum refining. Avoidance could perhaps be achieved by the use of lower yielding, but more highly resistant seeds. Actually, the implication of the formal model is that the receptor firm operates a greenhouse that employs air cleaning devices that reduce the concentration, z, inside the greenhouse below the outside concentration, e. The simple exposure-avoidance and emission-abatement functions used in this model are

$$z = Z(e, L_v, K_v), \qquad e = mE(L_b, K_b)Y. \tag{2}$$

The derivatives of the avoidance and abatement functions with respect to the labor and capital inputs, which are Z_L, Z_K, E_L, and E_K, are negative and decrease in absolute value as the quantity of the respective input increases. These derivatives are what economists call "marginal products." The derivative, Z_e is positive and Z_{ee} is greater than or equal to zero. The derivative, X_z, is negative.

In this economy, the total demand for labor and for capital are constrained to fixed available quantities of these inputs.[2] There are then three sets of marginal conditions for the efficient allocation of these input in production.[3] The first marginal condition is that the marginal product of either input in the direct production of good x, which is X_L or X_K, equals the marginal product of that same input in avoidance, which is X_zZ_L or X_zZ_K, and also equals the marginal product (measured in units of x) of that same input in abatement by polluting firms. This triple equality, in terms of labor and then capital, is

$$X_L = -X_zZ_L = nX_zZ_eE_LY, \qquad X_K = -X_zZ_K = nX_zZ_eE_KY. \tag{3}$$

[2] The assumption that total input quantities are constants is often made to simplify economic analysis. For a model in which the total quantities of both labor and capital are variables, see [16].

[3] The marginal conditions for efficiency in production can be derived from the following Lagrangian expression in which the output of industry x is maximized subject to a fixed level, y_o, of the output of good y and fixed total quantities, L_o and K_o, of the inputs:

$$\psi = x + \lambda(y_o - y) + \mu(L_o - nL_x - nL_v - mL_y - mL_b) + \gamma(K_o - nK_x - nK_v - mK_y - mK_b)$$

Equations (1) and (2) may be used to substitute functions of L_x, K_x, L_v, K_v, L_y, K_y, L_b, K_b, n and m for x, z, e, and y, so that only these ten decisions variables and the three constants, y_o, L_o, K_o, remain in the Lagrangian.

It makes good sense that at the margin each input is equally productive in all three of its applications.[4]

There is an efficient number of firms, n and m, when each identical firm operates at the point at which the sum of the direct marginal product of each input times the combined quantities of that input "exhausts" the firm's total product, that is

$$X = X_L[L_x + L_v] + X_K[K_x + K_v], \qquad Y = Y_L[L_y + L_b] + Y_K[K_y + K_b]. \tag{4}$$

It follows from (4) that when firms employ inputs for avoidance or for abatement, they necessarily operate in the range of decreasing returns to scale.[5]

The final marginal condition for economic efficiency is that the opportunity cost of the marginal unit of good y, measured in units of good x, is

$$-\partial x/\partial y = [X_L - nX_zZ_eEY_L]/Y_L = [X_K - nX_zZ_eEY_K]/Y_K. \tag{5}$$

This expression, which defines the smallest quantity of good x that must be given up so that one additional unit of good y can be produced, is what economists call the "marginal rate of transformation."

II. EFFICIENCY OF PORTER'S COMBINATION TAX AND SUBSIDY

In this section of the article, it is demonstrated that the marginal conditions for production efficiency, (3) and (4), are achieved in a competitive market economy in which the government imposes a franchise fee or operating tax on each polluting firm at the beginning of each period and then pays them a per unit subsidy for emissions abated during the period. The assumption that markets are perfectly competitive, which is commonly made in economic analysis, has the consequence that each firm produces the quantity of output at which its marginal cost of production equals the market price. This is crucial if the ratio of market prices,

[4] This is the case of an interior optimum because both sets of inputs, (L_v, K_v) and (L_b, K_b), have positive values. Corner solutions, in which either set, (L_v, K_v) or (L_b, K_b) is zero, are examined in [17].

[5] This is equivalent to operating on the upward sloping portion of the firm's long-run average cost curve. Marginal conditions (3) and (4) can be doublechecked with the following numerical example (adapted from [18, Table 1]) in which n identical firms in industry x each operate according to the production function, $X = (14L_xK_x - L_x^{1.5}K_x^{1.5})(1 - z)$; m identical firms in industry y operate according to $Y = 108L_yK_y - L_y^2K_y^2$; the emission factor is $E = 1/(1296000[1 + L_b^{0.5}K_b^{0.5}])$; the pollution level is e = mEY; the pollution exposure is $z = e/(L_v^{0.5}K_v^{0.5})$; and the constants are $y_o = 1296000$ and $L_o = K_o = 9000$. The efficient solution is $L_x = K_x = 7.70238$, $L_v = K_v = 2.21138$, n = 532.765, $L_y = K_y = 6.34575$, $L_b = K_b = 1.47945$, and m = 475.170.

which is what determines the total quantities of goods that consumers demand, is to equal the marginal rate of transformation defined in (5).

The magnitudes of the Porter tax and subsidy are based on marginal pollution damage per unit of emissions, which in this model is

$$s = -Z_e X_z n p_x. \tag{6}$$

This formula for marginal pollution damage, s, has the following logical interpretation. The marginal unit of emissions causes an increase in pollution exposure measured by the derivative, Z_e. This increase reduces the output of each firm in the receptor industry by $-X_z$ times the increase in exposure. The marginal damage, s, is this reduction in output over all n firms in industry x, valued at p_x, the competitive market price of good x.

Porter's lump sum tax or franchise fee is the market value of the foregone output of industry x, associated with the marginal unit of emissions, that is s, times the quantity of emissions before abatement. This benchmark quantity of emissions is E_0, which is the emission rate in the absence of pollution control (that is, when $L_b = K_b = 0$), times the quantity of output that the firm would produce if it did not abate, which is Y_o. The franchise fee or operating tax is therefore sE_oY_o per period for each polluting firm.

The polluting firm is then paid a subsidy of s for each unit of emissions abated, receiving a total payment of $s[E_oY_o - EY]$ each period. On balance, the government necessarily receives more in franchise or operating tax revenue than it pays out for abatement. It is assumed that this net revenue is redistributed to consumers in a neutral fashion, say, in proportion to their incomes.

In the Porter scheme, the total profit of a firm in industry y is

$$\pi_y = p_y Y + s[E_o Y_o - EY] - w[L_y + L_b] - r[K_y + K_b] - sE_o Y_o \tag{7}$$

where w, the wage rate, r, the price of capital, p_y, the price of good y, and s are taken as given by the individual competitive firm. Observe that the two sE_oY_o terms in (7) cancel out. (It may be assumed that the franchise fee is paid at the same time that the abatement subsidy is received so that there are no time-value of money considerations.) The condition for profit maximization is obtained by setting the derivative of (7) with respect to, say, labor equal to zero and solving for p_y. The result is the familiar economic rule that the competitive firm produces the level of output at which price equals marginal cost, that is,

$$p_y = w/Y_L + sE. \tag{8}$$

It is of interest that the firm treats sE as a component of marginal cost even though s is a per unit subsidy. This is the case because the production of the marginal unit of output entails an opportunity cost of sE in foregone subsidy revenue.

It can similarly be shown that each firm in industry x produces the output at which its marginal cost equals market price, that is

$$p_x = w/X_L \,. \tag{9}$$

It follows, by substitutions of (6), (8), and (9), that the ratio of market prices, p_y/p_x, does indeed equal the marginal rate of transformation as defined in (5) above. As a result, consumers purchase quantities of goods x and y such that the efficient opportunity cost, (5), prevails.[6]

In this market economy, firms minimize their total costs. Therefore polluting firms abate until the marginal cost of abatement, which is $-w/E_L$, equals the payment for abatement, s, and receptor firms use a combination of L_x and L_v such that their respective marginal products, X_L and X_zZ_L, are equal. It follows from these equalities within the two industries, with respect to both labor and capital, that marginal conditions (3) are satisfied.

Porter's combination tax and subsidy raises the relative price of good y, thereby reducing demand for that good and increasing the demand for good x. In the long-run, there will be fewer polluting firms, who will now abate and therefore operate at a larger scale. Pollution will be less and firms in industry x will avoid less and operate at a smaller scale. Finally, free entry and exit of firms will drive profits in both industries to zero. That each firm in industry y will then be operating at the efficient scale can be demonstrated by setting (7) equal to zero, substituting (8) for p_y and wY_K/Y_L for r to obtain the product exhaustion condition in (4) above. That Y_L/Y_K equals w/r follows from the equality (a well-known condition for cost-minimization) of X_L/X_K and w/r and from equation (5) above. Thus, as a consequence of the implementation of Porter's combination tax and subsidy, the resulting cost-minimization by competitive firms and choice by these firms of their profit-maximizing output levels, and the resulting entry of new firms driving profits to zero, there is an allocation of resources among firms such that, for any given quantity of good y, the output of good x is the maximum possible output of that good.

III. ADMINISTRATIVE ADVANTAGES OF THE PORTER SCHEME

If market incentives are to be used to control pollution, it was Coase's [8, p. 35] preference ". . . that a factory owner with a smoky chimney should be given a bounty to induce him to install smoke-preventing devices." Coming as it did from one of the most influential and probably the most frequently cited economic articles of all times, this gave rise to the view that a pure subsidy (or bounty) for each unit of emissions abated is economically equivalent to a pure tax for each unit of pollution emitted. Subsequently, however, economists [9-12] realized that

[6] In a perfectly competitive economy in which w = r = \$1,000.00, the efficient allocation defined in footnote 5 can be sustained by paying a subsidy, s = \$5,842,400.00, for each microgram per cubic meter or part per million abated and collecting a franchise fee or operating tax, sE_oY_o = (\$5,842,400.00)(1/1,296,000)(2592) = \$11,685.00 per period, from each polluting firm. In this economy, the market prices are p_x = \$64.907 and p_y = \$7.5563, and firms earn zero profits.

the pure subsidy approach would generate inefficiently large profits in the polluting industry. The entry of new firms, attracted by these profits, eventually drives them to zero, so that

$$\pi_y = p_y Y + s[E_o Y_o - EY] - w[L_y + L_b] - r[K_y + K_b] = 0. \tag{10}$$

Making the same substitutions as before, it follows that

$$Y < Y_L [L_y + L_b] + Y_K [K_y + K_b], \tag{11}$$

indicating, by comparison with (4), that each firm is operating at too small a scale and hence there are too many firms in the polluting industry. This is an inefficient arrangement for in theory it would be possible (thought not by any automatic market mechanism) to reallocate resources in such a way as to have more of all goods! In effect, this pure subsidy approach, which is inefficient, breaks down to a lump-sum bribe, sE_0Y_0, and a unit tax, sEY. Porter, however, adds a lump-sum fee, sE_0Y_0, that offsets the excessive profits and thereby neutralizes the perverse entry attraction of the pure bribe.

The pure subsidy for abatement, without Porter's entry tax, is likely to result in even greater excess profitability if polluting firms are allowed to claim (and it is unlikely that the government would have sufficient information to prove otherwise) that the output, Y_0, that they would have produced if they did not abate, is equal to their current output. In that case [19], polluting firms would increase their output, Y, above the efficient quantity until the resulting increase in subsidy receipts, which would then be $s[E_0 - E]Y$, no longer exceeds the resulting increase in production costs, thereby enhancing still more the profitability of the polluting industry and its perverse attraction for new entrants. In Porter's scheme, however, this is not a problem; it is permissible to let Y_0 equal Y because the sE_0Y_0 terms in (7) cancel out.

Yet another advantage of Porter's combination tax and subsidy is that it conforms to the format used by the U. S. Environmental Protection Agency [20] for reporting emission factors for stationary sources of pollution. Typically, the emission factors are first listed for each source in the absence of controls, which are the E_0 in the present model, followed either by the collection efficiencies or actual emission factors, E, associated with alternative control methods. As experience with emission factors grows, as it would under Porter's approach, the accuracy of these two sets of published numbers would continue to improve.

A final advantage of Porter's combination tax and subsidy for controlling pollution is that it provides a cross check on the emission data given by the polluting firm. If, to lower its entry tax, a firm misleads the authorities into believing that E_0Y_0 is lower than it should be, the firm would then receive a correspondingly smaller subsidy for abatement. Or if, to increase its subsidy the firm claims a higher quantity of abated emissions than deserved, this would draw the attention of the authorities to the possibility that the firm might be understating its benchmark emissions. There is in effect a double check, one in the form of a tax and the other a payment, that makes cheating more risky and more detectable.

IV. SUMMARY

Whereas air pollution is usually controlled by emission standards, economists have long advocated the use of market-oriented instruments such as a tax on emissions. The advantages of the tax are its efficiency properties; the disadvantage is that polluting firms may understate the quantity of emissions on which they owe taxes. An alternative approach that may lessen the problem of cheating is based on the model of Porter [1].

Porter's combination tax and subsidy for controlling pollution requires each firm to pay an operating tax or franchise fee of sE_0Y_0 per period, but then to be paid a unit subsidy of s for the total quantity of emissions abated each period, which is $[E_0Y_0 - EY]$. Because the two sE_0Y_0 terms cancel out, Porter's combination entry tax and abatement subsidy should in theory result in the same behavior by the polluting firm as would the imposition of a tax equal to s on each firm's total emissions, EY. In the case of the tax on emissions, however, firms would be required to state only their net emissions after abatement, EY, whereas to implement Porter's entry tax and abatement subsidy, firms would have to report what their emissions would have been in the absence of abatement and then calculate the emissions abated on the basis of control efficiencies of the pollution control methods that they use.

Mathematically, Porter's combination tax and subsidy are identical to a conventional tax on emissions, but it may be that in practice they would be more effective in fostering compliance than the tax. Separate reporting for the operating tax and for the abatement subsidy would bring more information to the attention of the regulatory authorities and make it more difficult for firms to provide incorrect numbers, especially when the U. S. Environmental Protection Agency is continuing to develop and update the two corresponding sets of scientific data. At the very least, if Porter's combination tax and subsidy is not implemented, his scheme does suggest a two-step method of reporting net emissions that may improve compliance under the more traditional tax approach.

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REFERENCES

1. R. C. Porter, The Long-Run Asymmetry of Subsidies and Taxes as Antipollution Policies, *Water Resources Research, 10,* pp. 415-417, 1974.

2. R. E. Kohn, Transactions Costs and the Optimal Instrument and Intensity of Air Pollution Control, *Policy Sciences*, in press.
3. J. D. Harford, Firm Behavior under Imperfectly Enforceable Pollution Standards and Taxes, *Journal of Environmental Economics and Management, 5*, pp. 26-43, 1978.
4. J. D. Harford, Violation-Minimizing Fine Schedules, *Atlantic Economic Journal*, pp. 49-56, 1987.
5. W. Harrington, Enforcement Leverage when Penalties Are Restricted, *Journal of Public Economics, 37*, pp. 29-53, 1988.
6. C. S. Russell, W. Harrington, and W. J. Vaughan, *Enforcing Pollution Control Laws*, Resources for the Future, Washington, D.C., 1986.
7. E. H. Mantell, On Economics and the Politics of Environmental Protection: Policy Conflicts Can Be Mitigated by Selective Enforcement and Tax-Financed Subsidies, *American Journal of Economics and Sociology, 44*, pp. 435-447, 1985.
8. R. H. Coase, The Problem of Social Cost, *Journal of Law and Economics, 3*, pp. 1-44, 1960.
9. D. F. Bramhall and E. S. Mills, A Note on the Asymmetry between Fees and Payments, *Water Resources Research, 2*:3, pp. 615-616, 1966.
10. A. M. Freeman, III, Bribes and Charges: Some Comments, *Water Resources Research, 3*, pp. 287-288, 1967.
11. R. B. Palmquist, Pollution Subsidies and Multiple Local Optima, *Land Economics, 66*, pp. 394-401, 1990.
12. A. V. Kneese and K.-G. Maler, Bribes and Charges in Pollution Control: An Aspect of the Coase Controversy, *Natural Resources Journal, 13*, pp. 705-716, 1973.
13. G. Yohe and P. MacAvoy, A Tax Cum Subsidy Regulatory Alternative for Controlling Pollution, *Economics Letters, 25*, pp. 177-182, 1987.
14. G. Yohe, More on the Properties of a Tax Cum Subsidy Pollution Control Strategy, *Economics Letters, 31*, pp. 193-198, 1989.
15. R. E. Kohn, *A Linear Programming Model for Air Pollution Control*, MIT Press, 1978.
16. R. E. Kohn, Variable Outputs along a Production Possibility Frontier with Inputs Constant by Choice, *Rivista Internazionale di Scienze Economiche e Commerciali, 36*, pp. 837-846, 1989.
17. R. E. Kohn, Nonconvexity in Shibata and Winrich, *Osaka Economic Papers, 40*, pp. 250-261, 1991.
18. R. E. Kohn, Efficiency in Abatement and Avoidance, *Socio-economic Planning Sciences, 22*:4, pp. 153-156, 1988.
19. G. Tullock, Asymmetry between Bribes and Charges: A Comment, *Water Resources Research, 2*:4, pp. 854-855, 1966.
20. U. S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors*, (3rd Edition), AP-42, Parts A, B, U. S. Government Printing Office, Washington, D.C., 1977.

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