On the economics of effluent charges

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Abstract: Using the theory of the competitive firm in long-run industry equilibrium the authors investigate the effectiveness of an effluent charge in controlling an industry's long-run level of pollution. The success or failure of such a charge turns out to hinge upon the conditions prevailing in the industry's output and input markets. If merely one of these markets is less than perfectly elastic and if in addition the corresponding demand or supply schedule has the normal slope, the success of the charge is guaranteed; otherwise it is not.

A propos de certains aspects économiques d'un impôt sur la pollution. A partir d'un modèle de firme concurrentielle en équilibre de longue période dans son industrie, les auteurs supputent l'efficacité d'un impôt sur la pollution comme instrument pour contrôler le niveau de pollution dans l'industrie en longue période. Il semble que le succès ou la faillite de cette stratégie dépend des conditions qui prévalent dans le marché pour le produit de l'industrie et dans les marchés pour les facteurs de production. Si dans au moins un de ces marchés, les conditions d'élasticité parfaite ne sont pas réalisées et si de plus la cédule de demande ou d'offre correspondante a une pente normale, la stratégie est gagnante; si ce n'est pas le cas, la stratégie fait faillite.

I

According to a standard result in micro-economic theory, indirect taxes typically cause a perfectly competitive, profit-maximizing producer to reduce its supply of the taxed output or its demand for the taxed input. Formally, this is a consequence of the fact that the tax rate and the taxed output or input form a conjugate pair permitting the exploitation of the qualitative content of the maximization hypothesis.[1] While in a purely technological sense pollution is an (unwarranted) output of the production process whose level may be more or

1 See Samuelson (1947) or Archibald (1965).

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less closely linked to the marketable output of the firm or to its use of an input or a subset of inputs, from an economic point of view pollution may be treated as a separate input of the firm which is either free or has a positive price in case pollution is taxed. Since effluent charges may then be viewed simply as an indirect tax on the 'input' pollution,[2] such charges are clearly an effective means of controlling it. But this result applies essentially in the short run, that is, as long as all other relevant parameters, including the prices the firm is facing, are kept constant.

The analysis of the long-run effects of an effluent charge or any other indirect tax is much less straightforward. Since the tax affects the decisions of all firms in the industry, and consequently the industry's aggregate supply and demand, raising an effluent charge is likely to trigger a series of consequent price adjustments. The long-run effect is therefore the sum of both the immediate response to the change in the rate and the responses to the ensuing price changes. Since these reactions may well work in opposite directions, it should be evident that in general it is virtually impossible to determine what an effluent charge achieves in the long run. One exception however, is the special yet popular case of a competitive industry which consists of identical firms and whose long-run equilibrium is characterized by zero profits. If this industry faces certain suitable supply and demand conditions in all its relevant markets, an effluent charge, even in the long run, will indeed be an effective way of controlling pollution. There are other constellations, however, in which the effluent charge may fail in the long run. It is the purpose of this short paper to develop this point in some more detail.

II

A natural approach to the analysis of the long-run effects of an effluent charge on the level of pollution of a competitive industry would consist of first developing the conventional (short-run) comparative statics of a single representative firm, then combining this with the implications of the zero profit characterization of long-run equilibrium, and finally attempting to derive the long-run changes in the industry's aggregate level of pollution. This approach is feasible, of course, but one can effectively short-cut this analysis by using a central result from the theory of the firm in long-run equilibrium that was developed by Ferguson and Saving (1969), Basset and Borcherding (1970), Silberberg (1974), and others. This theory considers an industry consisting of identical competitive firms which maximize their individual profits

2 To treat pollution as a separate input at the discretion of the firm has the advantage of generality. In particular, with this approach there is no need to specify which input or output proper causes the pollution, what the functional relation might be, or how abatement activities work if there are any at the firm's disposal. The only assumption we make (implicitly) is that the firm's technology defined on all inputs (including pollution) is well behaved in the sense that it is compatible with profit maximization.

$$\pi = py - \sum_{i=1}^{n} w_i x_i, \tag{1}$$

subject to some sufficiently well-behaved constraint of the form $g(y, x_1, \ldots, x_n) = 0$ that summarizes the available technology as well as possibly some other relevant constraints. Here, y denotes the single firm's output, $x_1, \ldots, x_n$ are its inputs, p is the output price, and $w_1, \ldots, w_n$ are consequently the input prices. The basic idea of this theory is that if profits will always be driven down to zero in long-run equilibrium, the representative firm will behave in the long run as if it were minimizing average cost. As Silberberg (1974, theorem 1) has shown, this implies that the matrix of cross-partial derivatives

$$S = \left(\frac{\partial(x_i^*/y^*)}{\partial w_j}\right) \tag{2}$$

is symmetric and negative semi-definite. It is important to note that the typical element in this matrix denotes the representative firm's long-run reaction if merely the input price w_j changes, and this price change is entirely passed on to the output price p (which equals average cost). These long-run reactions thus incorporate the effects of two price changes: the effect of the (original) change in the input price, and the effect of the consequent change in the output price. Using the envelope theorem, it is easy to derive the latter's magnitude from the zero profit condition. Generally, between two long-run equilibria we must have

$$\begin{aligned} d\pi^* &= (\partial\pi^*/\partial p)dp - \sum_{i=1}^{n} (\partial\pi^*/\partial w_i)dw_i \\ &= y^*dp - \sum_{i=1}^{n} x_i^* dw_i = 0 \end{aligned} \tag{3}$$

which implies immediately $dp = dw_j \cdot x_j^*/y^*$ if w_j is the only input price that was allowed to change.

We mentioned already that one may view pollution as an input of the firm. Consequently, we are free to identify, say, x_n with the representative firm's level of pollution and accordingly w_n with the effluent charge and utilize the basic results just mentioned to address our principal question. To do so we shall investigate the long-run effects of effluent charges within three different frameworks: first, it will be assumed that the polluting industry faces a perfectly elastic supply in all its input markets; second, that the demand for the industry's output as well as the aggregate supply of its inputs with the exception of one input $x_{j \neq n}$ are completely elastic; and finally the general situation in which neither the demand for the industry's output, nor the supply of any of its inputs need to be perfectly elastic.

1. Consider then the first case of an industry facing a perfectly elastic supply in all its input markets. This is exactly the one covered by the theory of the firm in long-run equilibrium, that is, the case where a change in the effluent charge w_n must eventually be passed on entirely to the output price. Using (3), we may

equivalently characterize this situation by the vector of price changes ($dp = dw_n x_n^*/y^*$, $dw_{i \neq n} = 0$, $dw_n \neq 0$). Let X_n represent the industry's aggregate level of pollution, Y its aggregate output, and note that aggregate pollution may be expressed as the product of aggregate output and the representative firm's intensity of pollution per unit of output. Differentiating totally, we have

$$dX_n = d(Yx_n^*/y^*) = \left[\frac{\partial Y}{\partial p}\left(\frac{x_n^*}{y^*}\right)^2 + Y\frac{\partial(x_n^*/y^*)}{\partial w_n}\right]dw_n. \tag{4.1}$$

Now, the second term in the bracket is clearly non-positive since the partial derivative $\partial(x_n^*/y^*)/\partial w_n$ is simply a diagonal element of the negative semi-definite matrix S. The first term will also be non-positive if demand for the industry's output is normal in the sense that demand will not rise when the output price rises ($\partial Y/\partial p \leqq 0$). Thus, we conclude that if aggregate supply of inputs is completely elastic and if aggregate demand for the industry's output is normal, an effluent charge is, in the long run, certainly not counterproductive in controlling the industry's level of aggregate pollution.[3]

2. Consider in turn the second case where the demand for the industry's output and the aggregate supply of its inputs, with the exception of the supply of input $x_{j \neq n}$, are completely elastic. In this situation, any change in the effluent charge will eventually have to be passed on entirely to the price of input j. Thus, in view of (3), this case is characterized by the vector of price changes ($dp = 0$, $dw_{i \neq j,n} = 0$, $dw_j = -dw_n x_n^*/x_j^*$, $dw_n \neq 0$). Note that here aggregate pollution may be represented in the form $X_n = X_j(x_n^*/y^*)/(x_j^*/y^*)$ where X_j denotes aggregate supply of input j to the industry. Differentiating totally, we have in view of the price changes characterizing this situation

$$dX_n = \left[-\frac{\partial X_j}{\partial w_j}\left(\frac{x_n^*}{x_j^*}\right)^2 + \frac{X_j y^*}{x_j^{*3}}\left(x_n^{*2}\frac{\partial(x_j^*/y^*)}{\partial w_j} - x_n^* x_j^*\frac{\partial(x_n^*/y^*)}{\partial w_j} - x_j^* x_n^*\frac{\partial(x_j^*/y^*)}{\partial w_n} + x_j^{*2}\frac{\partial(x_n^*/y^*)}{\partial w_n}\right)\right]dw_n. \tag{4.2}$$

The second term on the RHS is again clearly non-positive, since the sum of the four terms inside the associated bracket is a quadratic form in S. The first term

3 This unambiguous result for the setup currently considered clearly contradicts Baumol and Oates, who analyse the same question (in a slightly less general setting) but conclude that the long-run effect of an effluent charge on aggregate pollution of a competitive industry remains unclear (1975, chapter XII, proposition 4). Baumol and Oates assume a given cost function for the representative firm which implies fixed input prices for the firm (and the entire industry) and hence completely elastic aggregate supply of all inputs to the industry. The ambiguity in Baumol and Oates's analysis is an immediate consequence of the fact that they apparently inadvertently identify the industry's long-run reaction to the effluent charge with that of the representative firm.

likewise will be non-positive if aggregate supply of input j is normal in the sense of $\partial X_j/\partial w_j \geqq 0$. Thus, an effluent charge will, in the long-run, not be counterproductive if aggregate supply of input j is normal, while aggregate supply of all other inputs and aggregate demand for the industry's output are completely elastic.

3. We have shown that an effluent charge is not counterproductive in the long-run if it is either entirely passed on to the output price or to some input price, and if aggregate demand for the output or supply of this input is normal. One would perhaps expect that by combining these two arguments one could show that an effluent charge will be effective in the long run irrespective of how it is eventually passed on as long as aggregate demand for the industry's output and aggregate supply of its inputs are normal. Unfortunately, however, these assumptions do not yet suffice to guarantee this. Consider, for example, an industry whose output and input markets are all normal ($\partial Y/\partial p \leqq 0$, $\partial X_{j\neq n}/\partial w_j \geqq 0$) but not necessarily completely elastic. If the effluent charge is changed, the only information about the consequent price adjustments we have is that altogether they must restore the zero profit equilibrium and thus satisfy (3). But this is still too little for a clearcut answer. To make the reason of the underlying ambiguity more visible decompose the entire change in the effluent charge into a sum of changes, each of which may per se be thought of as being exclusively passed on to either the output price or to some input price. In other words, define

$$dw_n = \sum_{i=0}^{n-1} dw_n^{\,i} \tag{5}$$

in such a way that (3) may be rewritten in the form

$$d\pi^* = (y^*dp - x_n^*dw_n^{\,0}) - \sum_{i=1}^{n-1}(x_i^*dw_i + x_n^*dw_n^{\,i}) = 0,$$

where all brackets vanish individually. With this construct, the general case currently considered may be characterized by the vector of price changes ($dp = dw_n^{\,0}x_n^*/y^*$, $dw_{i\neq n} = -dw_n^{\,i}x_n^*/x_i^*$, $dw_n = \sum_{i=0}^{n-1} dw_n^{\,i}$). Accordingly, we may express the entire long-run change in aggregate pollution by the sum

$$dX_n = dX_n^{\,0} + \sum_{i=1}^{n-1} dX_n^{\,i} \tag{4.3}$$

where $dX_n^{\,0}$ is the RHS of (4.1), with dw_n replaced by $dw_n^{\,0}$; and $dX_n^{\,i}$ is the RHS of (4.2), with dw_n replaced by $dw_n^{\,i}$. Now, given normal conditions in all markets, (4.3) is signed unambiguously only if all the $dw_n^{\,i}$ in (5) have the same sign. To put it positively, the industry's aggregate level of pollution will certainly not rise in the long run if, after some rise in the effluent charge, its output price does not fall and none of its input prices rises. Then all the $dw_n^{\,i}$ would be non-negative and all the components of the RHS of (4.3) would be non-positive by (4.1) and (4.2). But there is nothing in our assumptions to guarantee this. Indeed, just what the industry's new equilibrium price vector will be and accordingly how the vector of price changes (dp, $dw_{i\neq n}$, dw_n) will look is essentially a matter of both the technology of the representative firm and the conditions prevailing in the industry's markets. Suppose that a large part of the effluent charge is eventually passed on to the output price ($dp \gtreqq 0$) and that some input $i \neq n$ (i.e., some input other than the 'input' pollution) is strongly superior. It is then entirely possible that despite the drop in the industry's aggregate output, the industry's demand for input i rises, which in view of the normality assumption would imply $dw_i \gtreqq 0$. Thus, we would already have a case where we are unable to determine whether or not the effluent charge is an effective means of controlling pollution in the long-run.[4]

III

Our results of the analysis of effluent charges are somewhat ambivalent. We have just indicated why it is, in general, not possible to determine whether or not an effluent charge levied on a competitive industry will be an effective way of fighting pollution in the long run. This ambiguity disappears, however, if in the adjustment process leading to a new long-run equilibrium no input price moves in the same direction as the effluent charge, and the output price does not move in the opposite direction. If this situation applies, then the assumption of normally sloped market demand and supply curves together with the profit maximization hypothesis and the zero profit condition permit the conclusion that an effluent charge is, in the long run, not counterproductive in controlling aggregate pollution.

Two such constellations where no ambiguity arises have been especially considered. One is the widely used case of a 'small' industry that faces a perfectly elastic supply in all its input markets. In this situation no input price can move, so that the effluent charge must eventually be passed on entirely to the output price. The other is the rather artificial case of an industry facing perfectly elastic demand and supply in all its markets except for one input market. In this situation, the charge must be passed on entirely to this particular input, so that again the effluent charge is clearly not counterproductive. Our analysis consequently suggests that the long-run effectiveness of an effluent charge remains essentially in doubt, unless the industry under consideration is small in the sense just indicated.

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4 To put it differently, our assumption that the demand curve for the industry's output is not upward sloping and that the aggregate input supply curves are not downward sloping is too weak always to guaranty the long-run effectiveness of an effluent charge (or any other indirect tax). In order to remove the ambiguity arising in cases such as the one just mentioned one has to take precautions against the possibility that in the adjustment process leading to a new long-run equilibrium cross-price effects become too strong.

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