A THEORETICAL FRAMEWORK FOR VIEWING POLLUTION PROBLEMS

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INTRODUCTION

In the 1960's, we developed a strong public conscience about the environment. The 1970's will reveal a great deal about our ability to better understand and manage the environment in socially acceptable ways. This task will require both theories and measurement techniques to empirically verify them. A welfare theory (based largely on Paretian welfare economics) states that we can say one system is preferable to another if the system makes at least one person better off and no one worse off. Most alternative systems in the real world, including those available to resolve pollution conflicts, do not meet this criterion. A change in the system normally makes someone worse off. Thus, Paretian, or the "new," welfare economics, is not really useful in making most policy decisions. The problem is compounded, because often we do not know how to measure the real effects of pollution on parties involved in and influenced by pollution. This later problem is aggravated by the fact that we have done very little to systematically record observations on pollution processes. The sheer size of the observational task is staggering. All we can ever hope to do is observe life forms which seem to be critical indicators of harmful pollutants. Filter feeders and life forms (such as man) at the ends of food chains are the most likely candidates. Many important variables are not observable because of our inability to measure them and others are just not recognized as being important with the current state of knowledge. Lack of data seriously handicaps applied research. The theoretical framework suggested is based on the concept of consumers' and producers' surplus which dates back to Marshall [14, pp. 124-132, 811]. Though controversial [9, 17], this measure of welfare has been widely used [8, 10, 15, 18, 19], mainly, because researchers working on an applied problem have found the concept to be empirically operational. Before discussing this theoretical framework, I will briefly consider the concept of an externality and allocative mechanisms to deal with public goods and externalities.

ON ALLOCATING ENVIRONMENTAL RESOURCES

In its simplest form, an externality exists when the actions of one party, B, affects the utility or production function of another party, A. Whether or not A will actually try to influence B's action depends upon the costs and benefits of his doing so. If A is motivated to attempt to influence the action of B, the externality may be termed potentially relevant [1, p. 373]. An externality may create economies or diseconomies, but it is the diseconomies which generally create conflict.

Pollution problems are generally caused by technological external diseconomies[1] created by some party who uses a resource such as air or water as though it were a free good and neglects any costs which may be inflicted on others. Consequently, there is an inefficient allocation of resources because

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[1] A technological externality is one that is transferred from one decision unit to another by a technical or physical linkage [12, p. 41]. Externalities can also be pecuniary, in which case they are transmitted by a market mechanism and do not generally lead to what is considered an inefficient resource allocation.

not all costs enter the polluter's resource use decision.

Some pollution problems arise quite innocently because what is right or wrong concerning the environment is situation sensitive and continual change can bring about new situations quite subtly. As our population and economic activities increase at growing rates in our finite environment, there are greater opportunities and dangers of one's actions creating an externality. Because of this situation, each decision-maker should be more alert to the implications of his actions.

Theoretically, in a costless bargaining situation, two parties will resolve an environmental dispute in an economically efficient (Pareto optimal) manner. The distribution of the benefits from pollution will, of course, be affected by the assignment of property rights. Over time, costs and benefits do influence the assignment of property rights [16, pp. 592-633, especially p. 602]. However, the assignment of property rights, with the associated ethical implications, is largely a function of the legal and political process. The political processes can, of course, specify a solution to the allocation problem by restricting the bargaining process. Much to the chagrin of economists this political solution to the allocation problem may be at considerable variance to the economic solution. Regardless of who holds property rights, the parties can find it to their mutual benefit to pollute the environment up to that point where B's net marginal gain from polluting the environment will equal the marginal cost to A of having his environment polluted. Because of this result, some economists agree that pollution problems should be resolved in a bargaining type framework.

Most agricultural pollutants enter the environment via two free goods—air and ground water. Whether man is capable of developing a decentralized mechanism which will serve the allocative function of a market in such public goods with externalities remains undertermined.[2] The market mechanism has not functioned for these resources because of the market requirement for provisions of ownership, control, and exclusion [4, pp. 362-363]. At present it seems that some judicial administrative process will be required to strongly assist the allocative process. Economists worry about such processes because of the difficulty of establishing that a particular allocative device will lead to (or perhaps even toward) a solution which is optimal in some socially meaningful sense.

Demsetz [5] has stressed the importance of control over the behavior of individuals which any allocative mechanism must have and the real world cost of this control. Clearly, if benefits from an optimal allocation of environmental resources are not sufficient to cover the cost of control with whatever allocative mechanism (centralized or decentralized) is required to attain the benefits, society will be better off with unabated pollution. If the rewards to society from pollution abatement are sufficient to cover the institutional costs of providing an allocative mechanism, the question of how much pollution is socially optimal still remains, as does the associated problem of how the costs and benefits from attaining this level of pollution should be distributed.

Society might use a majority vote to settle pollution conflicts. In this case the vote would have to be unanimous if such an approach is to be Pareto optimal. Regardless of the means chosen to allocate environmental resources, policymakers need measures of the social costs and benefits for various levels of environmental pollution. Let us turn to a theoretical framework which may be of use to the applied researcher in an attempt to assess benefits from alternative policies. The framework provides no help in measuring the costs of providing the institutional mechanism for administering a particular policy, and it provides only a partial equilibrium analysis.

A THEORETICAL FRAMEWORK

Suppose that a farmer's demand for fertilizer to produce a crop is given by D and that he faces a perfectly elastic supply function, S, for the input so that under conditions of a free market the farmer would maximize profits by using q_1 units of fertilizer (Figure 1). Further, suppose that the farmer's use of the chemical has environmental implications depicted by environmental damage or externality function E. This function is a relationship between the net marginal social cost of fertilizer pollution (measured in value of dollars to the producer) and the quantity of fertilizer used. The assumption of knowledge of such a function is a very strong assertion. Bound up in this theoretical function are all the social costs of the "spill over" effects of the input on the environment [6, pp. 66-103]. If the price of fertilizer had included

[2]Hurwicz [11] has been interested in the problem of institutional processes which have some hope of performing as a competitive system. He suggests that we accept as competitive those processes for which informational decentralization is possible. More recently he has been considering decentralized mechanisms for internalizing externalities. Davis and Whinston [2] and an exchange between Wellisz [20] and Davis and Whinston [3] have contributed to the question of how to internalize externalities in a decentralized decision process.

the environmental cost, the farmer would have found it most profitable to use only q_2 units of fertilizer as indicated by his new derived demand D'.

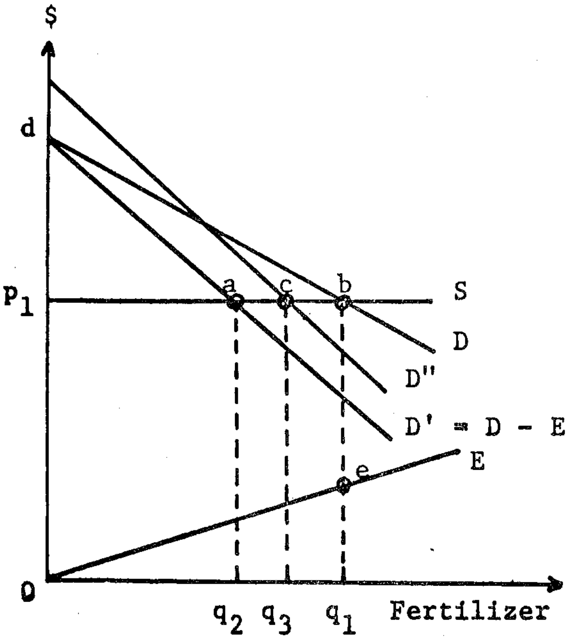

FIGURE 1

The farmer's gain from using fertilizer in an unrestricted manner is represented by the area p_1bd and the cost to society by Oq_1e. The farmer would be willing to use additional fertilizer, and pay society for the privilege if he had to, as long as his marginal gain was greater than the marginal cost to society (i.e., at the level of input being considered, $D' > S$), assuming a free market situation. Similarly, if the marginal cost to society had to be paid by the farmer and was greater than the farmer's marginal revenue (i.e., $S > D'$), it would pay the farmer not to use the marginal increment of fertilizer. Thus, the quantity q_2 would represent a shortrun socially optimal equilibrium in a frictionless ceterus paribus world.

If all farmers have to pay the social cost of their externalities, one would expect the industry supply function for the product being produced with fertilizer to shift to the left and to raise the price of the product. This would in turn shift the individual farmer's derived demand for fertilizer to the right. After all adjustments were completed, the firm's demand for fertilizer might be as depicted by D'' which yields a stable solution of q_3. My colleague, B. R. Eddleman, pointed out that it is possible for q_3 to be to the right of q_1 if the firm's derived demand for fertilizer shifts enough. Since one would expect a reduced supply of product at the industry level, a larger usage of the input at the firm level would indicate that the industry was made up of fewer and larger firms after the adjustment process. Large firms may have a relative advantage in the adjustment process. The distribution of benefits of social action to clean up the environment is an important issue for the social scientist but one which is not considered herein.

In this simplified one input (x), one output (y), knowledgeable world, the anlaysis can also be depicted in terms of the optimal quantity of product (Figure 2). The profit maximizing solution for the farmer when the externalities are ignored is q_1'. And, it is q_2' when externalities are included in the production decision. $E_y = E \cdot (\frac{dx}{dy})$. Again this is a shortrun static result. Since adjustment at the industry level would be expected to increase price from p_y to p_y', the equilibrium after all adjustments would be q_3'.

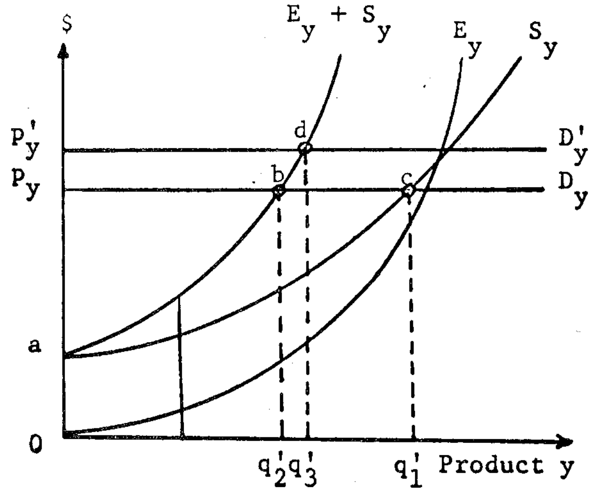

FIGURE 2

To be more realistic the idea of bringing externalities into the decision framework can be expanded into a multi-input, multi-product model. Consider the following production function with n inputs and two products where the first m inputs may pollute the environment:

$$y_1 = f(x_1, \dots, x_m; x_{m+1}, \dots, x_n; y_2 | \dots)$$

Again, assume the producer faces perfectly elastic functions for input supplies and product demands. With this information, one can derive the firm's supply function for y_1 for any fixed value of y_2, say y_2^o.

Given y_2^o the well-known conditions on the expansion path for y_1 if externalities are ignored are:

$$\frac{p_{x_1}}{\frac{\partial y_1}{\partial x_1}} = \dots = \frac{p_{x_n}}{\frac{\partial y_1}{\partial x_n}} \tag{1}$$

With marginal externalities of the type[3] $E_i = g(x_i)$, $i = 1, \dots, m$, these conditions for a socially optimal expansion path become:

$$\frac{p_{x_1} + E_1}{\frac{\partial y_1}{\partial x_1}} = \dots = \frac{p_{x_m} + E_m}{\frac{\partial y_1}{\partial x_m}} = \frac{p_{x_{m+1}}}{\frac{\partial y_1}{\partial x_{m+1}}} = \dots = \frac{p_{x_n}}{\frac{\partial y_1}{\partial x_n}} \tag{2}$$

For given y_2^o, supply functions associated with these two expansion paths for y_1 might look much the same as S_y and $E_y + S_y$ in Figure 2. For a given amount of y_1 being produced the two curves would differ by an amount

$$\sum_{i=1}^{m} E_i \frac{\partial x_i}{\partial y_1}.$$

The level of output which maximizes returns to society is again q_2^1. Again we can argue that with frictionless and rational bargaining q_2^1 will attain in the shortrun and q_3^1 after industry adjustments.

In the models of Figures 1 and 2, there is a question about the opportunity cost of resources which are released from the production process when the solution is shifted from the q_1's to the q_3's. Sidestep this problem by assuming that alternatives exist for these displaced resources which are as socially desirable as their use in the production of y. For this and other reasons, the model represents only a partial analysis. Also, there is no consideration of what happened to prices of close substitutes for the commodity and the inputs used to produce it, and while we have considered the model only at the farm level, there may be some important considerations between the farm and final consumption.

Aggregation beyond the firm may be depicted as in Figure 3, where curves are represented in a linear manner to simplify exposition. However, in order to represent areas of consumers' and producers' surplus as a measure of social welfare, additional strong assumptions of a constant and identical marginal utility of money for each member of society are needed. Less stringent assumptions might be that the income effects due to changes in prices of inputs and outputs are negligible.

The demand and supply curves are those for the industry and have their bases in individual utility functions and firm supply functions, respectively. The externality or damage function represents a vertical summation of the m marginal externality functions (E_i, Figure 2) created by the actions of each producer at each level of output. Again the socially optimal level of output for the industry is Q_2, because Q_1 does not include all the cost of supplying the economic good y and therefore represents an economically inefficient result.

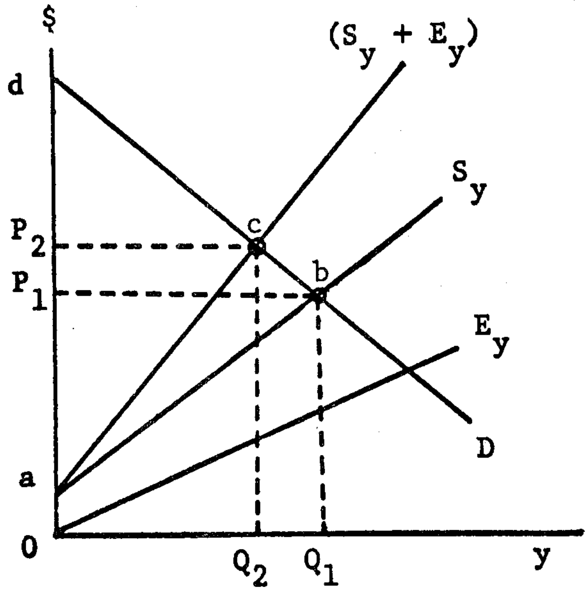

FIGURE 3

Theoretically, the functions in Figure 3 derive from individual supply and utility functions. From a research point-of-view, there is an interesting question of the consequences of deriving the functions directly—particularly since our profession has considerable experience with demand and supply analyses. Unfortunately, this expertise does not extend to functions like E_y.

If one could determine the total cost of pollution TC_p as a function of output, would

$$\frac{\partial TC_p}{\partial y} + S_y$$

yield a valid measure of $S_y + E_y$? The answer to the question would depend on how much the marginal net social costs of individual inputs affect the expansion paths from which S_y derives. If S_y is derived from firm supply curves which are, in turn, derived from expansion paths like (1) which are at considerable variance from the socially optimal expansion

[3]The E_i's represent net marginal cost functions.

paths (2), then a direct empirical measure of E_y would seem inappropriate. The inappropriateness of the estimate is based on the fact that the pollution observed and used to estimate E_y was based on production from socially inefficient resource use patterns.

Does this result leave us with an empty box with respect to determining social optima from direct empirical measurement of pollution costs? Perhaps not—at least in those cases where the expansion paths of individual producers are not at variance (or only slightly at variance) with the socially optimal expansion paths. Turn now to some examples of pollution where such seems to be the case.

EXAMPLES

Some agricultural pollutants are produced in essentially rigid proportions with output. Animal wastes (including odors) from cattle feedlots provide a good example. In such a case, the wastes are joint products and would not affect the expansion path for the production of beef under given technology.

Certain inputs which create pollution problems in agriculture may have very little effect on the expansion path. For example, the production response to certain pesticide sprays is believed by some to take on the form of a near stepped function as depicted in Figure 4. That is, the product is responsive to the input only over a rather narrow range of the input. The producer must either use the input at a rate near q_2 or in many cases not produce. (This seems to be the case in the winter vegetable area of South Florida.) In such cases, the solution would be relatively stable over a considerable range of pesticide prices so that the inclusion in price of the net social marginal cost due to pollution may have little effect on the expansion path which includes only the private costs of inputs. Another very similar example is provided by sugar cane burning in South Florida. It seems that if you produce you must burn. Consequently, the input of burning is similar to a zero-one variable, and the pollution from burning is produced in some rather fixed proportion of output. Therefore, the input of burning would have little effect on the expansion path which includes only the private cost of the inputs.

Another situation which may admit direct estimation of the environmental damage function might be termed the natural disaster or random event case. Again, the need for certain pesticides and for burning provide examples. An insect infestation (e.g. the army worm in the Midwest) may require a pesticide to save a grain crop. Heating of citrus groves in Florida to reduce the damage of a freeze provides another example. In such circumstances, the social cost of the pollutant (the pesticide or the smoke from heaters) may condition the level of optimal output, but would have very little effect on input mix, given that it was socially desirable to save more of the crop than would survive without nature receiving an assist.

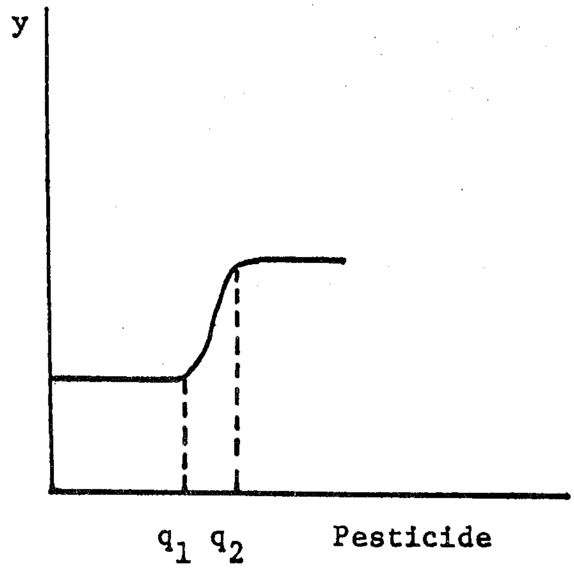

FIGURE 4

In each of these cases where the socially efficient expansion paths do not seem to vary from the individual producer's expansion path, a direct approach to measuring environmental damage would lead to little bias. As a result, we may, as agricultural economists, be able to take advantage of our considerable stock of knowledge with regard to demand and supply analysis in the study of pollution problems.

AN OVERALL MATHEMATICAL MODEL

Frank Edwards and I have used such a model in an attempt to gain some insight into the socially optimal level of pesticide use for an agricultural region [6, 7]. We used a quadratic programming model to aggregate across crops. Our model assumed that the supply and demand functions for each crop were linear and separable. The model we used can be modified to admit jointly produced or jointly consumed products. Though each production (consumption) activity would assume that products are produced (consumed) in fixed proportions, proportions could be varied by increasing the number of activities. The more general version of the model may be stated as follows:

For a set of pollution abatement policies, r, r = 1, . . . , s, rank the policies on the basis of estimated welfare Wr, where:

$$W_r = \underset{x_i, y_j, z_k}{\text{maximum}} \left\{ \sum_{i=1}^{m} \int_{o}^{x_i} f_i(x_i)dx_i - \sum_{j=1}^{n} \left[\int_{*}^{y_j} (g_j^r(y_j) + h_j^r(y_j))\, dy_j \right] - \sum_{k=1}^{q} \int_{*}^{z_k} h_k(z_k)dz_k \right\}$$

*Integration from intercept on y_j (or z_i) axis if intercept occurs where y_j (or z_i) $\geq$ 0, if not integration from zero.

Subject to:

$$\sum_{j=1}^{n} a_{\iota j}^{r}\, y_j \lesseqgtr b_\iota, \qquad \text{for } \iota = 1, \ldots, \eta \qquad (3)$$

$$\sum_{j=1}^{n} \alpha_{kj}^{r}\, y_j - z_k = 0, \qquad \text{for } k = 1, \ldots, q \qquad (4)$$

$$x_i - \sum_{j=1}^{n} \delta_{ij}\, y_j = 0, \qquad \text{for } i = 1, \ldots, \mu \qquad (5)$$

where $\mu > m$ if a certain x_i represents a set of products consumed in fixed proportions.

$$c_{\lambda k}(z_k) \leq C^{*}_{\lambda k}, \qquad \text{for } \lambda = 1, \ldots, p \qquad (6)$$

where:

$f_i(x_i)$ = demand function for the i^{th} product. The i^{th} variable could represent a set of products being consumed in rigid proportions.

$g_j^r(y_j)$ = supply function for the j^{th} product under the r^{th} policy alternative. The j^{th} product could represent a set of products being produced in fixed proportions.

$h_j^r(y_j)$ = a "damage" or "externality function," a functional relationship between the marginal cost of pollution to society caused by producing y_j and the quantity of y_j produced. The pollution externalities which enter $h_j^r(y_j)$ should be those which are unique to y_j. Some externalities result from an input (e.g. a pesticide) which is required by more than one y_j. In such cases the externalities should be reflected through $h_k(z_k)$.

$h_k(z_k)$ = an "externality function," a functional relationship between the marginal cost of pollution to society from the use of input z_k and the quantity of z_k used.

$a_{\iota j}^{r}$ = the quantity of the ι^{th} resource required to produce a unit of the j^{th} product. This quantity could be a fixed coefficient or a function of y_j.

b_ι = the quantity of the ι resource available for production in the region being studied.

α_{kj}^{r} = the quantity of the k^{th} polluting input required per unit of the j^{th} product produced under the r^{th} policy.

δ_{ij} = the proportion of y_j devoted to the i^{th} product. If x_i and y_j are the same product δ_{ij} = 1. If y_j is an activity which produces a set of products in fixed proportion, δ_{ij} will be the proportion of y_j yielding product x_i.

$c_{\lambda k}(z_k)$= a functional relationship between the k^{th} pollutant which enters the λ^{th} environmental element and the amount of the pollutant placed in the environment.

$C^{*}_{\lambda k}$ = the maximum level of the k^{th} pollutant which society is willing to admit in the λ^{th} environmental element.

The model can be solved for a unique maximum with a separable program[4] if the $f_i(x_i)$ $g_j^r(y_j)$, $h_j^r(y_j)$, $h_k(z_k)$, and $c_{\lambda k}(z_k)$ meet necessary convexity requirements.

The objective function of the model is separable in the x_i, y_j, and z_k. Although, as indicated, joint products could be aggregated into one activity, the model as specified does not permit synergistic effects among the z_k.

The static nature of the model represents a gross abstraction from the real world. One can use longrun estimates of supply and demand. However, the build-up phenomenon of certain pollutants is a dynamic process and can only be crudely accommodated within a static framework.

The model permits externalities to enter in one of two ways–either through $h_j^r(y_j)$ or $h_k(z_k)$. The inclusion of both types of externality functions permits somewhat more flexibility in structuring the model.

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[4]The IBM separable programming feature of MPS/360 was used to solve a similar model.

However, to avoid double counting, a given externality must enter only one of these functions.

CONCLUSIONS

The framework suggested was a static optimization model. Economists may be overly concerned with optimal solutions when perhaps they should look at the real world situation as being n^{th} best and then direct their attention to the economic problems associated with reducing n. Such an approach would make our science less one of position and more one of movement. Perhaps this approach would make our recommendations more acceptable to the political processes which are an important consideration. However, if we ignore theoretical developments regarding position or equilibrium (and the associated properties of equilibria) we may not be able to say much about the direction of needed change.

As stated earlier, if the socially optimal expansion path for a producer is at considerable variance with the expansion path for that producer without consideration of environmental externalities, then the research process to determine a socially optimal level of pollution must start with production function analysis. However, if including pollution externalities has little effect on the individual producer's expansion path, the problem may be approached directly from the product side. The latter approach is particularly enticing since our profession has such a rich history and what appear to be reasonably satisfactory tools for demand and supply analysis.

The estimation of damage functions remains as the greatest obstacle to meaningful research. Data for this task are almost entirely inadequate. As applied economists, we have been somewhat guilty of playing down the role of observation and data collection and of dwelling on techniques which assume the existence of data. Those who have tried to do empirical research on pesticide problems will recognize the need to let the pendulum swing back to greater support for data collection and reporting. However, in this observational process we must maintain a deep concern for theory or we may end up with the wrong data or data in an unusable form.

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