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PESTICIDE RESIDUES AND ENVIRONMENTAL ECONOMICS*

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The substitution of capital for labor characterizes industrialized economies of the world. Labor so released can then pursue leisure activities, or may be utilized in the production of new capital goods or services.

The effect of industrialization in agriculture has been to substitute capital not only for labor but also for land. Developed countries of the world have continued to increase agricultural output with declining labor resources and a constant or declining land base. As labor resources leave agriculture for urban employment, farms become larger and more dependent on non-agricultural industry to supply many of the inputs to agricultural production. These large farms also tend to produce fewer intermediate products.[1]

Increasing amounts of capital are being used in agricultural production to purchase inputs of higher quality and larger quantities. These improved inputs can be observed in the technical developments in varieties, animal breeding, fertilizer, mechanization and chemical pest control.

Partly, as a result of these developments, the supply of agricultural products in the United States has increased faster than demand, resulting in farm incomes that were substandard relative to those in other sectors of our economy. In an industry characterized by several million individual firms, owners and managers of agricultural resources reacted to decreasing incomes with a desire for capital goods designed to lower unit costs of production. Therefore, in spite of a history of incomes unconducive to labor inflows, capital has entered agriculture, at a rate equal to or exceeding that of any other industry in the nation.

Public and private sources have developed technology designed to increase agricultural output with fewer input resources. One offspring form of this technology has been the development of chemical compounds to control pests, diseases, and undesirable weeds. Demand for these products by farmers has grown dramatically.

With the increase in the use of chemicals to control pests, crop

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[1] Breimyer, *The Three Economies of Agriculture*, 44 J. Farm Econ. 679 (1962).

production has become less diversified and more mechanized. The advent of new varieties, cheaper fertilizers, and pesticides has eliminated the need for producing crops in rotations throughout much of the plains and the corn belt. Given the way agriculture is now organized, a high degree of pest control is an important part of commercial agriculture and determines the competitive ability of a large number of commercial farmers.

Chemicals used to control pests are of several different types. Those that have received the most attention recently are the insecticides, represented principally by the chlorinated hydrocarbons, the organic phosphates, and the carbamates. In the control of weeds and brush, phenoxyacetic acid (2,4-D), arsenicals and carbamates and phenol compounds are common. Other compounds are used, but the above are the principal ones. Some insecticides contain metals such as copper and zinc, while others contain materials botanically derived, such as the pyrethrins. However, the bulk of the materials used in insecticides are organic compounds that are synthesized by modern chemistry.

A chemical material used in pest control becomes a part of the environment. Some of the material may be found in the remains of the controlled pest, in the soil, the plant or animal that is being protected, the water, the air, or in other organisms such as people, domestic animals, fish, wildlife, and other living matter.

Some compounds such as parathion volatilize rapidly after spray application and in a relatively short period of time, perhaps days, there is no measurable residue in the treated area. Other compounds like the chlorinated hydrocarbons are very persistent, and a measurable residue of the compound itself or of a degradation product may remain for many weeks, even years. From the standpoint of persons using the pesticide, this persistence is a very desirable characteristic because it reduces the need for repeated applications.

Farmers used approximately 458 million pounds of active chemical ingredients in the United States for pest control in 1964. About 90 percent was applied to planted crops, with the balance used on livestock, stored products and other uses. Of the total pesticides used by farmers, fungicides, herbicides, and insecticides accounted for about 37, 18, and 34 percent, respectively, and the remainder were for defoliants, fumigants, rodents, etc.[2]

There are over 10,000 different commercial products marketed as pesticides which are developed from about 250 basic chemical products. Pesticides used by farmers are not diverse in chemical in-

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[2] Eichers, *Quantities of Pesticides Used by Farmers in 1964*, 131 U.S.D.A. Agric. Econ. Rep. (1968).

gredients. Data from 1964 indicate that two ingredients accounted for 55 percent of the herbicides used. Six insecticide ingredients accounted for 75 percent of the insecticides used and one ingredient (sulfur) accounted for 80 percent of the fungicides applied by farmers.[3]

Discovery of traces of the commonly used pesticide materials in the tissue of man, other animals and birds has raised the question of environmental pollution resulting from pest control. Laboratory findings suggest that at sufficiently high dosage levels, some pesticides may produce carcinogenic and mutagenic effects. The fact that DDT has become widely dispersed and the possibility of adverse ecological changes has made chemical pest control one of the important issues of our time.

The rationale for farm adoption of chemical pest control has been outlined above. However, there are other economic issues associated with chemical pest control that assist in focusing on the problem. Chemical pest control is not unlike other technological developments that have shown various kinds of interdependencies. The invention and widespread adoption of automobiles has resulted in vast changes in the way of life of almost everyone in the United States. Highways have crisscrossed the country and travelers have generated noise, litter and gaseous residuals. The price of our great automotive mobility has been not only the resources that go directly into manufacture, operation, and service of cars and highways but also alteration of the landscape, noise, and a change in the chemical characteristics of the air.[4]

Since a pesticide is not destroyed, but only transformed or moved about in the environment, the residual may enter the consumption function and/or production function of persons who were not a part of the decision that brought about the pesticides' application. In so doing, the pesticide residual results in what economists call an externality or an external effect.[5] The external effect may be either beneficial or harmful to the externally affected party. Of principal significance is that the amount of the external effect cannot be controlled by the person receiving it. If one farmer's pest control activities result in fewer pests in the fields of surrounding farmers, these neighbors have no control over the quantity of benefits they receive. They have no means other than charity to reward their

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[3] *Id.*

[4] For a discussion of the economic and public policy issues related to the use of pesticides see Headley and Lewis, The Pesticide Problem: An Economic Approach to Public Policy, (1967).

[5] Ayers & Kneese, *Production, Consumption, and Externalities*, 59 Am. Econ. Rev. 282 (1969).

neighbor for his beneficial actions. Similarly, if a farmer's use of pesticides results in a downward trend in wildlife that is enjoyed, even aesthetically, by others. there is no direct economic signal to the farmer causing him to take account of these values in his decision-making process.

Economists have long recognized the existence of external effects generating implications on the utility of individuals, but the consequences of these externalities have been largely ignored in economic analyses. There is little theoretical basis for measuring externalities, and it is this lack of theoretical basis which makes it difficult to interpret the meaning of externalities in a social welfare sense. To complicate matters, externalities–especially those associated with environmental quality–seem to be intensifying with new technology and increasing population.

A system which cannot interpret these extramarket effects may be justifiably forced to suppress them with seemingly arbitrary political action in order to obtain the necessary time for measurement problems to be solved. For example, the effects of the persistent pesticides in the environment have been difficult to measure and interpret. Such difficulties have led to a state of ignorance which has created social pressure for a holding action by banning the use of these persistent pesticides.

The measurement problems created by residuals in the environment clearly fall within the domain of scientific inquiry. These problems are also recognized as being interdisciplinary, but the responsibilities of individual disciplines remain somewhat obscure. A clearer partitioning of responsibilities will evolve as individual disciplines develop expertise in solving various parts of the problems.

The objectives of this paper are to discuss externalities and public policy in environmental quality management, to briefly review two empirical studies concerned with the agricultural use of pesticides, to explore the social implications of these studies for environmental management and to suggest areas for additional research. Hopefully, the effort will demonstrate an integrative role which economists can play in the interdisciplinary problems of environmental quality management.

I

EXTERNALITIES AND PUBLIC POLICY

When consumption and/or production decisions lead to costs or benefits for persons not involved in the decisions, an "externality" is generated.[6] Externalities in turn create a desire on the part of externally affected parties for "participatory decision making." The intensity of the desire is a function of value judgments concerning individual freedom and property rights.

To illustrate these thoughts and give some direction to the discussion, consider the following example: an entrepreneur discovers that he can rearrange his factors of production in a way which creates the following consequences:

1. His cost of production is lowered.
2. He can eliminate 50 percent of his labor force.
3. Some air pollution is created.

As a profit maximizer, the entrepreneur would prefer to go ahead with the rearrangement of his factors of production because of the highly desirable internal economy, in the form of reduced costs. But his freedom to do so might be conditioned by the following externalities which would be felt by others:

1. If the price that consumers pay for the product declines, they would enjoy an external economy.[7]
2. Competitive firms would suffer an external diseconomy, since their cost structures might no longer be competitive with that of the innovative firm.
3. Those workers who lose their jobs in the rearrangement would suffer an external diseconomy, at least in the short run.
4. Society would experience an external diseconomy in the form of increased air pollution.

Neither of the first two externalities is in serious conflict with the values of our society, and neither is likely to affect the entrepreneur's freedom to act. We certainly would approve of consumers receiving an external economy in the form of lower prices, and since we pay homage to efficiency and competition, we probably would not feel much sympathy for the other firms that are placed at a competitive handicap.

The third externality contains more potential for dispute. Does the firm with the power to lay off 50 percent of its workers have any social responsibility for its action? In the early history of industrial-

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[6] For a detailed treatment of the concept of an externality, see Buchanan & Stubblebine, *Externality*, 29 Economica 371 (1962).

[7] Under pure competition we would not expect a price reduction in the short run since the entrepreneur can sell all of his output at the prevailing price. A lower price, therefore, would imply that there is some negative slope to the firm's demand function. The ultimate consumer price would depend upon the precise shape of the function, as well as the adjustment, through time, of the other firms' demand and supply functions.

ization, management generally enjoyed superior bargaining power, but as labor unions developed, the freedom and power of the entrepreneur was considerably restrained. Current conflicts in the railroad industry and in the United States Postal Service over employee displacement concern the basic question of management-employee rights, which often are importantly influenced by economic power. The desire for participatory decision making becomes sufficiently intense and a "countervailing power"[8] for confrontation develops whenever the expected gains from action exceed the expected costs in effort.

The last externality raises some interesting questions about rights and values in our society. Does the entrepreneur have the right to pollute the air? To tell him that he cannot use the atmosphere for the unregulated disposal of waste products is certainly tampering with his freedom. The atmosphere has historically been a free good, available in unlimited quantities to all. Furthermore, conservation, on a national scale, is of recent vintage compared to our much longer history of resource exploitation. In recent years a doctrine of what might be called "net social benefit" has gained a foothold, and where there has been conflict, this doctrine seems to have encroached upon the older doctrine of "efficiency and individual freedom." In the allocation of environmental resources, society is coming to realize that one man's freedom becomes another man's bondage. The atmosphere is now an economic, or scarce, good and therefore some priorities must be placed on the ways it is used. Since environmental resources exhibit considerable commonality, their allocation requires the use of public policy to decide how they will be allocated. The desire for participatory decision making will influence these policies as the preferences of affected parties are revealed to policy decision makers.

There are, generally speaking, three ways in which disputes created by externalities may be settled. One is by negotiation (including merger or internalization) between the opposing parties. A second is through the political or legislative process, and the third is through litigation.[9] All three of these result in participatory decision making, though the latter two are less direct than the first. Negotiation is usually preferred in our society and is generally more expeditious, but some types of problems are not easily resolved in this way. Environmental pollution is one of these. Not only is it difficult and expensive to organize the parties for negotiation, but the configuration of property rights is not clear. Because the benefits and costs are

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[8] J. Galbraith, American Capitalism, The Concept of Countervailing Power (1956).

[9] A fourth might be "moral suasion" from some outside party.

not clear, property rights tend to be shaped by subjective notions of benefits and costs, as illustrated in the following passage from Prosser:

> a person is permitted "to make use of his property or to conduct his own affairs at the expense of some harm to his neighbors. He may operate a factory whose noise and smoke cause some discomfort to others, so long as he keeps within reasonable bounds. It is only when his conduct is unreasonable, in the light of its utility and the harm which results, that it becomes a nuisance. . . . The world must have factories, smelters, oil refineries, noisy machinery, and blasting, even at the expense of some inconvenience to those in the vicinity, and the plaintiff may be required to accept and tolerate some not unreasonable discomfort for the general good."[10]

Changing the configuration of property rights is a gradual process, conditioned by social mores and common law precedents. The pesticide issue seems to be a good case in point. While the benefits and costs are vague at this point in time, considerable social anxiety is being caused by the possibility of environmental damage from persistent pesticides, and the configuration of property rights is gradually changing to constrain one's unlimited right to pollute. In short, society has become aware of the potential external diseconomies of pesticide usage, and participatory decision making is being established, mainly through the legislative process.

In summary, this is the relationship between externalities and public policy: externalities create a desire for participatory decision making. This desire gains representation through economic power blocks (labor unions, consumer protection organizations, etc.), governing bodies, the courts, or a combination of the three; and a solution or a policy decision is reached (through negotiation, legislation, or litigation) based on notions, too often quite subjective and imprecise, of social benefits and costs. Property rights which reflect the benefits and costs are established in the process.

If social benefits and costs are to be the major determinants of public policy and property rights, then it behooves us to use the best data available and to develop more precise measures of social welfare. One has the impression that in many such decisions, policy makers have used the screams of constituents as the measure of social welfare. Such a system does not provide measures that help in appraising alternative policies in a modern society which must of necessity plan ahead.

Two studies which provide empirical measures that have relevance for pesticide policies are contained in the next section.

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[10] W. Prosser, Law of Torts 398, 412 (2d ed. 1955).

The first study attempts to measure the productivity of pesticides. It is a traditional economic study in the sense that it is strictly market oriented. Its scope is broad, for it is concerned with the marginal value productivity of pesticides for United States agriculture as a whole.

The second study attempts to include externalities in a policy decision model to determine which of two pesticide usage policies should be favored for a specified measure of social welfare. The second study is restricted geographically to Dade County, Florida.

II
TWO EMPIRICAL STUDIES:

A. *Measuring the Contribution of Pesticides to Agricultural Output*[11]

Aggregative data for the year 1964[12] of a random sample of 393 counties, were used to estimate regional and national production functions in an attempt to measure the contribution of pesticides to agricultural output. The functions fitted were of the exponential type and, for each region, regressed dollar value of crop sales by county on expenditures for fungicides, herbicides, insecticides, other pesticides, a measure of man years of family labor, acres of crop land, expenditures for hired labor and tons of fertilizers.

The partial derivative of the estimated equation with respect to the pesticide variable in question provides an estimate of the marginal contribution of that pesticide. That is, the change in output resulting from a one unit change in pesticide input.

There are those who argue that to estimate the contribution of pesticides to farm output begs the question and can only reinforce the "conventional wisdom" that pesticides are profitable for farmers, ignoring the other aspects of pesticides such as external effects. However, this is not the point of the research. One way of assigning a value to the non-market costs and benefits is to measure changes in market values required to achieve non-market objectives. Then, if the policy decision is made to pursue the non-market objectives, by implication the non-market objectives are "worth" at least as much as the market determined sacrifices necessary to achieve them. The

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[11] The research in this section was under the direction of J. C. Headley and draws on earlier work on the pesticide problem. See for instance, Headley and Lewis, *supra* note 4, and Headley, *Estimating the Productivity of Agricultural Pesticides*, 50 Am. J. of Agric. Econ. 13 (1968). The cooperation of the Economic Research Service in providing data is gratefully acknowledged.

[12] The pesticide data were obtained from the 1964 pesticide use survey made available by the Economic Research Service of the U.S. Department of Agriculture. Individual farms were surveyed throughout the nation. These individual farm data on pesticide use were aggregated to county estimates and combined with data from the 1964 Census of Agriculture measuring output and levels of other inputs.

contribution of pesticide technology to farm output is one of the measurable benefits which society may have to partially give up for other objectives such as a "cleaner environment." It is this contribution that the research attempts to measure.

Table I provides the results of the analysis and shows the estimated change in crop sales resulting from a one ounce increase in selected active pesticide ingredients, holding the levels of other farm inputs constant. Since there are no data on the efficiency of pesticide application for this sample, the analysis assumes equal efficiency in application between observations. The amount of pesticide applied is a proxy variable for the amount reaching the target pest. To the extent that this assumption is not valid, the measures of pesticide contributions will differ due to any mean difference in application efficiency. There are estimates for each farm production region and for the nation as a whole.

TABLE I

MARGINAL CONTRIBUTIONS OF SELECTED TYPES OF PESTICIDES TO CROP SALES, BY REGION, U.S., 1964[a]

	Pesticide Type		
Region	Herbicides	Insecticides	R^2 of Estimating Equation
NORTHEAST	--	\$ 1.31/ox.[b]	0.84
APPALACHIAN	\$ 0.60/oz.	\$ 0.31/oz.	0.76
SOUTHEAST	--	\$ 0.005/oz.	0.94
DELTA	\$ 0.22/oz.	\$ 0.30/oz.[b]	0.95
CORN BELT	\$ 2.38/oz.[b]	\$ 0.76/oz.	0.75
LAKE	\$-1.02/oz.	\$11.09/oz.[b]	0.66
NORTH PLAINS	\$ 0.13/oz.	--	0.70
SOUTH PLAINS	\$ 1.05/oz.[b]	\$ 0.06/oz.	0.96
MOUNTAIN	--	\$13.85/oz.[b]	0.88
PACIFIC	--	\$ 1.74/oz.[b]	0.97
UNITED STATES	\$-0.21/oz.	\$ 1.52/oz.[b]	0.76

[a] All contributions were measured at the geometric mean level of use per county with other inputs at their geometric mean levels in 1964. Complete information on these equations is available from the authors of this article.

[b] All of these contributions were derived from partial regression coefficients that were significantly different from zero at the level $\alpha = 0.05$.

Examination of the table gives an idea of the overall contribution of each pesticide type and a picture of the regional variation in marginal contribution. In the first attempt, measures of fungicides, herbicides, insecticides and other pesticides were included in the functions estimated. However, since none of the fungicide or other pesticide regression coefficients were statistically significant at conventional significance levels, these variables were dropped from the equation.[13] In four regions, the Northeast, Southeast, Mountain and Pacific, measures of herbicides were dropped from the equations due to non-significance. The measure of insecticide use was dropped from the North Plains function for the same reason. The fact that partial regression coefficients for certain variables are not statistically significant does not in any way infer that the input in question is ineffective in local situations. It merely reflects that there was not sufficient partial correlation between the variance in the input and output to provide a statistically reliable measure. The absence of a relationship could have been due to a small variance in the input between counties, or to the output variance having been explained by other inputs correlated with the input in question, or to other factors which were not included in the function such as variations in type of agriculture, weather or quality of other inputs.

Table I only displays regional estimates for the marginal contribution of herbicides and insecticides for the reasons mentioned above. Some of these coefficients are statistically significant and some are not and are so indicated in the table. There are also estimates for both types of pesticides obtained by combining the data into one national function.

Regional differences in the contribution of herbicides to crop sales show that only in the Corn Belt and the South Plains were the marginal contributions based on statistically significant coefficients. The largest marginal contribution estimated for herbicides is in the Corn Belt, the largest regional user of herbicides. The negative results in the Lake region and the United States as a whole are not immediately explainable. Variation in type of farming may be responsible for the negative signs. On the basis of this evidence alone, one would not want to conclude that so much herbicide material has been applied that production has been reduced. The marginal contribution of herbicides estimated for the South Plains was next largest and, as in the case of the Corn Belt, based on regression coefficients that were statistically significant. While the South Plains region is not among the largest users of herbicides, hay, pasture, and grains other than corn, wheat and sorghum receive more herbicides in this region than in any other.[14]

Economic theory postulates that inputs will be increased to the point where the marginal contribution equals the cost of obtaining another unit of the input. Given a price of 10 to 15 cents per ounce

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[13] Statistical significance here means that the hypothesis that the true regression coefficient equals zero could be rejected with the probability of Type I error equal to 0.05. Lack of statistical significance implies that this hypothesis could not be rejected.

[14] Eichers, *supra* note 2.

of material, the results for herbicides in the table are consistent with the rapidly expanding market for agricultural herbicides.

With the exception of the North Plains region, positive estimates of the contribution of insecticides were obtained for all regions included and for the nation as a whole. The results are mixed in terms of consistency. As a region, the Southeast and Southern Plains rank one and three respectively in amounts of insecticides used. The Delta region ranks number two. Contributions at the margin in the Southeast and the Southern Plains were not significantly different from zero, suggesting that the region may be using about as much insecticide materials as can be profitably used. A similar suggestion applies to the Appalachian region, an area of intensive insecticide use. The regression coefficients for insecticides for five of the ten regions were statistically significant but no estimate was obtained for the North Plains. When all data were combined into a national function, a significant relation was also obtained. The small or non-significant contributions for the Appalachian, Southeast, Delta, South Plains and the Corn Belt are consistent with a *priori* reasoning based on the amounts of insecticides used in these regions. If causally supported, the results suggest that these areas are making nearly optimal use of insecticides in a market sense. The extremely large contributions estimated for the Lake and the Mountain regions are not reasonable and may be due to variation in the type of agriculture within the region rather than a measure of the productivity of insecticides *per se*. The national market for insecticides has been expanding, especially since 1950. These results are consistent with that fact, but would suggest that in certain areas at least an economic equilibrium is being approached from the producer's short run viewpoint, not necessarily a social equilibrium.

Measurement of the aggregate contribution of pesticides to farm output is a difficult and at present imprecise endeavor. Data availability limit the estimation techniques. The principal conclusion from what has been done is that the results support the hypothesis that pest control through chemical pesticides is making a definite contribution to farm output over and above the cost of the resources used directly in pest control.

A curtailment of pesticide use in agriculture, without some form of substitute pest control, will reduce the magnitude of the benefits represented by the contributions just discussed. This rather crude analysis gives only approximate results but in general shows a dependence on pesticides to control insects as well as a definite reliance in two regions on herbicides for weed and brush control. As broader environmental objectives conflict with chemical pest control, the cost of achieving a more desirable environment will be in part measured by sacrifices in benefits from pest control technology as it is currently developed and used.

B. Externalities and Pesticide Usage[15]

Economic theory says that in a competitive economy a farmer will increase his usage of pesticides until the value of the product from the last unit applied equals the cost of the last unit. Our experience with pesticides over the past 20 years leads us to suppose that the marginal value of pesticides to agriculture has indeed been greater than their marginal cost, having witnessed an increase in pesticide usage. The empirical study of the previous section supports this hypothesis.

The research discussed in this section was concerned with a slightly different aspect of the pesticide issue. While the comparison of marginal productivity with marginal cost is appropriate for the individual in deciding how much pesticide to use, it may *not* result in the "best" quantity from a social welfare perspective. This is because the marginal costs and/or marginal benefits which all the pesticide users experience may not coincide with those which society as a whole experiences. For example, a farmer's marginal cost of pesticides may include items such as the price he must pay for them, the cost of labor and machinery he uses to apply them, and so on. But his marginal cost does *not* include items like damage to human health and wildlife or reductions in air and water quality. He feels these only indirectly in his alternate role as a member of society. To the extent that these consequences exist, they are partially borne by other members of society. The purpose of this empirical study was to look at these "extramarket" costs, or externalities, and attempt to incorporate them into some measure of social welfare.

The measure of welfare used in the study consisted of consumers' plus producers' surplus, modified for observable externalities neglected in the surplus calculation.[16] For each of two specified pesticide usage policies, two hypotheses about the shape of the "externality function" (to be explained later), and three variations under one of the policies, this measure of welfare was maximized over the production of the eight

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[15] Much of the material in this section was adapted from a previous paper, Langham & Edwards, *Externalities in Pesticide Use*, published in the American Journal of Agricultural Economics in December 1969. For details of the entire study see Edwards, Economic Externalities in the Agricultural Use of Pesticides and an Evaluation of Alternative Policies. 1969 (unpublished Ph.D. thesis, University of Florida).

[16] *See* Edwards, *supra* note 15 at 19, for the mathematical formulation of the model. This formula also may be obtained from the authors of this article.

major crops in Dade County, Florida.[17] Finally, the policies were ranked by their maxima.

Since Marshall[18] first developed the concept, economists have vacillated about the use of consumers' and producers' surplus as a measure of social welfare. Hicks[19] and Hotelling[20] helped revive professional interest in the concept, and it now appears to have gained growing acceptance as an approximate measure of welfare of various social alternatives.[21] One of its greatest advantages is the fact that it is empirically operational. Its major disadvantages are that it requires strong assumptions about the marginal utility of money[22] and about income effects of price changes.[23] The measure also neglects externalities unless they are explicitly incorporated as was attempted in this study.

1. *Alternative Policies Evaluated.* The pesticide controversy presently revolves around two groups of insecticides–the chlorinated hydrocarbons and the organic phosphates. The organic phosphates are highly toxic but non-persistent in the environment. Most accidental deaths and illnesses are caused by pesticides from this group. In contrast, the chlorinated hydrocarbons are relatively non-toxic and cause very few problems in the short run. But, they are persistent (the half-life of DDT is over 10 years in some soils) and the possibility of their detrimental effects on the environment has created considerable social anxiety.

The two policies evaluated reflect a substitution of less persistent pesticides for the more persistent ones, the goal recommended by the President's Science Advisory Committee.[24] The organic phosphates were used to represent the less persistent pesticides and the chlorinated hydrocarbons to represent the more persistent ones, a dicotomy which is valid for the majority of pesticides in each group. The two alternative policies were:

Policy 1. Current pesticide usage practices.

Policy 2. A 50 percent reduction in the per acre usage of

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[17] Excluded crops were approximately 18 in number and accounted for less than 14 percent of Dade County's planted acreage in 1966-67.

[18] 1 Marshall, Principles of Economics (1961).

[19] Hicks, *The Rehabilitation of Consumers' Surplus,* 12 Readings in Welfare Economics 325 (Arrow & Scitovsky eds. 1969).

[20] Hotelling, *The General Welfare in Relation to Problems of Taxation and Railway Utility Rates,* 6 Econometrica 242 (1938).

[21] Tinter & Patel, *Evaluation of Indian Fertilizer Projects: An Application of Consumer's and Producer's Surplus,* 48 J. Farm Econ. 704 (1966).

[22] Lerner, The Economics of Control: Principles of Welfare Economics 23-40 (1944).

[23] Hicks, *supra* note 19 at 326.

[24] U.S. President's Science Advisory Committee, Use of Pesticides (May 15, 1963).

> chlorinated hydrocarbons on the crops studied and an induced increase in the usage of organic phosphates to maintain crop quality and yield.[25]

Since it was impossible to empirically observe the region's substitution rate between chlorinated hydrocarbons and organic phosphates, an interval estimate for up to a 50 percent reduction in chlorinated hydrocarbons was developed through consultation with entomologists familiar with the region. The estimates used in the model for this interval were 0.3, 0.4, and 0.5 pounds of organic phosphates to replace 1.0 pound of chlorinated hydrocarbons when both are measured in units of 100 percent concentrated material. The impact of these substitution rates on the crop supply functions were then deduced by using production cost data[26] and pesticide cost data gathered in Dade County.

2. *Measuring Externalities.* Considerable effort was required to get even crude measurements of externalities. As stated previously, there is little basis in economic theory for non-market measurement. Thus there has been little pressure for the systematic collection and reporting of basic data on quantities of pesticides being used, residues of pesticides in various elements of the environment, and incidents of environmental damage.[27] The lack of these data will impede the determination of relationships between pesticide inputs and residues and between residues and environmental damage.

In this study, an attempt was made to by-pass the physical cause and effect relationships that exist between pesticides and externalities. The effort was aimed at relating a dollar measure of the social costs of externalities to the amount of a pesticide being used. This effort had some rather severe limitations. First, only those externalities which could be observed were measured. By and large these were acute external diseconomies which created controversy. Second, in many cases, the measurement of an externality was uncomfortably subjective in that it lacked a market determination.

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[25] Research is now underway to explore the consequences of banning selected chlorinated hydrocarbons by crops.

The 50 percent policy, although somewhat subjective, is probably closer to current legislative trends than a banning policy. Many of the new laws, while banning certain chlorinated hydrocarbons such as DDT, permit the usage of others and the net effect is likely to be closer to a 50 percent reduction than a 100 percent reduction.

[26] Brooke, *Cost and Returns from Vegetable Crops in Florida: Season 1964-1965 With Comparisons*, Agric. Econ. Mimeo Rep. EC 66-10 (University of Florida Dept. of Agric. Econ. Feb., 1966).

[27] Two nationwide surveys to obtain regional (multistate) estimates of the agricultural use of pesticides have been coordinated by the Farm Production Economics Division of the Economic Research Service. A third is being considered and future plans call for obtaining similar estimates as a part of the soil monitoring work. The effort helps fill a complete void but is strictly limited to agriculture and does not provide data at the local and state levels.

Finally, an estimation of this type overlooks moral and/or aesthetic considerations to the extent that these are not directly related to measurable externalities.[28]

The objective in measuring externalities was to obtain structural estimates of the externality function:

$$C(t) = H[z_1(t), z_2(t)] = \sum_{i=1}^{2} [h_i(z_i(t))]$$

Where $C(t)$ is a dollar measure of externalities in period (t) and $z_1(t)$ and $z_2(t)$ are pounds of 100 percent concentrated chlorinated hydrocarbons and organic phosphates, respectively, used in Dade County in period (t).

Since time series or cross sectional data were not available, it was only possible to estimate one point on this function. To obtain the estimate, the records of farmers and pesticide firms for the 1966-67 crop year were used. An average per acre usage, by crops and by type of pesticide, was developed and then expanded to obtain the County estimates. Sources of information on externalities included growers, insurance claims, veterinarians, biologists at the Everglades National Park, the National Audubon Society, and the Community Studies on Pesticides Program of the United States Public Health Service.

The diagnosis of pesticide poisoning of humans and pets was not found to be precise. If pesticide poisoning was diagnosed, it was usually attributed to an organic phosphate—most often parathion. The total cost estimate of $4,590 for the 1966-67 crop year in Dade County included those cases about which there was doubt, and in this sense, was biased upward for the organic phosphates.[29]

There was very little substantive information on externalities attributable to the chlorinated hydrocarbons. If damage is caused by this group of pesticides, it is of a chronic, long term nature which cannot be adequately observed and substantiated at the present time. In an effort to partially overcome this shortcoming, sensitivity analysis was used on the externality function to observe the effect of higher levels of damage on public welfare.

3. *Analytical Results.* The solution to the model for a specified policy consisted of (1) the maximum value of the objective function, which was a measure of the net social benefits of the crops studied, (2) the crop acreages consistent with the above objective function and policy, and (3) the pounds of z_1 and z_2 consistent with the objective function and policy.

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[28] If the physical relationships between pesticide usage, residues in the environment, and environmental damage were known, the model is capable of handling value judgments about these factors (through environmental constraints in the model) even though it might be impossible to directly place a dollar value on them.

[29] For the details on how this estimate was obtained see Edwards, *supra* note 15 at 102.

Two sets of solutions were generated. These can be summarized briefly as follows:

1. Solution Set 1

   a. The externality function for this solution set was:

   $$C(t) = e_1 z_1(t) + e_2 z_2(t)$$[30]

   where:

   $e_1 = 0, 1, \ldots, 5$

   $e_2 = 0, .0337, 1.0, 2.0, \ldots, 5.0$

   The observed level of externalities is represented by the values $e_1 = 0$ and $e_2 = .0337$. The solutions for Policy 1 are shown in Table 2. These results indicate that the environmental damages, or externalities, would have to be many times larger than those actually observed before the solution acreage would be affected. The objective function was decreased the most when the coefficient of z_1 was 5.0 (i.e., $5.00 of environmental damage for every pound of chlorinated hydrocarbon used). At this point it was 2½ percent below that when the coefficient of z_1 was 0.0, for current pesticide usage practices.

   b. For the externality function in "a" above, the model was run for Policy 2, a 50 percent reduction in the per acre usage of chlorinated hydrocarbons. Under Policy 2 three substitution rates were used, as explained earlier, and a model solution was generated for each. It was found that within the range from 0.3 to 0.5 pounds of organic phosphates per pound of chlorinated hydrocarbons, the solution acreage was very stable, varying less than one hundreth of one percent. This leads to the conclusion that the aggregate substitution rate between chlorinated hydrocarbons and organic phosphates is not a critical variable for the crops studied in Dade County and may not be worthy of much additional research expenditure. The solutions for Solution Set 1, Policy 2 are shown in Table 3. As indicated by a comparison of these tables, the objective function at observed externality levels (z_1 coefficient = 0 and z_2 coefficient = .0337) was approximately one percent less under Policy 2 than Policy 1.

2. Solution Set 2.

It was the prevailing consensus that rather than being a linear function, the z_2 portion of the externality function was shaped as in Figure 1. Figure 1 implies that as organic phosphates increase, externalities increase at a decreasing rate. In

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[30] The coefficients of z_1 and z_2 represent slopes of linear relationships between externalities expressed in dollars, and pounds of chlorinated hydrocarbons and organic phosphates respectively. In the case of organic phosphates, the observed externality level was $4590 and the corresponding usage level was 136,200 pounds, so the slope of a linear function passing through this point and the origin would be .0337. Parametric programming was employed on both e_1 and e_2 to investigate the sensitivity of the solution to these parameters.

TABLE II
COMPUTER RESULTS FOR SOLUTION SET 1, POLICY 1[a]

Solution vector										
Coefficient of: z_1	z_2	Objective function in dollars	y_1 Tomatoes in acres[b]	y_2 Potatoes in acres[b]	y_3 Beans in acres[b]	y_4 Corn in acres[c]	y_5 Squash in acres[b]	y_6, y_7, y_8 Groves in acres[b]	z_1 Chlorinated hydrocarbons in pounds[e]	z_2 Organic phosphates in pounds[e]
0	0	42,802,722.	19,000	7,700	5,800	1,650	3,080	10,340	220,914	133,563
0	1.	42,669,706.	19,000	7,600	5,800	1,650	3,080	10,340	220,785	132,975
0	2.	42,536,914.	18,900	7,500	5,800	1,650	3,080	10,340	220,050	132,060
0	3.	42,405,123.	18,900	7,500	5,800	1,600	3,080	10,340	218,015	131,737
0	4.	42,273,714.	18,800	7,400	5,800	1,600	3,080	10,340	217,279	130,821
0	5.	42,142,892.	18,800	7,400	5,800	1,600	3,080	10,340	217,279	130,821
0	.0337	42,798,221.	19,000	7,700	5,800	1,650	3,080	10,340	220,914	133,563
1.	.0337	42,578,851.	18,900	7,600	5,800	1,600	3,080	10,340	218,143	132,325
2.	.0337	42,363,263.	18,800	7,600	5,800	1,500	3,080	10,340	213,466	131,352
3.	.0337	42,150,933.	18,800	7,600	5,800	1,450	3,080	10,340	211,431	131,029
4.	.0337	41,941,635.	18,700	7,600	5,800	1,350	3,080	10,340	206,754	130,056
5.	.0337	41,735,808.	18,700	7,600	5,800	1,300	3,080	10,340	204,719	129,733

[a] Source: calculations made by the authors.

[b] Solution differs from the optimum by not more than 100 acres.

[c] Solution differs from the optimum by not more than 50 acres.

[d] Grove acreage is constrained at the 1966-67 level.

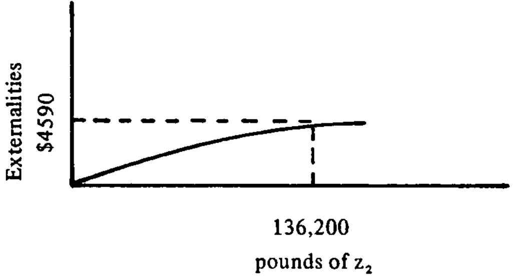
[e] All quantities are in pounds of 100 percent concentrated material.

TABLE III
COMPUTER RESULTS FOR SOLUTION SET 1, POLICY 2[a]

Solution vector		Objective function in dollars	y_1 Tomatoes in acres[b]	y_2 Potatoes in acres[b]	y_3 Beans in acres[b]	y_4 Corn in acres	y_5 Squash in acres[b]	y_6, y_7, y_8 Groves in acres[d]	z_1 Chlorinated hydrocarbons in pounds[e]	z_2 Organic phosphates in pounds[e]
Coefficient of:										
z_1	z_2									
0	0	42,417,683.	18,800	7,600	5,800	1,650	3,080	10,340	109,764	176,298
0	1.	42,241,632.	18,800	7,500	5,800	1,650	3,080	10,340	109,610	175,683
0	2.	42,066,758.	18,700	7,500	5,800	1,600	3,080	10,340	108,379	174,505
0	3.	41,892,666.	18,700	7,400	5,800	1,600	3,080	10,340	108,314	173,891
0	4.	41,719,394.	18,700	7,400	5,800	1,550	3,080	10,340	107,297	173,161
0	5.	41,547,184.	18,600	7,300	5,800	1,550	3,080	10,340	106,929	172,098
0	.0337	42,411,742.	18,800	7,600	5,800	1,650	3,080	10,340	109,764	176,298
1.	.0337	42,302,145.	18,800	7,600	5,800	1,600	3,080	10,340	108,746	175,568
2.	.0337	42,193,399.	18,800	7,600	5,800	1,600	3,080	10,340	108,746	175,568
3.	.0337	42,085,681.	18,700	7,600	5,800	1,550	3,080	10,340	107,425	174,389
4.	.0337	41,978,622.	18,700	7,600	5,800	1,500	3,080	10,340	106,408	173,659
5.	.0337	41,872,414.	18,700	7,600	5,800	1,500	3,080	10,340	106,408	173,659

a. Source: calculations made by the authors
b. Solution differs from the optimum by not more than 100 acres.
c. Solution differs from the optimum by not more than 50 acres.
d. Grove acreage is constrained at the 1966-67 level.
e. All quantities are in pounds of 100 percent concentrated material.

Figure 1



order to test the influence of this hypothesis on the model solution, the following externality function was used:

$$C(t) = e_1 z_1(t) + z_2^b(t)$$

where:

e_1 varied from 0.0 to 5.0

$b = .708$

The parameter, b, was established by forcing the function to pass through the origin and through the observed point on the function.

If the hypothesis illustrated in Figure 1 is, in fact, true, it would tend to narrow the differential in social welfare between Policy 1 and Policy 2. This would give the opponents of persistent pesticides a stronger case for advocating the substitution of organic phosphates for chlorinated hydrocarbons. Table 4 shows a comparison of model solutions for the two hypotheses.

From all of the model solutions it appears that a 50 percent reduction in the usage of chlorinated hydrocarbons could be effected with about a one percent decrease in the net social benefits of the crops studied. In stating such a conclusion however the reader must bear in mind its limitations. Aside from the assumptions concerning social welfare and the measurement of externalities, a specific adjustment process was assumed. Other adjustment possibilities such as biological insect control and modification of cultivation practices were not permitted. Furthermore the possibility of some decline in food quality was not analyzed—largely because of the complexity of evaluating consumers attitudes and buying patterns.

Companies are now concentrating their research efforts primarily on developing new pesticides which are less persistent and more specific to the target pest. In short, the "state of the arts" is changing in a way favorable to the substitution of less persistent pesticides for the more persistent ones. Thus we might expect that through time, cheaper and more effective non-persistent pesticides will be de-

TABLE IV
DIFFERENCES IN THE VALUES OF THE OBJECTIVE FUNCTIONS BETWEEN POLICY 1 AND POLICY 2 UNDER ALTERNATIVE HYPOTHESES ABOUT THE SHAPE OF THE EXTERNALITY FUNCTION

Coefficient of z_1	Hypothesis 1[a]			Hypothesis 2[b]		
	Policy 1[c]	Policy 2[d]	Policy 2 minus Policy 1	Policy 1[c]	Policy 2[d]	Policy 2 minus Policy 1
			Dollars			
0	42,798,221	42,411,742	-386,479	42,798,467	42,412,503	-385,964
1.	42,578,851	42,302,145	-276,706	42,579,082	42,302,897	-276,185
2.	42,363,263	42,193,399	-169,864	42,363,483	42,194,150	-169,333
3.	42,150,933	42,085,681	- 65,252	42,151,153	42,086,418	- 64,735
4.	41,941,635	41,978,622	36,987	41,941,854	41,979,349	37,495
5.	41,735,808	41,872,214	136,406	41,736,026	41,872,942	136,916

a. $C(t) = e_1 z_1(t) + .0337 z_2(t)$

b. $C(t) = e_1 z_1(t) + z_2^{.708}(t)$

c. Current pesticide usage practices.

d. A 50 percent reduction in the per acre usage of chlorinated hydrocarbons and a substitution rate of 0.4 pounds of organic phosphates per pound of chlorinated hydrocarbons.

veloped which might mitigate even the small cost differential which exists for the alternative policy at the current state of the arts. To completely ignore this trend would be foolish, but the researchers were unable to explicitly recognize it in the model. Nevertheless, this development and the disruptions that would be caused by total immediate banning of the hydrocarbons do suggest a multi-stage versus a single stage approach to reducing the usage of chlorinated hydrocarbons. In the multi-stage approach evaluated was, for example, a 50 percent reduction policy, as was attempted in this research. If it is beneficial, or not "too detrimental" to welfare, it is pursued. When it is accomplished, a 50 percent reduction policy is again evaluated and again pursued if not "too detrimental" to welfare. This process continues as long as welfare is improved or until the governing body decides the price of further pesticide reduction is "too high." At each stage of the process a new state of the arts prevails which the analyst may recognize in his model. Such an approach would permit the accumulation of valuable knowledge as the process continues. It would also contain less predictive error simply because the near future is easier to forecast.

CONCLUSIONS

In the past, economists have for the most part tended to ignore or assume away the problem of "external effects." However, in recent years external effects problems have received more attention in the literature. It appears that an increasing public awareness will require that externalities be more fully considered in reaching solutions to social problems of the future. As this comes to pass, theory of value needs to be refined in order to measure and incorporate externalities in policy decisions.

In order to improve the information available to decision makers concerned with the pesticide issue, research should be developed to show the amounts of pesticides being used in various locales. A systematic reporting of sales by quantity and type of pesticide at the user level should be considered. Research in Dade County, Florida indicates that agricultural users normally purchase on an "as needed" basis.[31] For these users, sales would measure usage. For the urban family, however, sales may be a less accurate measure of use. In any case, data are needed on total usage (on farms, in homes, and by

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[31] Growers report that by doing so, they save on transportation costs since the pesticides are delivered directly to the field, they do not tie up money in inventories, and they avoid storage and spoilage problems. It therefore seems reasonable that this method of purchasing might be prevalent in other geographical areas as well.

business and public agencies) so that the amount of potential pollutants going into the environment can be continually measured.

More information is needed on ecosystems. The importance of pest species to other pest and non-pest organisms needs clarification. Arguments made concerning the undesirability of extinguishing wildlife species can also be applied to pests. It is doubtful that eradication, even if it could be done, is really desirable over the longer term.

Existing environmental monitoring work does not provide an output which can be interpreted for policy purposes. It is not enough to know how much pesticide residue exists in some element of the environment. We need to know if this residue is "bad," or "good," or "neutral." The residue must be linked to a measure of damage. We are not implying that monitoring work should be curtailed–indeed it should probably be increased. But the consequences of "x" parts per million of DDT in an environmental element are unknown and the answer seems far away. We need to begin the process of generating meaningful time-series data on animal populations–including deaths by probable cause. If this task is to be performed systematically it should be made the responsibility of a central agency. Our society is in the unenviable, if not impossible, position of attempting to make decisions about environmental processes and we know neither the inputs nor outputs of the processes. What is said here could be generalized to most problems with residuals in the environment.

In addition to information on environmental damage from pesticides, more complete information is needed on damage from pests. Damage functions, where damage is a function of pest population and other environmental conditions, need to be developed by pest, crop and geographical location. Research in this area would also provide more complete data on the marginal benefits of alternative pest control measures.

Even with perfect knowledge of the effect of pesticides on the environment, society still needs a decision model to help integrate the fragments of the problem and compromise conflicting value judgments. It is in this area the political and social scientists will find their greatest challenge.

The research approach and its support are extremely important to progress in reducing the uncertainty in the area of pest control and public policy. If pest control is as important to production as it appears from early empirical studies and if the side effects of chemical pest control are as important as they are alleged to be, then a change in the research approach is mandatory if the efficiency and equity aspects of environmental resource use are to be handled in a manner approaching optimality. Previous methods, relying on incremental decisions without an overall framework, will no longer serve the public interest.