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The Nature of Benefits and Costs of Use of Pest Control Methods*

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Integrated pest management (IPM) strategies are often strongly advocated as a means of increasing farm income while at the same time decreasing pesticide use and thus the external costs associated with pesticides. These impacts, though they may be true for some individual producers, are not necessarily the final outcome of widespread adoption of IPM. Emphasis of this paper is on the nature of such paradoxes, and the conditions under which they can occur. Although the focus of the paper is on effects that are manifested in the marketplace, other effects such as external costs of pesticides and non-producer costs for developing and/or implementing IPM are included for completeness.

A mathematical treatment of the paradoxes is given to add concreteness to the paper. But before proceeding with a mathematical treatment, it may be useful to take a superficial, graphical look at the paradox that while individual producers may gain from adopting IPM, income to producers as a group will not necessarily increase with widespread adoption. The classical explanations of this paradox is that with inelastic demand, total revenue and thus profit would decrease with an increase in production attributed to adoption of IPM. Of course, early adopters would reap windfall gains, but as more and more producers adopt IPM, aggregate income would decline. Although this classical argument is valid for a perfectly inelastic

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supply curve, it is not usually appropriate to the analysis of IPM because it does not account for impacts on production cost. That is, to measure farm income effects, one must take an a priori view of the supply curve rather than viewing supply a posteriori. When this view is taken, it can be seen that inelastic demand is not necessarily a condition for aggregate farm income to decrease with widespread adoption of IPM. Figures 1 and 2 illustrate these points. In figure 1 it can be seen that a shift in supply resulting from adoption of IPM will increase producers' surplus which, for purposes of this paper, is equated with farm income including the rent to fixed factors of production. Note, however, that figure 2 illustrates a case where aggregate income will decrease, even with elastic demand. In this case, supply shifts more at high prices than at low prices, which is typically the case with pest control methods since low cost producers tend to be those without serious pest problems.

Social Welfare Impacts

Complete mathematical treatment of benefits and costs that are manifested in markets, and the distribution of these values, requires specification of a Walrasian system of multiple horizontally and vertically related markets. However, for expository convenience, consider only two horizontal market levels, specifically the markets for raw agricultural products and the markets for inputs to agricultural production. Also for expository convenience, only five groups of economic actors are considered: (1) producers of agricultural products; (2) consumers of raw agricultural products; (3) input suppliers; (4) people who bear external costs or derive external benefits from production and/or input usage; and (5) those who pay the social overhead costs of IPM. While these groups are usually not mutually exclusive, the surplus doctrine in conjunction with the compensation criterion, implies that social welfare can be measured by:

$$(1) \qquad W = \Pi_Q + CS_Q + PS_x + E - G$$

where W is net social benefits; Π_Q is the profit or rent accruing to producers; CS_Q is consumers surplus measured in general equilibrium in the raw agricultural product markets, which is surplus for final consumers plus all forward rents; PS_x is producers surplus in the input markets, which is rent in input markets plus all backward rents plus surplus for raw material suppliers (Collins; Chavas and Collins); E is external benefits (costs); and G is the social overhead cost for IPM programs.

Most IPM strategies represent a distinct and discrete change from conventional pest control. However, before turning to discrete changes, it is perhaps instructive to consider an infinitesimally small change in the mix of pest control technologies and information systems. Letting M be a proxy variable denoting the technology-information mix, the change in net social benefits for an infinitesimally small change in M will be:

$$(2) \qquad \frac{\partial W}{\partial M} = \frac{\partial \Pi_Q}{\partial M} + \frac{\partial CS_Q}{\partial M} + \frac{\partial PS_x}{\partial M} + \frac{\partial E}{\partial M} - \frac{\partial G}{\partial M}$$

Let us now examine each of the terms on the right-hand side of equation (2) for a multi-product, multi-input case. Mathematical treatment of profit effects of changes in a factor such as M commonly begins with an assumption about optimizing behavior on the part of producers. Here, however, it is not essential to make any restrictive assumptions about optimizing behavior; rather, the analysis can be based on an assumed behavioral relationship.[2/] Then the analysis can focus on the profit incentive to adopt and the aggregate impacts of adoption. Consequently, consider a behavioral relationship for a multi-product producer, postulating that acreage of the jth crop depends on per acre net returns of that crop and competing crops:[3/]

$$A_{ij} = \bar{A}_{ij} \left(R_{i1}, \ldots, R_{iJ}\right) \tag{3}$$

where A_{ij} is acreage of the jth crop for the ith producer; and R_{ij} is per acre net returns, defined to be:

$$R_{ij} = P_j \, Y_{ij} - \sum_k r_k \, X_{ijk} \tag{4}$$

where P is the per unit price of the jth product; Y_{ij} is per acre yield; r_k is price of the kth input; and X_{ijk} is per acre input usage. The set of X's can be defined to include application rates for each pesticide used or which can be used, different methods of scouting for insects, and all non pest control inputs. An implicit production function relates Y_{ij} to X_{ijk}. Production of the jth crop by the ith producer will be $Q_{ij} = A_{ij} \, Y_{ij}$, and total production of the jth crop will be $Q_{\cdot j} = \sum_i A_{ij} \, Y_{ij}$.

Profit Impacts

Profit to the ith producer can be represented by the profit function:

$$(5) \qquad \Pi_i = \sum_j A_{ij} R_{ij} = \sum_j \tilde{A}_{ij} R_{ij}$$

which can also be expressed as:

$$(6) \qquad \tilde{\Pi}_i = \sum_j (P_j Y_{ij} - \sum_k r_k X_{ijk}) \tilde{A}_{ij}$$

Since individuals view product demand and factor supply as perfectly elastic, the incentive for an individual to adjust the IPM technology-information mix, M_i is [4/]

$$(7) \qquad \frac{\partial \tilde{\Pi} i}{\partial M_i} = \sum_j (P_j Y_{ij} - \sum_k r_k X_{ijk}) \frac{\partial \tilde{A}_{ij}}{\partial M_i}$$

$$+ \sum_j (P_j \frac{\partial Y_{ij}}{\partial M_i} - \sum_k r_k \frac{\partial X_{ijk}}{\partial M_i}) \tilde{A}_{ij}$$

Equation (7) will be positive, zero, or negative, depending on whether the producer is under utilizing M_i, using the profit maximizing M_i, or over utilizing M_i. The remaining analysis in this paper will focus on the case where (7) is positive, since this is the case commonly encountered in pest control.

Consider now the impacts of increased adoption of IPM, or increased use of M_i, on industry profits. Summing over producers, industry profits can be represented by:

$$(8) \qquad \tilde{\Pi}_Q = \sum_i \tilde{\Pi}_i = \sum_i \sum_j (P_j Y_{ij} - \sum_k r_k X_{ijk}) \tilde{A}_{ij}$$

Since it is usually not appropriate to assume perfectly elastic product demand and factor supply at the industry level, the change in industry profits will be: 5/

(9) $$\frac{\partial \bar{\Pi}_Q}{\partial M} = \sum_i \frac{\partial \bar{\Pi}_i}{\partial M_i} = \sum_i \sum_j (P_j Y_{ij} - \sum_k r_k X_{ijk}) \frac{\partial \bar{A}_{ij}}{\partial M_i}$$

$$+ \sum_i \sum_j (P_j \frac{\partial Y_{ij}}{\partial M_i} + Y_{ij} \frac{\partial P_j}{\partial M_i} - \sum_k r_k \frac{\partial X_{ijk}}{\partial M_i} - \sum_k X_{ijk} \frac{\partial r_k}{\partial M_i}) \bar{A}_{ij}$$

Rearranging terms, equation (9) can be expressed as:

(10) $$\frac{\partial \bar{\Pi}_Q}{\partial M} = \sum_i [\sum_j (P_j Y_{ij} - \sum_k r_k X_{ijk}) \frac{\partial \bar{A}_{ij}}{\partial M_i} + \sum_j (P_j \frac{\partial Y_{ij}}{\partial M_i} - \sum_k r_k \frac{\partial X_{ijk}}{\partial M_i}) \bar{A}_{ij}]$$

$$+ \sum_i \sum_j (\bar{A}_{ij} Y_{ij} \frac{\partial P_j}{\partial M_i}) - \sum_i \sum_j \sum_k (X_{ijk} \frac{\partial r_k}{\partial M_i})$$

The first term in brackets on the right-hand side of (10) can be related to equation (7) which shows the individual incentive to adopt M. As noted previously, we are interested in the case where indiviudals are underutilizing M_i; hence, the first term in brackets in (10) will be positive. Note, however, that the last two terms in (10) can have any sign, depending on industry adjustments as translated into price changes. The direction of impact is easier to see in the case of a single product. If adoption of IPM results in an acreage and output increase and thus a product price decrease, the second term on the right-hand side of (10) will be negative. The final term can be either positive or negative, depending on whether the weighted value impact on input usage increases or decreases. Hence, equation (10) can be either positive or negative, depending on changes in production, input usage, and the slopes of general equilibrium product demand and factor supply curves.

Effects on Input Use

Industry use of the kth input will be:

(11) $$X_{..k} = \sum_i \sum_j X_{ijk} \tilde{A}_{ij}$$

The change in total use of the kth inputs used in agricultural production, resulting from adoption of IPM, will be:

(12) $$\frac{\partial X_{..k}}{\partial M} = \sum_i \sum_j X_{ijk} \frac{\partial \tilde{A}_{ij}}{\partial M_i} + \sum_i \sum_j \tilde{A}_{ij} \frac{\partial X_{ijk}}{\partial M_i}$$

An interesting paradox relating to total pesticide use can be examined with equation (12). If an increase in M involves reduced per acre use of pesticides, the last term in (12) for a pesticide input will be negative. However, the first term on the right-hand side of (12) will be positive if acreage expands as a result of adoption of M. Thus, total pesticide use can increase, even though the intensity of pesticide use decreases.

Impacts on Surpluses and Net Social Welfare

Consider now the impacts on net social welfare, equation (2), of a change in M. Close inspection of equation (10), which shows the impacts on industry profits, will reveal that the next to last term is the negative of the change in consumer surplus:

(13) $$\frac{\partial CS_Q}{\partial M} = -\sum_i \sum_j (\tilde{A}_{ij} \; Y_{ij} \frac{\partial P_j}{\partial M_i}) = -\sum_j \sum_j Q_{ij} \frac{\partial P_j}{\partial J_i}$$

Similarly, the last term in (10) is the negative of the change in surplus for producers of X:

$$(14) \qquad \frac{\partial PS_X}{\partial M} = \sum_i \sum_j \sum_k (X_{ijk} \frac{\partial r_k}{\partial M_i})$$

Substitution of (10), (13), and (14) into (2) gives:

$$(15) \qquad \frac{\partial W}{\partial M} = \sum_i [\sum_j (P_j Y_{ij} - \sum_k r_k X_{ijk}) \frac{\partial \bar{A}_{ij}}{\partial M_i} + \sum_j (P_j \frac{\partial Y_{ij}}{\partial M_i} - \sum_k r_k \frac{\partial X_{ijk}}{\partial M_i}) \bar{A}_{ij}] + \frac{\partial E}{\partial M} - \frac{\partial G}{\partial M}$$

In the absence of externalities, E, and social overhead costs, G, equation (15) will be non-negative for any adjustment in the set M_i which moves individual producers closer to the individual profit maximizing level of M_i. Thus, we have the familiar result that if one or more producers are not using the profit maximizing level of M, social welfare can be increased by an adjustment in the set M_i that moves it to, or closer to, the privately optimal level. However, whether these benefits accrue to producers, consumers, or both depends on the specific case considered.

With externalities and social overhead costs, equation (15) can be of either sign. In one case, the social overhead cost changes, $\frac{\partial G}{\partial M}$, could outweigh any benefits manifested in the marketplace. In another case, the change in external costs could be negative because total pesticide use would increase with adoption of IPM, as was illustrated with equation (12).

Lumpy Changes in IPM

For lumpy changes in M, impacts on industry profits can be obtained by integrating (10) from the initial M to the final M. Similarly, impacts on total use of pesticides, consumer surplus, surplus for input suppliers, and net social welfare can be obtained by integration of (12), (13), (14), and (15), respectively. Although space does not allow for mathematical specification of these integrals, it is very important for empirical work to note that integration must be from one general equilibrium point to a new general equilibrium point. For example, in estimating impacts on consumer surplus, which is the integral of (13), integration must be along a set of general equilibrium demand functions where all other prices in the economy are allowed to adjust. Thus, for empirical work it is imperative to have a model that either explicitly or implicitly accounts for general equilibrium adjustments. Worded another way, empirical estimates based on partial equilibrium curves, which are typically estimated in econometric models and are implicit in many other aggregate models, will give biased results, with the magnitude of bias depending on how strong markets are interrelated.

Another word of empirical caution is that to compute the effects of IPM on aggregate profit, we are usually better off using a direct profit function rather than the area above a product supply curve and below price. The only case where the two measures is equivalent is if the supply curve is also a marginal cost curve. In practice, we seldom know whether supply is marginal cost, so use of the area above supply and below price may include factors such as risk premium and expectations that are never realized.[6]

Mathematical derivations given above were for the adoption of an IPM technology-information mix. The derivations also hold for other changes, such as a technology change (Chavas and Collins) or a pesticide ban. Of course, for a lumpy change, one must use the appropriate integration points, which will differ from the case discussed above.

Concluding Remarks

This paper has attempted to provide a concrete explanation of some of the paradoxes associated with widespread adoption of integrated pest management. IPM is often "sold" on the basis that it increases farm income and decreases pesticide use. Neither of these claims can be taken as a foregone conclusion. Generally consumers will benefit from IPM through relatively lower food prices, and the component of social welfare that is manifested in the marketplace will also increase. But whether aggregate farm income will increase or decrease, and whether net social benefits will increase is a moot point that can only be answered by empirical studies.

Empirical analysis of the aggregate economic impacts of widespread adoption of IPM is challenging indeed. Even more challenging is educating lay people on the paradoxes associated with widespread adoption of IPM, or for that matter any technology. As Hildreth notes, this is a challenge which we must face in the future.

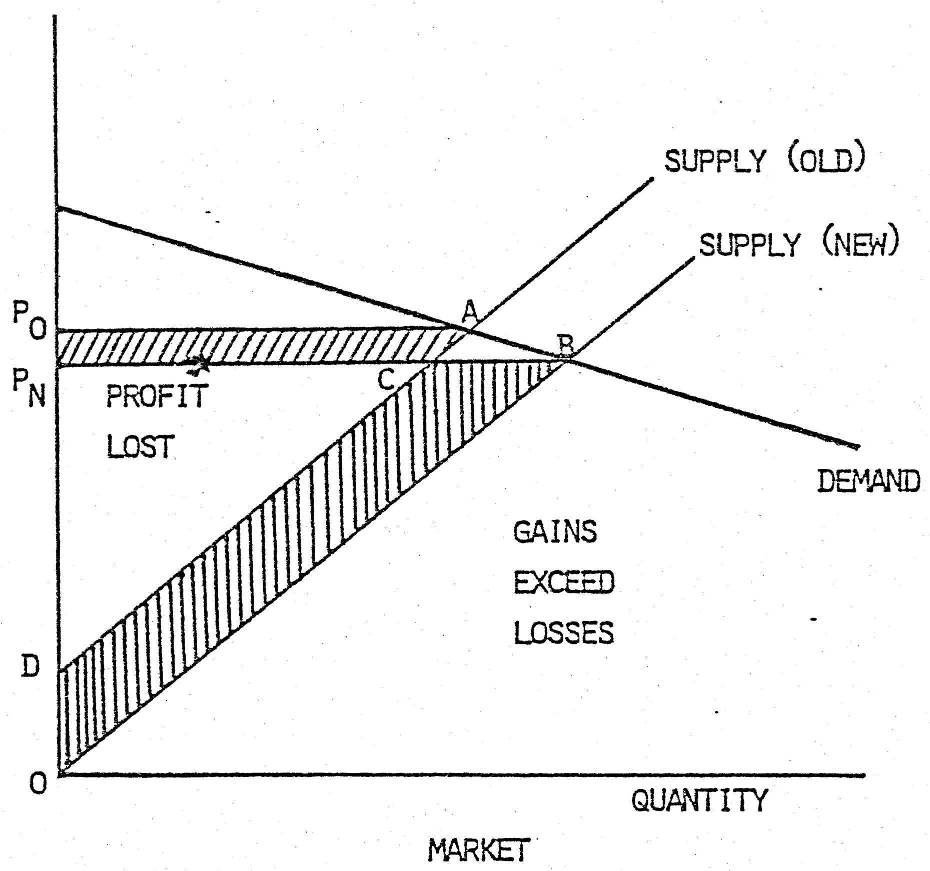

Figure 1. Situation where aggregate profits increase.

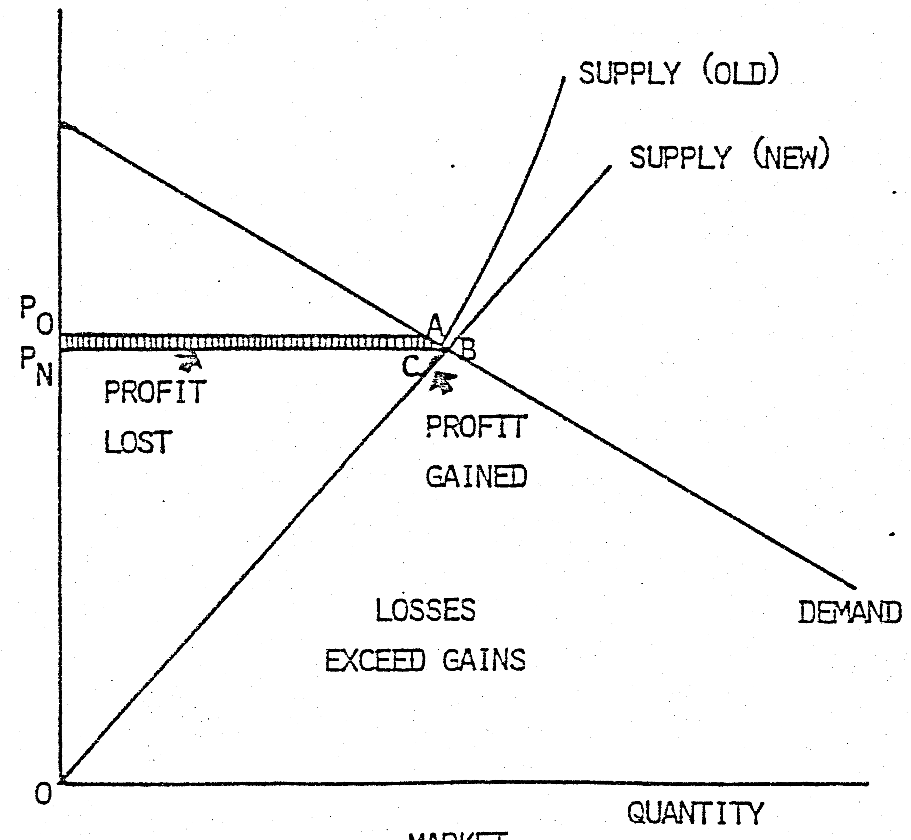

Figure 2. Situation where aggregate profits decrease.

References

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Footnotes

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Potential practitioners of aggregate economic analysis of pest control methods should be advised that an appropriate sub-title for this paper is "How to Find Out if Academic Freedom Exists at Your Institution." In other words, due to the paradoxical nature of benefits and costs, release of empirical estimates of such quite often leads people to inquire about one's tenure status, common sense, sanity, and heredity.

1/ Equation (3) can be derived from profit maximization for some production relationships and constraints. A more general case would have $\tilde{A}(P, Y, r, X)$. Results based on this more general case are similar to results based on (3); but (3) is used for notational convenience.

2/ The result that PS_x measures backward rents and CS_Q measures forward rents is, however, derived from profit maximization assumptions in other markets.

3/ A product subscript, j, was not included for M since pest control on different crops may be interrelated. The variables X_{ijk} and Y_{ij} are implicit functions of M_i; thus R_{ij} and $\tilde{A}_{ij}$ are also implicit functions of M_i.

Footnotes (continued)

4/ Due to the connection between individual firm's decisions and market price, the price P_j is an implicit function of M_i, for all i. Similarly, r_k is an implicit function of M_i, for all i.

5/ If the supply curves shown in figure 1 and 2 are general equilibrium marginal cost curves and the demand curves are general equilibrium relationships, it can be shown that integration of (15), excluding E and G, for a lumpy change in M will give the measure of welfare change that is shown in these figures. However, if the supply curve does not reflect marginal cost, then one must use a profit function to measure the impacts of widespread adoption of IPM on industry profits.

6/ The case of unrealized expectations can be seen by setting up a profit maximization model, but assuming that the producer consistently over or under estimates the marginal physical productivity of pesticides. Then the area above the derived supply curve and below price will measure expected profit, which will never be realized. This seems to be a plausible case in regard to pesticides.