The Impact of Uncertainty on Pesticide Application

by

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ABSTRACT

Uncertainty is introduced into several components of a simple pest management model. It is shown that risk aversion leads to higher quantities of pesticides and to a decline in economic thresholds, implying higher frequency of applications. The reduction of uncertainty via better dissemination of information is thus recommended.

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The economic aspects of pest management are increasingly attracting attention of economists. Various aspects have been studied recently, such as pest resistance, (Hueth and Regev [1974]), the timing and frequency of spraying (Hall and Norgaard [1973], Talpaz and Borosh [1974]), externalities related to pest control (Feder and Regev, [1975], Regev et al. [1976]), etc. An important aspect of pest problems is the uncertainty on the part of farmers. The uncertainty results from both the existence of various random effects in any ecosystem, and the limited information available to farmers. The presence of uncertainty has been recognized by economists dealing with pest control, but published works have either been related to a specific crop (Carlson, [1970]) or illustrative in nature (Davidson and Norgaard, [1973]). The present paper introduces uncertainty in a simplified economic pest management model, and studies in a rather rigorous way the impact of uncertainty regarding pest damage and pest density. Uncertainty with respect to pesticide effectiveness is discussed too. The analysis enables one to make several definite statements concerning the relation between the degree of uncertainty and the quantity of pesticide applied. Similarly, the effect of uncertainty on the "economic threshold" pest population is studied.

This paper builds on a previous work of the author which deals with a general class of models involving optimization under uncertainty.

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(Feder [1976]). Proofs for assertions made in the present paper are not required, as they may be deducted from theorems proved in the above mentioned study.

2. *The Model*

The formulation of the model is adopted in part from Feder and Regev (1975, p. 81), which rely, in turn, on previous works related to the economics of pest control.

It is assumed, for simplicity, that all inputs other than pesticides are applied in an optimal way, and are not affected by changes in pest density or pesticide dosage. The maximal net yield value per acre,1/ which can be obtained if no pest damage is incurred, is denoted by ϕ , and it is assumed that other inputs costs have been deducted. The damage per pest (per season) is δ dollars, and total damage if pesticides are not applied is $\delta.N$, where N is the number of pest present. The effect of pesticide on the pest population is measured by a dosage response function (also referred to as "kill function") of the form

$$(1) \qquad k = k(x) \ ; \quad k' > 0; \quad k'' < 0; \quad k(0) = 0; \quad k(\infty) = 1$$

where k is the percentage of pest killed and x is the volume of pesticide applied.2/

The cost of a unit of pesticides is assumed constant3/ and denoted by C. This cost does not include the cost to society due to pesticide

1/ All variables will be defined per acre.

2/ See discussion regarding the kill function in Regev et al. [1976].

3/ In fact the results will not change if a strictly convex cost function is assumed.

pollution, since the latter is not considered by individual farmers.

The profit per acre for the season is thus

$$\pi = \phi - \delta N \, [1 - k(x)] - Cx \tag{2}$$

It is implicitly assumed that pesticide spraying takes place before pest damage is incurred. Due to the "common property" pattern of most pest problems, a single farmer will have a planning horizon of one season only.1/

Assuming risk aversion on the part of farmers, and ignoring the size of the farm (since the choice of area unit is arbitrary) the objective function may be described as

$$\max_{x} \; EU \{ \phi - \delta N[1 - k(x)] - Cx \} \tag{3}$$

where E is the expectation operator, and $U(.)$ is a concave utility function such that $U' > 0$, $U'' < 0$. It will be further assumed that the measure of absolute risk aversion (i.e., $\frac{-U''}{U'}$) is not increasing in profits.2/

The first order condition for optimum is

$$E \, U' \, (\delta \, N \, k' \; - \; C) \; \leq \; 0 \tag{4}$$

where strict inequality implies $x = 0$. Second order conditions are satisfied by the concavity of U and $k(x)$.

1/ See discussion in Feder and Regev (1975) and Regev et al. (1976).

2/ This property has been advocated by Arrow (1965).

So far we have not discussed the random elements in the model. There are several possible stochastic effects in the components defined above, and these will be treated one at a time, for the purpose of simplicity and convenience in mathematical handling.

Suppose, first, that the damage per pest is random such that $E(\delta) = \bar{\delta}$. The randomness of δ could be subjective, as a result of farmers' lack of information. On the other hand δ can indeed be random due to weather effect on pest behavior, etc.

The following propositions follow directly from theorems proved in Feder (1976), for a general class of models involving uncertainty:

Proposition 1:

(i) comparing to a stiuation of certainty (where $\bar{\delta}$ is known to prevail), the impact of uncertainty in δ is to increase the level of pesticide application.

(ii) an increase in uncertainty (represented by a mean preserving spread of δ) will result in an increase in the optimal pesticide dosage.[1/]

1/ Although part (i) is a special case of part (ii), they are stated separately since part (i) requires weaker assumptions regarding the utility function. See Feder (1976).

Proposition 2:

An increase in the expected value of pest damage $(\bar{\delta})$ implies an increase in the optimal level of pesticide application.

In the case of uncertainty which is only subjective, (i.e., because of farmers lack of knowledge), assertion 1 implies that the dissemination of information regarding pest damage will reduce the use of pesticides. Even if the randomness of δ is objective, better information is likely to reduce the level of uncertainty and thus cut down the volume of pesticide consumption. These results demonstrate the importance of extension service activities in the field of pest studies.

Additional results may be obtained regarding the notion of "economic threshold" (ET). The ET was defined by Headly (1972, p.105) as "the population (of pests) that produces incremental damage equal to the cost of preventing that damage". Since the marginal cost of preventing an additional unit of damage is usually assumed to be increasing, it follows that at pest densities lower than the ET, pesticides will not be applied. This definition assumes implicitly that the objective is maximization of profit, which is proper in a situation where uncertainty is not involved. In the case considered in the present paper, however, the definition has to be slightly modified, taking into account the modified objective function. Accordingly, we define the ET as follows:

following Tedei's JET paper def. $\tilde{\delta} = \delta + (\delta - \bar{\delta})r$

$\pi = \Phi - \tilde{\delta} N(1-k(x)) - C(x)$

$Z = Eu'(\delta N^* k'(0) - c) = 0$

$Z = Eu'\{[\tilde{\delta} - (\delta-\bar{\delta})] N^* k'(0) - c\} = 0$

following Tedei's JET paper

$\tilde{\delta} = \delta + (\delta - \bar{\delta})r$

or

$\delta = \tilde{\delta} - (\delta - \bar{\delta})r$

let $\tilde{\delta} = 0$ by (1)

then

$\pi = \Phi + (\delta - \bar{\delta})r N(1 - k(0)) - Cx$

totally differentiating:

$$dZ = \frac{\partial Z}{\partial N^*} dN^* + \frac{\partial Z}{\partial r} dr = 0$$

or $$\frac{\partial Z}{\partial N^*} dN^* = - \frac{\partial Z}{\partial r} dr$$

$$\frac{dN^*}{dr} = - \frac{\partial Z/\partial r}{\partial Z/\partial N^*}$$

$$\frac{\partial Z}{\partial r} = -Eu' N^* k'(\delta - \bar{\delta}) + [\delta N^* k'(0) - c] Eu''(\pi)(\delta - \bar{\delta}) N^*$$

$$\frac{\partial Z}{\partial N^*} = -Eu' \underbrace{(\delta - \bar{\delta}) r}_{\delta} k' + (\delta N^* k' - c) Eu'' \underbrace{(\delta - \bar{\delta}) r}_{\delta}$$

The economic threshold is that level of pest density (say N^*) at which the farmer is indifferent between applying a unit of pesticide or no pesticides at all. At N levels smaller than N^* pesticides will not be applied.

In terms of our model, N^* must satisfy the following condition

(5) $$E\,U'\,(\delta\,N^*\,k'(0) - C) = 0$$

It is easy to show that

(6) $$N < N^* \rightarrow E\,U'\,[\delta\,N^*\,k'(0) - C] < 0 \rightarrow x = 0$$

Consider now an increase in uncertainty, represented by a mean preserving spread of δ. Following the analysis in Feder (1976), a total differentiation of (5) yields

(7) $$\frac{dN^*}{dr} = \frac{\{\,N^*\,k'(0)\,E\,U'(\delta-\bar{\delta}) - N^*\,E\,U''\,[\delta\,N^*\,k'(0) - C]\,(\delta-\bar{\delta})\,\}}{-\,E\,U'\,\delta\,k'(0) + E\,U''\,[\delta\,N^*\,k'(0) - C]\delta}$$

where r is a monotonic increasing index of uncertainty.[1/] One can show that the numerator is positive while the denominator is negative.[2/]

1/ See Lemmas 1, 3 in Feder (1976).

2/ This is shown by writing $E\,U''[\delta N^*\,k' - C]\delta = E\,U''[\delta N^*\,k' - C]\,(\delta-\bar{\delta}) + \bar{\delta}\,E\,U''(\delta N^*\,k' - C)$ and noting that the first term is negative by Feder (1976) lemma 3, while the second is negative by lemma 2.

While the result above refers to a marginal increase in risk, one may compare the behaviour under uncertainty to a no risk situation. Suppose that $\bar{\delta}$ is the (non-random) rate of damage per pest. Then, the ET, say $\tilde{N}$, is defined by

$$(8) \qquad \bar{\delta}\, \tilde{N}\, k'(0) - C = 0$$

Under uncertainty, the ET (N^*) is defined by equation (5), which may be manipulated to yield

$$\bar{\delta}\, N^*\, k'(0) \left[1 + \frac{\sigma_1}{\bar{\delta}\, E\, U'} \right] - C = 0$$

where σ_1 = covariance (δ, U').

One can show that $\sigma_1 > 0$, which implies $N^* < \tilde{N}$. The following proposition can thus be stated:

Proposition 3:

(i) comparing to a situation of certainty (where $\bar{\delta}$ is known to prevail), the introduction of uncertainty regarding δ implies a lower economic threshold.

(ii) an increase in uncertainty will result in a lower economic threshold.

Proposition 3 implies that because of uncertainty pesticides are being applied in situations where the number of pest is rather low, and would not justify chemical treatment were the farmers better informed. Being risk averse, the farmers prefer to "play it safe" even at relatively low levels of pest populations.

Another component of the model which may be viewed as random is the number of pest N. In most cases, farmers estimate the level of N by rather crude methods. Even when more accurate counts are taken, these are only samples, and the true number is random. The impact of uncertainty regarding N on the volume of pesticides applied is analogous to that of uncertainty in δ, as asserted in the two propositions:1/

Proposition 4:

(i) Comparing to a situation of certainty (where $\bar{N}$ is known to prevail), the impact of uncertainty in N is to increase the level of pesticide application.

(ii) An increase in uncertainty will result in an increase in the optimal pesticide dosage.

Proposition 5:

An increase in the expected value of pest population ($\bar{N}$) implies an increase in the optimal level of pesticide application.

Since we now treat N as a random variable, the definition of the economic threshold cannot refer to a particular pest population, but rather to particular mean of the distribution of N. Suppose that $N = \bar{N} + \varepsilon$, where $\bar{N}$ is the mean and ε is random, $E(\varepsilon) = 0$. The ET is defined now as the value of $\bar{N}$ for which equation (5) holds while the distribution of ε does not change. One can show then that the following proposition holds:

1/ See Feder (1976). For simplicity, pest damage (δ) is now assumed non-random.

Proposition 6:

(i) comparing to a situation where $\bar{N}$ is known with certainty, the introduction of uncertainty in N reduces the economic threshold.

(ii) An increase in uncertainty regarding N reduces the level of the economic threshold.

The dosage response function may be assumed stochastic too. In that case however, the impact of uncertainty depends on the particular assumptions concerning the stochastic element in the function. The discussion is not presented, therefore, in terms of propositions, but is rather illustrative. If one hypothesizes that the dosage response function is of the form $k(x) = \varepsilon\ h(x)$, where $h(x)$ is the kill function under ideal (laboratory) conditions and ε represents the (random) effects of weather (taking values in the interval (0, 1)) then the following results are obtained:

1. An increase in uncertainty will decrease the level of pesticides applied.
2. An increase in uncertainty will increase the economic threshold.
3. An increase in the mean of ε will increase the volume of pesticides applied.

The specification above implicitly assumes that the distribution of random effect ε is independent of the quantity of pesticides applied. However, when the distribution of the random variable ε depends on the volume of pesticides sprayed, the results may be different. For instance, if the variation in pesticide effectiveness declines with higher levels of pesticides, it may be optimal on the part of farmers to spray more than under full certainty conditions.

3. *Conclusions*

The general conclusion to be drawn from the propositions stated in the present paper is that a higher degree of uncertainty regarding pest densities and damage rates leads to higher levels of spraying. In addition, pesticides are used more frequently due to a lower economic threshold of pest population. The higher reliance on pesticides may be viewed as excessive, to the extent that uncertainty can be reduced by a proper distribution of information already available, or by generating information through research projects which entail a reasonable cost.

It should be emphasized that a decline in the degree of uncertainty increases farmers' expected utilities, thus they should be willing to incur some cost in exchange for information. Indeed, a market for information regarding pest management has already emerged in the form of pest management consulting firms. However, it seems that public agencies may have a better potential, at least in some aspects, since there may be sizable economies of scale in the field of information generation and dissemination.

The benefits to society from policies which reduce the level of uncertainty include not only the savings in resource use. Many pesticides are harmful to the environment, and a decline in applications is desired, much more so in the case that farmers' welfare is not decreased as a result.