# AN ADVANCED METHOD FOR ECONOMIC THRESHOLD DETERMINATION: A POSITIVE APPROACH*

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## INTRODUCTION

Economic entomologists have historically concerned themselves with reducing or preventing insect damage. These goals have led to the "economic threshold" concept used by entomologists to define a pest population level at which controls should be initiated (National Research Council, pp. 240). Stern (1966) defined it as " ... the pest population density at which control measures should be determined to prevent an increasing population from reaching the economic injury level." A serious attempt was made by J.C. Headley to define the economic threshold as the " ... population (of pests) that produces incremental damage equal to the cost of preventing that damage" (Headley, p. 105). Although logically sound, Headley's model, designed to quantify its definition, fails to treat the time dimension properly as shown in Hall and Norgaard's two-variable model (Hall and Norgaard, pp. 199-201). This two-variable model holds only under rather strong assumptions (Borosh and Talpaz, pp. 642-643), and *a priori* considers only a situation with a single pesticide treatment policy. A multiple treatment case was developed (Talpaz and Borosh, pp. 769-775) with equal physiological time intervals between treatments, which may apply to some special cases. An interesting effort to introduce increasing pest resistance was made by Hueth and Regev (pp. 543-555).

All these analytical-deterministic models[1] assume highly simplified situations with a single pest, a controlled environment, a lack of pest-plant interaction, and, above all, unstructured pest population dynamics. " ... In reality, the decision to spray is complicated by the presence of more than one pest and interrelationships between pests, benefical predators and parasites which may also be killed by the pesticide. Furthermore, the toxicity of some pesticides is persistent; weather, pest density and the availability of food, among other factors, influence net population growth rates ... " (Hall and Norgaard, p. 201). Progress in accumulating knowledge on highly complex plant and insect biologies may take years before some realistic models can be constructed. Even so, highly sophisticated mathematical algorithms will be needed to arrive at the optimal pest management strategies for the normative, analytical and stochastic type case. This pessimistic-sounding prospect should not discourage further research in the analytical normative approach. On the contrary, it calls for more intensive and coordinated effort to advance it.

There is room for designing some positive (as opposed to normative) approaches in pest control studies. Major reasons include the facts that: (1) validation and evaluation of strategies developed could be carried out, detecting shortcomings and disadvantages of such methods for further investigation and research, and (2) in the absence of such

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[1] For an additional survey of pest management models and an application of dynamic programming to pest control in storaged grain, see Shoemaker.

strategies, farmers' practices and entomologists' recommendations could be corrected or redirected by the feedback information provided.

This paper describes a positive analysis procedure generating a measure for precise timing of pesticide treatment(s) against a key cotton insect pest. Maximization of net income was the assumed objective.

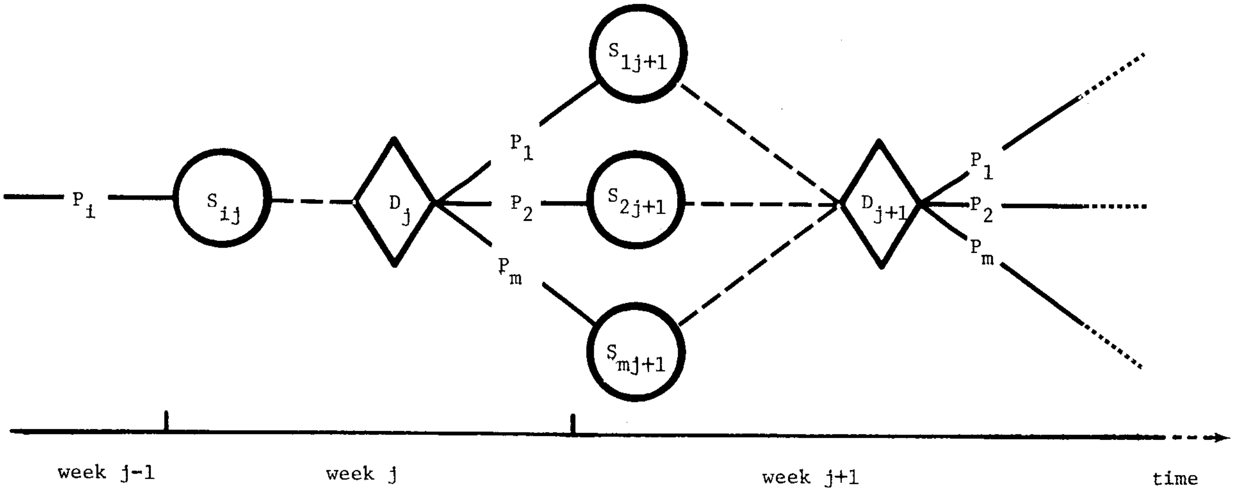
## THE DECISION MAKING PROCESS

Producers participating in the Texas Cotton Pest Management Program receive a weekly or bi-weekly (depending on the likelihood of encountering damaging insect populations) field inspection by trained cotton scouts. Scouts record the number of pest species as well as damage they cause. Level of benefical insects and the fruiting rate of the cotton plant are also noted. This information is made available to the cotton producer in the form of a Cotton Producer's Insect Report. This document indicates insect and fruit counts and provides economic thresholds for each species as recommended by the Texas Agricultural Extension Service. Upon receiving the report, a grower can compare the pest numbers and damage found by the field scouts with the economic threshold level to arrive at an insecticide treatment decision. Usually the grower consults the County Extension Entomologist to gain professional advice before an insecticide application is made. Together they arrive at a treat or no treat decision.

The decision-making process can be described as a tree, illustrated in Figure 1. Consider (discrete case) the state of the system $S_{ij}$ at the beginning of the $j^{th}$ week, in the $i^{th}$ state ($i = 1, 2, \ldots m$ possible states) where $S_{ij}$ is a vector composed of variables measuring pest population levels, crop potential, crop injuries or damages and so on. The particular values of these variables are measured by the scouts at that date. At this point, the cotton producer, after observing $S_{ij}$ and receiving the scout's recommendation, reaches decision $D_j$, again a vector composed of variables like quantity and quality of pesticide and method of application. The complex biological process subject to the stochastic behavior of the environment is represented by the set of probabilities Pi's, which transform the system into the next state $S_{ij+1}$.

Unfortunately, probabilities enabling us to reach a policy set aimed at optimizing certain objective functions (like the maximum net income)are unknown. Stern (1973) summarizes the situation: "Decision making in pest control is thus often conducted in a clouded atmosphere of biased and fragmentary information, particularly where there are no guidelines to yield/pest density ratios. As a result, the grower is unable to predict the outcome of his decision ... (and) the decision maker cannot protect an ordinary insurance principle" (p. 262). Carlson (pp. 217-218) proposed to replace the unknown probabilities with the subjective probabilities, and applied Bayesain decision theory procedures to

**Figure 1. THE BASIC STRUCTURE FOR A PEST CONTROL DECISION TREE**



optimized control strategy. However, this procedure is totally dependent on the subjective probabilities offered. They are difficult to establish through a scientific approach.

Assume that a producer bases his treatment decision on the percent damage already caused at any particular moment. This criteria could be easily criticized, for costs of treating the field should be measured against benefits generated from preventing *future and additional damages*. But, because such future damages can only be poorly predicted at best, Carlson chose subjective probabilities (again based on the current damage degree or the insect population level).

There is no available information on what a producer's subjective probabilities were at any decision point, but information about pesticide applications, observed damage, and population levels do exist under the scout program mentioned above.

Hence, if the economic threshold has any merit, one should be able to relate, at least *ex-poste,* the insect population level or damages to the decision to treat.

Formalizing this decision criteria, let

$$(1)\ D_j = \begin{cases} 1 \text{ (treat) if insect population} \geq \tau \\ 0 \text{ (no treatment) otherwise} \end{cases}$$

where $\tau$ is the population (or damage) level which induced the producer to treat for the first time. Such a decision criteria is consistent with the entomologists' terminology and recommendations.

In such a situation, the pests-plant system is under powerful environmental influences, and wide gaps in our understanding of the major biological process still exist. A simple decision rule like equation (1) may not be inferior to a more complex and sophisticated one. Such a simple strategy must be put to a test, or, stated differently, the profit for the producer can be maximized if there exist $\tau_{opt}$ in $\tau$ such that (2) $\Pi_{max} = f(\tau_{opt})$ where $\Pi_{max}$ is the maximum net income per acre and $\tau_{opt}$ is the minimum insect population level triggering an initial treatment ($D_j = 1$). If $\tau_{opt}$ cannot be found analytically (lack of biological theory and stochastic inputs), we may resort to some statistical methods and answer at least one important question: What specific insect population or damage levels could have been tolerated and still resulted in maximum profit?[2] Alternatively, for the risk evaders, it is possible to quantify the loss function for treating at lower insect population levels.

## OBTAINING THE FUNCTIONAL FORM

Considering biological and economical aspects of a pest management system, one would expect the net benefit per acre, as a function of $\tau$, to have an S-shape behavior. The basic logic behind such an assumption is as follows: At very low levels of $\tau$, damage observed by scouts is misleading; it would better be termed potential damage — it may not be realized as a final loss. It is well recognized that natural abscission and shedding is necessary for high yield; moreover, artificial or insect-caused shedding may even increase the yield. Hammer obtained no loss in yield when all squares were removed for the first six weeks of the flowering period. Similarly, Dunnam et al. found no significant difference in yield when squares were removed for the first four weeks of flowering. Only by removing them for a period of nine weeks did a yield loss result. Gaines et al., at two Texas stations, showed slight gains in yield when plants were not dusted for thrips control during early growth. These observations were confirmed in numerous later studies. The negative slope region ($\Pi_\tau < 0$) can be explained by the existence of the pest's natural regulating factors, abiotic and biotic, exerting mortality on the pest population. The biotic mortality factors increase in intensity as pest populations increase, thus reducing the damage potential and the resultant effect on yield.

At intermediate infestations ($\Pi_\tau > 0$), there is a trade-off between cost of controls and crop damage reductions. At a lower level of $\tau$, cost increase is greater than change in damage reductions. As $\tau$ increases, however, the differences minimize until, at the point of $\Pi_{max}$, they are equal. Throughout this range

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[2] An analogy for such a simple decision rule can be seen in M. Friedman's advocacy for a constant growth rate of the money supply (in a recent lecture he proposed to amend the constitution to that effect). As a basis for this proposal, see, for example, M. Friedman and Anna Schwartz, "A Monetary History of the United States, 1867-1960," (Princeton, N.J.: Princeton University Press for NBER, 1963).

the net income curve is positively sloped.

Beyond $\Pi_{max}$, the curve is again negatively sloped, but for another reason. Pest control is less effective because the plant cannot compensate for injuries already caused. They will be realized as future damage.

In obtaining the explicit form of (2), many functional forms were tested: logarithmic, exponential, linear and polynomial types. The polynomial form was finally selected for its convenience and for yielding the highest $R^2$ value. The explicit form is given by

$$(3)\ \Pi = a_0 + a_1 \tau + \ldots + a_n \tau^n + b\ V$$

where V is a zero-one variable according to two cotton varieties, and n is the polynomial order to be determined below.

## DATA AND PROCEDURE

Information included yield, insect populations, damage and insecticide treatments for fields in the Texas Blacklands. This data was compiled weekly by scouts under the supervision of Texas Agricultural Extension Service entomologists. This region was selected because there is mainly one key pest, the cotton fleahopper, *Pseudatomoscelis seriatus,* that attacks cotton during the first three weeks of primordial "pin head" square production. The cotton fleahopper is not considered a damaging pest after this three-week period. This selection follows Stern's (1973, p. 264) research recommendations: Economic threshold should first be determined for the one or two "key" pests attacking a particular crop. In a pest complex, a key pest is one that is perennial, persistent threat dominating chemical control practices."

1973 records of 141 cotton fields were used for the two major cotton varieties in the region: 'Lankart' (V = 0), in eg. (37), and 'Tamcot' (V = 1). Lack of sufficient costs and returns data forced the approximation of the "net benefit" Π, based on the recorded yield in pounds of lint.

$$(4)\quad \Pi = L \cdot P_L + L \cdot n\ P_s - N \cdot C$$

where $L$ = lint (lbs./acre)
$P_2$ = price of lint at the farm level = \$0.4 per lb.
$n$ = 1.6/2000 a constant to calculate the amount of cotton seed in tons
$P_s$ = price of cotton seed = \$100/ton
$N$ = number of pesticide treatments
$C$ = cost per treatment = \$5

Two basic versions of equation (3) have been estimated: (i) $\tau$ is measured in terms of the insect population as percent infested plants. In the second model, (ii) $\tau$ is measured in terms of percent damage squares, including both natural and insect-caused damage (in the case of the cotton fleahopper, it is nearly impossible to distinguish between the two causes).

## ESTIMATION AND RESULTS

Ordinary Least Square method was used to estimate parameters of equation (3). The polynomial order (n) was initially set at 5, and then a stepwise routine selected those parameters significantly different from zero at the 90% level in the t-test. The stepwise was used in a forward and backward selection and resulted in the same independent variable set shown in Table 1.

**Table 1. ESTIMATED COEFFICIENTS FOR EQUATION (3)**

| Independent Variable | Coefficient | Value | t-value | Significance Value |
|---|---|---|---|---|
| Intercept | $a_o$ | 209.747 | 17.74 | .0001 |
| $\tau$ | $a_1$ | -2.0549 | -2.05 | .0425 |
| $\tau_2$ | $a_2$ | 0.1011 | 3.64 | .0004 |
| $\tau_3$ | $a_3$ | -0.00085 | -4.18 | .0001 |
| V | b | -34.4672 | -2.99 | .0033 |

**$R^2$ = .2651, F = 12.2651 (SIGNIFICANT IN .0001), ST. DEV. = 52.5415**

Model (ii) ($\tau$ is percent damage) yielded higher $R^2$ and absolute t values than model (i), which failed the F-test as well. Therefore, model (i) was dropped from further consideration.

The low level of $R^2$ was not surprising. Knowing the complexities involved in the cotton production process, the importance of other input applications like fertilizers, herbicides, labor, machinery, etc. and the vulnerability to the micro-environmental effects on the yield, one could not expect to explain the entire cotton profitability by pest control practices alone. Far more important, the optimal level, $\tau_{opt} = 67.3\%$ damage, was not revealing because the plant's age must be taken into consideration (due to its capability of compensating for early injuries with decreasing rate as its age increases).

To take age into account, equation (3) was modified to be

$$(5)\ \Pi = a_{00} + bV + a_{11}\Pi P_1 + a_{12}\tau^2 P_1 + a_{13}\tau^3 P_1 + \ldots + a_{ij}\tau^J P_i + \ldots$$

For $J = 1,2,3$ as in equation (3), and $i = 1,3, \ldots, 6$ are the time periods, such that

$$P_i = \begin{cases} 1 \text{ if } \alpha_i \leq \text{plant age} < \alpha_{i+1} \\ 0 \text{ otherwise} \end{cases}$$

and $\alpha_i$ was arbitrarily chosen in 10-day intervals beginning with $\alpha_1 = 40$ (then $\alpha_2 = 50$, $\alpha_3 = 60$ and so on). The $a_{ij}$ can be interpreted as slope shifters, with respect to the age period, of the $a_j$'s in equation (3). The estimation results for equation (4) are given in Table 2.

Table 2. **ESTIMATED COEFFICIENTS FOR EQUATION (4)**[3]

| Independent Variable | Coefficient | Value | t-value | Significance Value |
|---|---|---|---|---|
| Intercept | $a_{oo}$ | 210.4061 | 28.07 | .0001 |
| $P_1\tau$ | $a_{11}$ | -2.8011 | -2.06 | .0044 |
| $P_1\tau^2$ | $a_{12}$ | 0.1030 | 2.86 | .0059 |
| $P_1\tau^3$ | $a_{13}$ | -0.0008 | -2.99 | .0040 |
| $P_2$ | $a_{21}$ | 0.0600 | 0.68 | .5017 |
| $P_2\tau^2$ | $a_{22}$ | 0.0288 | 0.69 | .4953 |
| $P_2\tau^3$ | $a_{23}$ | -0.0003 | -0.60 | .5504 |
| V | b | -21.1001 | -1.53 | .1326 |

**$R^2$ = .3732, F = 3.6386 (SIGNIFICANT IN .0015), ST. DEV. = 39.3689**

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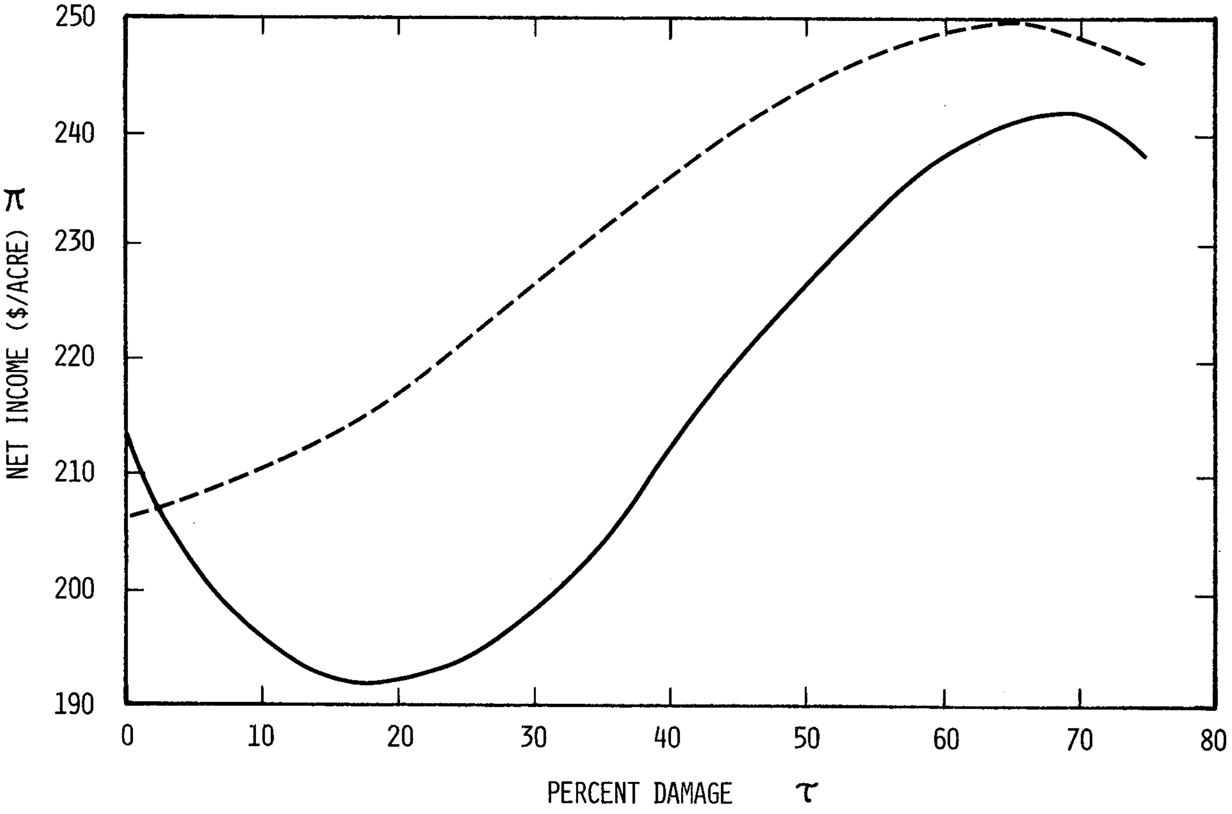
[3] The number of observed fields has been reduced from 141 in equation (3) to 103 in equation (4) because of missing data on crop planting time.

## INTERPRETATION AND DISCUSSION

Only the first period's (40-49 days) estimated parameters were significant, while period 2 (50-59 days) parameters possessed low t-values. The other periods (60 days and beyond) possessed virtually no significance (hence being ignored here). Since the $a_i$'s parameters are nearly orthogonal to the $a_k$'s for $i \neq k$, it is possible to pull each of the three sets and predict the value of $\Pi$ for the entire range of possible $\Pi$, shown in Figure 2 (the intercept of the 2nd period was estimated separately). The curves for the second period (broken line) is shown only for comparison. For the first period, the $\Pi$ curve forms and S-shape with a global maximum at $\tau^{(1)}_{opt} = 68.1\%$ damage. The second period curve is concave with a maximum at $\tau^{(2)}_{opt} = 64.4\%$ damage.

Figure 2: NET INCOME VS. DAMAGE LEVELS FOR TWO PLANT'S AGE INTERVALS. (PERIODS 1 AND 2 ARE REPRESENTED BY THE SOLID AND BROKEN LINES, RESPECTIVELY)



From a purely statistical point of view, conclusive strategy can be derived for the first period. The rest are not significant. Nevertheless, it would be constructive to inspect the curve for period 2. Comparing $\tau^{(1)}_{opt}$ with $\tau^{(2)}_{opt}$ it can be seen that as the age increases, the optimal $\tau$ decreases as expected, due to the plant's inability to compensate for damage by regenerating fruiting points. Also, the possibility of reducing natural enemy populations too early and applying added pesticide treatments is avoided. The same effect might be responsible for the consistent concavity of the second period curve. An interesting point should be raised about farmers' being risk evadors. The majority of the farmers treated when $\tau$ was well below $\tau_{opt}$.

## CONCLUSION AND LIMITATIONS

Results of this study illustrate an empirical economical phenomenon previously suggested but never proved; namely, the economic threshold is a dynamic measure, not static and varies with time. This has been demonstrated for the cotton fleahopper in the Central Texas Blackland. The economic threshold was calculated to be 68.1% damage within a "window" time interval of 40-49 day-old cotton.

The major questions which arise are: Is this behavior general as far as other insects or crops are concerned? What about more than a single insect population interaction? Will this behavior persist in other years?

To answer these questions, more research is needed. The main contribution of this paper is to establish, methodologically, a specific economic threshold for pesticide treatment, where cotton pests are defined as a function of prevailing market prices, insect-plant relationship and plant age. This approach could be applied in the absence of normative models and in evaluating new and existing pest control policies.

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