ECONOMIC ANALYSIS OF COTTON INTEGRATED PEST MANAGEMENT STRATEGIES

Peter S. Liapis and L. Joe Moffitt

In an attempt to combat problems of insect resistance and the increasing cost of new insecticides, integrated pest management (IPM) systems have been developed for many crops, including cotton. Cotton IPM systems include such components as scouting to determine when control actions should be taken, planting trap crops, and using short season varieties of cotton. Regardless of the component(s) of IPM systems for cotton, when a decision is made that a direct control action is warranted, the control action most often used is the application of insecticides. Thus, although IPM strategies may reduce the frequency of insecticide applications and consequently reduce the possible problem of insecticide resistance, the use of conventional, broad-spectrum insecticides continues to be the primary control tool when insect outbreaks occur.

To reduce the reliance on broad-spectrum insecticides, biology-based control techniques have been proposed as substitutes for insecticide applications in certain cases. Biology-based controls include, for example, releases of natural enemies (parasites or predators), releases of sterile males, and the use of pheromones.

The theoretical basis for biology-based control is well established in entomological literature (e.g., Debach; Huffaker and Messenger). A major advantage of biology-based control is the minimal disruption of the ecosystem. Possible problems with secondary pest outbreaks, or pest resurgence, are reduced with the use of biology-based controls.

Economic evaluation of biology-based control, especially releases of natural enemies, with some exceptions (Reichelderfer and Bender; Liapis; Richardson and Badger) has been lacking. Also lacking has been the comparison of biology-based control with other pest management strategies under risk. The purpose of this paper is to report on an evaluation of strategies, including biology-based control, under risk, utilizing the exponential-utility, moment-generating function approach to stochastic efficiency recently developed by Yassour, Zilberman, and Rausser.

STUDY AREA

The data for this study are derived from a 1981 test undertaken to determine the feasibility of releasing the wasp *Trichogramma prediosum,* an egg parasite, to control the *Heliothis* complex—the cotton bollworm and the tobacco budworm—on cotton. The test was located in Portland, Arkansas, where reports indicate that *Heliothis* are the key insect pests (Phillips et al.; Teague).

Unlike other cotton-growing areas where actions to control *Heliothis* are taken on a field-by-field basis, management in Portland is based on a community concept. In 1976, Dr. J. R. Phillips of the University of Arkansas initiated a community-wide integrated *Heliothis* management program. The community program treats all fields as a single field for the purposes of *Heliothis* control; that is, when a decision is made to treat, all fields in the community are treated (Teague). An additional component of the community approach is treatment, generally in June, of the first *Heliothis* generation that attacks cotton; this suppresses the population and sometimes postpones further applications until late August (Phillips et al.). The early *Heliothis* generation is usually suppressed with highly selective material. Applications later in the season, however, generally use broad-spectrum insecticides (Phillips et al.). Control of other pests such as plant bugs or boll weevils is not included in the community concept because in the past control actions against pests other than *Heliothis* have been minimal (Phillips et al., Teague).

COTTON INTEGRATED PEST MANAGEMENT STRATEGIES

This study was designed to evaluate alternative *Heliothis* management strategies. One strategy consists of releasing *Trichogramma.* If larval densities are high, *Baculovirus heliothis* (Elcar®)[1], a highly selective insecticide, is used in conjunction with *Trichogramma.* This is referred to as the biological control strategy in this paper. The second strategy is the Portland community management strategy. Also included were fields not treated for *Heliothis;* these untreated fields were located both within and outside the Portland area. Control of pests other than *Heliothis* in all test fields was made on the basis of scouting and advisement reports.

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[1] This term, used by Phillips et al. (p. 47), is also referred to as *Heliothis* NPV (nuclear polyhedrosis virus).

Twenty growers with a total of over 1,000 acres participated in the test. Sixteen of the growers farmed within the Portland community and four outside the community.

ECONOMIC MODEL AND ANALYSIS

An economic model is used to compare the four cotton pest management strategies. The objective of the analysis is to determine which of these management strategies is on the average efficient and which is efficient from the standpoint of a risk-averse economic decision-maker, that is, a grower. The analysis proceeds as follows. First, alternative probability densities are specified for each management strategy. In this regard, we allow two plausible density possibilities (gamma and normal) and thereby permit a subsequent assessment of the soundness of our conclusions with respect to choice of profit density. Second, the risk-neutral efficient strategy is determined from these densities by selection of the management strategy giving the largest expected net return. Third, the exponential-utility, moment-generating function (EUMGF) approach to stochastic efficiency (Yassour et al.) is employed to identify efficient cotton IPM strategies under risk.

According to the EUMGF approach, risk considerations are entertained in the model via grower risk preferences as reflected by a single-attribute utility function. The efficient cotton IPM strategy under risk is defined as the strategy that maximizes expected utility. This approach readily accommodates alternative profit densities and yet suggests a unique efficient strategy under risk. In contrast, stochastic dominance (Hadar and Russell), though less restrictive of risk preferences than EUMGF, often leads to inconclusive results. To implement the model, price, control cost, and yield are considered for each management strategy.

In specifying a probability density for profit achieved under a pest management strategy, the sources of randomness in profit must be identified. In particular, both cost and yield variability make the net return associated with each cotton IPM strategy uncertain. For example, the random nature of cost yield results from a number of environmental factors that impact both the implementation and effectiveness of each strategy. First, it is assumed that these sources of variation lead ultimately to a probability density function for net revenue that is not symmetric, but skewed to the right (Mood, Graybill, and Boes), as in the case of the gamma probability density. This assumption is based on the notion that below-average net revenue is more likely than above-average net revenue in cotton production. Implicit in this notion is the belief that the probability of all factors in the agro-ecosystem being favorable to production and pest management, and hence providing for above-average net revenue, is exceeded by the probability that perhaps a single adverse factor will lead to below-average net revenue. This discussion with reference to yield was originally advocated by Day in his analysis of skewed cotton yield distributions. In this analysis, cost uncertainty is also included as a factor accounting for differences in implementation costs of the diverse technologies under consideration. For comparison, results are also obtained under the assumption of normally distributed net revenue.

Profit per acre under an IPM strategy is

$$(1) \qquad \Pi = (P \cdot Y) - C$$

where

Π = revenue net of pest management cost (dollars per acre),
P = cotton price received by farmers (dollars per pound of lint),
Y = yield per acre (pounds),
C = pest management cost (dollars per acre).

Yield and cost in equation (1) are treated as random variables (Yassour et al.)[2].

First, we assume that random yield and pest management cost in equation (1) combine to produce random profit that is gamma distributed; that is,

$$(2) \qquad \Pi \sim (\lambda\alpha/\Gamma(\alpha)\,)\,\Pi^{\alpha-1} e^{-\lambda\Pi} \qquad ;\Pi \geqslant 0$$

where α and λ are parameters of the density to be estimated. The density indicated by (2) is nonsymmetric, with a median exceeded by its mean; hence, below-average profit is more likely than above-average profit. As was discussed earlier, this type of distribution may be plausible for cotton production. Note that equation (2) requires that net revenue be nonnegative; however, this is not a serious restriction in view of the definition of net revenue as gross revenue minus only pest management cost. Alternatively, we assume that profit is a normal random variable; that is,

$$(3) \qquad \Pi \sim (2\pi\,\sigma^2)^{-1/2} e^{-(1/2\sigma^2)(\Pi-\mu)^2}$$

where μ and σ are the mean and standard deviation of net revenue, respectively, and must be estimated from available data, and π is the number 3.14159. Again, we make no specific assertions related to the probability distributions of the underlying random variables, yield and pest management cost. We suggest only that their combined influence results in the symmetrically distributed net revenue given by equation (3).

The EUMGF approach to stochastic efficiency involves using the negative exponential-utility function given by

$$(4) \qquad U(\Pi) = -\,e^{-r\Pi}$$

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[2] The analysis indicated subsequently was also conducted assuming gamma and normal yield distributions and nonrandom price and cost. These assumptions are identical to those employed by Yassour et al. in their numerical illustration of the EUMGF approach. The findings described in this paper did not change under these alternative assumptions.

to rank stochastic technologies according to expected utility.[3] The unknown coefficient, r, in this utility function reflects constant absolute risk aversion. A dollar measure of the utility loss due to risk, or risk premium, is approximately proportional to the value of this coefficient (e.g., Pratt). Thus, the constant absolute degree of risk aversion may be viewed as a constant subjective marginal cost of risk. In the following, this is a parameter that will be varied to identify the efficient IPM strategy corresponding to different degrees of averseness to risk.

IPM strategies are marked in terms of dollar amounts (rather than utility). For his reason, comparisons are made using the amount of certain income that produces utility equaling the expected utility of a stochastic IPM strategy. This amount of income is referred to as the certainty equivalent. The expressions for the certainty equivalent of an IPM stategy under the gamma and normal densities (see Appendix) are respectively

$$(5) \qquad CE\gamma = (1/r)\,(\overline{\Pi}/S_{\Pi})^2 \ln[1 + (S_{\Pi}^2/\overline{\Pi})\, r]$$

and

$$(6) \qquad CE_N = \overline{\Pi} - (r/2)(S_{\Pi}^2)$$

where Π is sample average profit; S_{Π} is the sample standard deviation of profit; and r is again the unknown risk parameter contained in the utility function. The certainty equivalents corresponding to each IPM strategy were evaluated according to the above formulas. Table 1 gives certainty equivalents, average profit, and standard deviation of profit for each strategy at various risk levels. Note that the high average profit associated with the *Heliothis* untreated community strategy makes it an apparently attractive approach for decision makers who are relatively unconcerned with risk. Moreover, this same group of decisions-makers would rank biological control as least preferred among the strategies evaluated.

Certainty equivalents are depicted diagramatically as a function of risk aversion in Figure 1. This figure shows that as risk aversion becomes important in grower decision-making, the biological control strategy is superior under both gamma and normal profit distributions. This result follows intuitively from the nature of the profit distributions corresponding to the

Table 1. Certainty Equivalents of Cotton IPM Control Technologies under Gamma and Normal Profit Distributions.[a]

Risk Aversion Coefficient r, $\overline{\Pi}$, and S_{Π}	Technology									
	Trichogramma (T_1)		Community (T_2)		Heliothis Untreated Community (T_3)		Heliothis Untreated Outside (T_4)		Optimal Choice	
	γ	N	γ	N	γ	N	γ	N	γ	N
0	278.94	278.94	348.31	348.31	376.42	376.42	309.27	309.27	T_3	T_3
.0001	278.78	278.78	347.54	347.54	375.37	375.37	308.56	308.56	T_3	T_3
.001	277.33	277.32	340.83	340.61	366.27	365.89	302.35	302.14	T_3	T_3
.01	263.88	262.73	288.42	271.30	298.95	271.10	254.35	237.99	T_3	T_2
.02	250.80	246.51	249.54	194.30	252.60	165.77	219.17	166.71	T_3	T_1
.05	219.89	197.86	183.78	-36.71	179.53	-150.22	160.40	-47.13	T_1	T_1
.1	185.05	116.77	133.16	-421.73	126.89	-676.86	115.70	-403.52	T_1	T_1
1.0	60.84	-1342.76	30.02	-7352.10	27.19	-10156.39	25.85	-6818.67	T_1	T_1
10	11.43	-15938.14	4.80	-76655.74	4.26	-104951.67	4.12	-70970.14	T_1	T_1
$\overline{\Pi}$	278.944		348.306		376.424		309.271			
S_{Π}	56.951		124.1		145.14		119.398			

[a] Mean ($\overline{\Pi}$) and standard deviation (S_{Π}) for each technology are shown.

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[3] The negative exponential utility function is often written as $U(\Pi) = A - Be^{-r\Pi}$. For convenience, we take A = 0 and B = 1 in equation (4). The ordering associated with the utility function is invariant under an increasing linear transformation.

strategies. The biological control strategy provides relatively lower mean profits; however, the dispersion of profit is also relatively lower. For this reason, the biological control strategy would be preferred by decision-makers with a preference for a more stable income.

A remaining issue is how the biological control strategy would actually be ranked by cotton growers. The results given in Table 1 suggest that the biological control strategy is preferred to the other IPM strategies considered in this study be decision-makers with a constant degree of risk aversion exceeding approximately .02.

Actual risk attitudes of the participating cotton growers were not elicited. However, the risk attitudes of cotton growers in California were analyzed extensively by Farnsworth. Over 60 percent of the cotton growers in his survey exhibited a constant degree of risk aversion that exceeded .02. Thus, it appears that risk aversion may play an important role in the insect control decisions made by cotton growers. While caution must be used in applying his results to other regions, pest control strategies that reduce risk, such as the biological control strategy considered in this study, may be preferred by many cotton growers.

CONCLUSIONS

This study, based on the recently developed exponential-utility, moment-generating function approach to stochastic efficiency, provides an economic analysis of cotton integrated pest management strategies under risk. Yield and pest management data obtained from participating growers in the Portland, Arkansas, area were used in the analysis. The EUMGF approach readily accomodates alternative net revenue and yield distributions. Several such alternatives were analyzed in this study with identical implications. Although caution should be exercised in drawing final conclusions, present results indicate that biological control of the *Heliothis* complex through release of a parasitic wasp, *Trichogramma,* is preferred to the other IPM strategies considered when risk aversion is an important characteristic of grower behavior.

The conclusions of this study are, of course, conditioned on the adequacy of the single-year experimental data and profit distributions used for analysis. Moreover, the conclusions may not be applicable to other cotton-growing areas where *Heliothis* spp. are key pests. The success of *Trichogramma* releases may also require a community-wide management approach, such as practiced in the test area. However, preference in the face of uncertainty is a basic component of grower behavior. Those who recommend new pest management strategies or who select pest management strategies for further study should be aware of the risk implications of their decisions. Consequently, explicit recognition of the stochastic nature of different pest management strategies is important in analyzing strategy alternatives.

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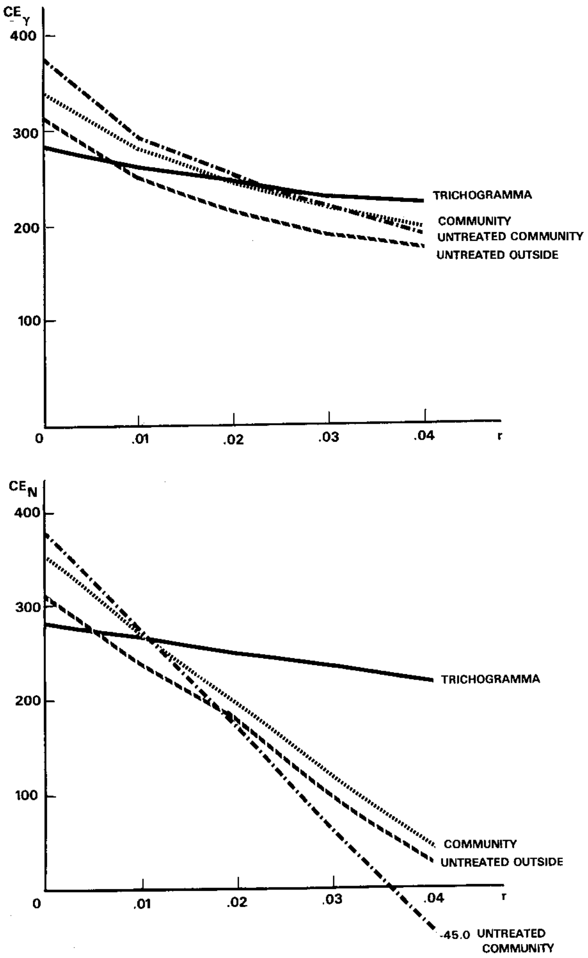

Figure 1. Certainty Equivalents of Cotton IPM Strategies under Gamma and Normal Profit Distribution.

APPENDIX

Derivation of the certainty equivalents contained in the text (equations (5) and (6)) is provided below. Notation is the same as in the text.

Equation (5) is based on the following:

(i) $\Pi = PY - C$; Y and C random,

P nonrandom

(ii) $\Pi \sim (\lambda^{\alpha}/\Gamma(\alpha))\ \Pi^{\alpha-1} e^{-\lambda\Pi}\quad \Pi \geqslant 0$

(iii) $U(\Pi) = -e^{-r\Pi}$

Under these conditions

$$E[U(\Pi)] = \int_0^{\infty} -e^{-r\Pi}\ \frac{\lambda^{\alpha}}{\Gamma(\alpha)}\ \Pi^{\alpha-1}\ e^{-\lambda\Pi}\ d\Pi$$

$$= -\frac{\lambda^{\alpha}}{(r+\lambda)^{\alpha}} \int_0^{\infty} \frac{(r+\lambda)^{\alpha}}{\Gamma(\alpha)}\ \Pi^{\alpha-1}\ e^{-(r+\lambda)\Pi} d\Pi$$

$$\text{(A.1)}\qquad = -\frac{\lambda^{\alpha}}{(r+\lambda)^{\alpha}}$$

By definition

$U(CE\gamma) = E[U(\Pi)]$

or from (iii) and (A.1) above

$$\text{(A.2)}\qquad -e^{-rCE\gamma} = -\frac{\lambda^{\alpha}}{(r+\lambda)^{\alpha}}$$

Solving (A.2) for the certainty equivalent gives

$$\text{(A.3)}\qquad CE\gamma = (1/r)\,\alpha \ln(1 + r/\lambda)$$

The method of moments estimates (see Mood, Graybill, and Boes) of α and λ are respectively

$$\text{(A.4)}\qquad \hat{\alpha} = \bar{\Pi}^2/S^2_{\Pi}$$

and

$$\text{(A.5)}\qquad \hat{\lambda} = \bar{\Pi}/S^2_{\Pi}$$

Substituting (A.4) and (A.5) into (A.3) gives

$$\text{(A.6)}\qquad CE_{\gamma} = (1/r)(\bar{\Pi}/S_{\Pi})^2 \ln[1 + (S^2_{\Pi}/\bar{\Pi})r]$$

as shown in Equation (5) of the text.

Equation (6) is based on (i) and (iii) above and (ii') where the latter is

(ii') $\Pi \sim [2\pi\,\sigma^2]^{-1/2}\ e^{-(1/2\sigma^2)(\Pi-\mu)^2}$

Under these conditions

$$\text{(A.7)}\qquad E[U(\Pi)] = \int_{-\infty}^{\infty} -e^{-r\Pi}\ [2\pi\sigma^2]^{-1/2}\ e^{-(1/2\sigma^2)(\Pi-\mu)^2}\ d\Pi$$

Completing the square on the l.h.s. of (A.7) gives

$$E[U(\Pi)] = -e^{1/2\sigma^2r^2-\mu r} \int_{-\infty}^{\infty} [2\pi\sigma^2]^{-1/2}\ e^{-(1/2\sigma^2)(\Pi-(\mu-\sigma^2r))^2}\ d\Pi$$

$$\text{(A.8)}\qquad = -e^{1/2\sigma^2r^2-\mu r}$$

Again, by definition

$U(CE_n) = E[U(\Pi)]$

From (iii) and (A.8)

$$\text{(A.9)}\qquad -e^{-rCE_n} = -e^{1/2\sigma^2r^2-\mu r}$$

Solving (A.9) for the certainty equivalent gives

$$(A.10) \qquad CE_n = \mu - \frac{1}{2} r \sigma^2$$

The method of moments estimates of μ and σ are respectively

$$(A.11) \qquad \hat{\mu} = \overline{\Pi} \qquad \text{and}$$

$$(A.12) \qquad \hat{\sigma} = S_{\Pi}$$

Substituting (A.11) and (A.12) into (A.10) gives

$$(A.13) \qquad CE_n = \overline{\Pi} - (r/2)(S_{\Pi}^2)$$

as shown in equation (6) of the text.