Risk Evaluation of Early Termination for Pest Control in Cotton

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The exponential utility, moment-generating function approach to stochastic efficiency is used to evaluate pest control technologies for cotton under normal, gamma, and beta distributed crop yields. Results suggest that early termination of cotton is more profitable than current practice but may not be preferred if risk aversion characterizes grower behavior. Research directions and policy implications are indicated.

Insect pests are among the most serious problems facing agriculture worldwide. Combined pre- and post-harvest crop loss due to agricultural pests is estimated to be as much as 45 percent (Pimentel). In the U.S. alone, more than $3.6 billion was spent on pesticides during 1981 (Eichers). Moreover, problems such as secondary pest outbreaks, resurgence, and particularly pest resistance to pesticides (see e.g., Flint and van den Bosch) may further increase pest control costs. It is not surprising that there is now considerable interest among researchers, growers, and policy makers in developing better pest management technology.

Integrated pest management (IPM) technologies which emphasize a variety of cultural, biological, and chemical pest control inputs are currently being developed for many crops. As these new technologies become available, economists have methods to evaluate them and make recommendations concerning implementation (Osteen *et al.*, McCarl). Economists may also participate in this research by reporting the directions for future work suggested by economic analysis.

The importance of risk in pest control decision making has been investigated in both theoretical and empirical contexts (Feder, Hall, Carlson). Hence, it appears important that economic analysis of new pest control methods account for risk. Recently, Yassour *et al.* developed an approach to technology assessment under risk which is well suited to economic evaluation of new pest management technologies. Their approach, referred to as the exponential utility, moment generating function (EUMGF) approach to stochastic efficiency, permits a conclusive ranking of technologies and more readily accommodates different stochastic specifications of technology than can other approaches such as stochastic dominance or linear mean-variance analysis.

A purpose of this paper is to assess an IPM technology for cotton using the EUMGF approach. We also investigate the implications of this conceptual framework for a very flexible crop yield distribution. The EUMGF approach is briefly reviewed in the next section and examined for three different yield distributions. Following this, early termination for pest control on cotton in California's Imperial

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Valley is compared to current practice. Concluding remarks are given in the last section.

The Model

Our objective is to determine the relative efficiency of IPM technologies from the standpoint of a risk averse economic decision maker; e.g., a grower. This section describes the model of Yassour *et al.* for assessment of stochastic technologies under risk and provides formulas needed to implement their method under the stochastic flexibility afforded by the beta probability distribution for crop yield.

The EUMGF approach, which assumes utility maximization and constant absolute risk aversion, provides a complete ranking of uncertain technologies. The negative exponential utility function

$$U(\Pi) = -\exp(-r\Pi) \qquad (1)$$

where

r = coefficient of absolute risk aversion
Π = profit
$= P_Y Y - C$

with

P_Y = nonstochastic price
Y = stochastic yield
C = nonstochastic cost

is used to rank technologies according to expected utility. The unknown coefficient, r, in equation (1) reflects a coefficient of constant absolute risk aversion (Pratt). In the following, this is a parameter which is varied to identify the efficient pest control technology corresponding to different degrees of averseness to risk. Note that the expected utility based on equation (1) is closely related to the moment generating function associated with the probability density function of yield (see Yassour *et al.*).

A production technology is considered efficient if its expected utility exceeds that of other alternatives. However, it is convenient to conduct the actual ranking of technologies in terms of dollar amounts (rather than utility) and for this reason the amount of certain income which produces utility equaling the expected utility of a stochastic technology is employed for making comparisons. This amount of income is referred to as the certainty equivalent (CE).

The probability distribution of crop yield is itself uncertain for most crops. The evidence reported by Day suggests that the yield distribution for some field crops may be nonsymmetric and skewed to the right such as in the case of the gamma density. Technologies may be compared under different stochastic specifications to investigate the sensitivity of results to distribution of yield. Expressions for the certainty equivalent under normal and gamma yield distributions were derived by Yassour *et al.* and are

$$CE_N = P_Y Y - (r/2)P_Y^2 S_Y^2 - C \qquad (2)$$

$$CE_G = (1/r)(\bar{Y}^2/S_Y^2) \cdot \ln[1 + (S_Y^2/\bar{Y})rP_y] - C \qquad (3)$$

respectively.

The beta probability density function can assume a variety of shapes (e.g., uniform, exponential, bell-shaped skewed left) depending on the values of its parameters (see Johnson and Kotz). Thus, this density permits great flexibility as a probability density function for crop yield. If yield is restricted to be positive and beta distributed then the probability density function of Y, denoted by $f_Y(y)$, is

$$f_Y(y) = \left[b^{p+q-1} \int_0^1 x^{p-1}(1-x)^{q-1}\,dx\right]^{-1} y^{p-1}(b-y)^{q-1}; \quad 0 \le y \le b \qquad (4)$$

with p, q, and b unknown positive parameters. Method of moments estimators of p, q, and b may be obtained by equating the sample mean, $\bar{Y}$, variance, S_Y^2, and third moment, M_3, of yield with corresponding theoretical values. Simultaneous solution of these equations gives

$$\hat{p} = \frac{2\left[\left(\frac{M_3}{\bar{Y}^3} - 1\right) - \frac{S_Y^2}{\bar{Y}^2}\left(\frac{S_Y^2}{\bar{Y}^2} + 2\right)\right]}{\frac{S_Y^2}{\bar{Y}^2}\left(\frac{M_3}{\bar{Y}^3} + \frac{S_Y^2}{\bar{Y}^2} + 2\right) - \left(\frac{M_3}{\bar{Y}^3} - 1\right)}$$

$$\hat{q} = \frac{\hat{p}(1 + \hat{p})}{(\bar{Y}^2/S_Y^2) - \hat{p}}$$

$$\hat{b} = \bar{Y}\left(\frac{\hat{p} + \hat{q}}{\hat{p}}\right)$$

By definition, the certainty equivalent is

$$U(CE_B) \equiv E[U(\pi)] \tag{5}$$

For the negative exponential utility function (5) implies

$$\begin{aligned} CE_B &= U^{-1}\{E[U(\pi)]\} \\ &= \frac{-\ln\{-E[U(\pi)]\}}{r} \\ &= \frac{-\ln\left[-\int_0^b -\exp(-rP_Y y + rC)f_Y(y)\,dy\right]}{r} \end{aligned} \tag{6}$$

From equations (4) and (6), the certainty equivalent based on beta distributed yield is

$$CE_B = \frac{1}{r}\left\{\ln\left[\hat{b}^{\hat{p}+\hat{q}-1}\int_0^1 x^{\hat{p}-1}(1 - x)^{\hat{q}-1}\,dx\right] - \ln\left[\int_0^{\hat{b}} y^{\hat{p}-1}(\hat{b} - y)^{\hat{q}-1}\exp(-rP_Y y)\,dy\right]\right\} - C \tag{7}$$

which may be evaluated by numerical methods. In the following section, certainty equivalents based on normal, gamma, and beta yield distributions are used to evaluate early termination for pest control in cotton.

Comparison of Pest Control Methods for Imperial Valley Cotton

California's Imperial Valley is among the most productive cotton growing regions in the world; yet cotton production may soon be unprofitable there due to agricultural pests (Burrows *et al.*). The pink bollworm (*Pectinophora gossypiella* (Saunders) is developing resistance to insecticides (Miller) and requires frequent insecticide treatments. Moreover, these treatments eliminate beneficial species resulting in secondary outbreaks of the tobacco budworm (*Heliothis virescens*). Both of these pests are capable of inflicting huge losses in yield unless population levels are controlled. The final result is establishment of a pesticide treadmill—continually rising costs which must be incurred to maintain a given (or declining) level of control.

An approach to cotton pest control in the Imperial Valley has been suggested recently. It was observed that most pest problems occur in this area during the last weeks of summer. This observation led to the suggestion that pest problems might be largely avoided simply by terminating production early, during the middle of August, rather than in late September as is currently done. Although some yield loss would occur due to early termination, it was hoped that reduced pest control, irrigation, and fertilizer costs would more than compensate.

Experiments were conducted for three years (1978–80) to compare early termination to current practices. Yield and variable input costs were monitored for fifteen commercial cotton fields with average field size equal to thirty-three acres. All farm management practices were the same for each group (early termination and long season) and were the conventional procedures followed in the area at the time of the study. Complete details of

TABLE 1. Certainty Equivalents for Early Termination and Long Season Cotton under Normal, Gamma, and Beta Yield Distributions, Imperial Valley, California.[a]

	Early Termination			Long Season		
	$\bar{Y}$ = 1,308.8 lbs.lint/acre S_Y = 268.67 lbs.lint/acre M_3 = 2,519,381,606 lbs.^{3} lint/acre C = $200.22/acre			$\bar{Y}$ = 1,488 lbs.lint/acre S_Y = 237.59 lbs.lint/acre M_3 = 3,538,667,520 lbs.^{3} lint/acre C = $355.31/acre		
r	CE_N	CE_G	CE_B	CE_N	CE_G	CE_B
.000	768.29	768.29	768.29	745.81	745.81	745.81
.001	748.53	749.05	748.14	730.35	730.64	729.81
.002	728.76	730.79	727.32	714.90	716.01	712.74
.003	709.00	713.44	705.96	699.44	701.89	694.60
.004	689.24	696.91	684.26	683.99	688.26	675.49
.005	669.47	681.15	662.41	668.53	675.08	655.50
.006	649.71	666.09	640.60	653.08	662.33	634.80
.007	629.94	651.69	619.01	637.62	649.99	613.57
.008	610.18	637.90	597.80	622.16	638.03	592.02
.009	590.42	624.68	577.11	606.71	626.44	570.37
.01	570.65	611.99	557.03	591.25	615.20	548.80
.02	373.01	507.87	395.55	436.70	518.63	362.27
.03	175.38	432.18	291.53	282.14	443.48	236.58
.04	−22.26	374.02	220.81	127.58	382.87	150.63
.05	−219.90	327.58	169.61	−26.98	332.66	88.42
.06	−417.54	289.43	130.70	−181.53	290.21	41.19
.07	−615.18	257.39	100.01	−336.09	253.73	4.02
.08	−812.82	230.03	75.12	−490.65	221.95	−26.09

[a] Mean ($\bar{Y}$), standard deviation (S_Y), and third moment (M_3) of yield along with variable cost (C) are shown for each technology.

the experiments are contained in Burrows *et al.*

Cotton average price received, estimated at $.74/pound of lint (Imperial County Agricultural Commissioner), was used in conjunction with the experimental yield and variable cost data to calculate certainty equivalents. The certainty equivalents corresponding to early termination and long season cotton were evaluated according to equations (2), (3), and (7) and are shown for various levels of constant absolute risk aversion, along with average yield, average variable cost, the standard deviation of yield, and the third moment of yield for both technologies, in Table 1. Certainty equivalents are also depicted diagrammatically in Figure 1 for ease of comparison.

It is, of course, possible that early termination and long season cotton have different yield densities.[1] Thus, certainty equivalents shown in Table 1 and Figure 1 may be compared under the various stochastic specifications for yield with each technology. Our results permit nine possible comparisons of certainty equivalents. Table 2 shows the range of constant absolute risk aversion over which each technology is preferred under each yield distribution pairing. As is evident from this table, risk efficiency depends both on the form of the yield distribution and degree of risk aversion. In all cases, early termination is preferred when constant absolute risk aversion is less than .004; however, long season cotton is preferred in several cases when constant absolute risk aversion

[1] Application of the Kolmogorov-Smirnoff test did not permit rejection of any of the yield distributions on statistical grounds.

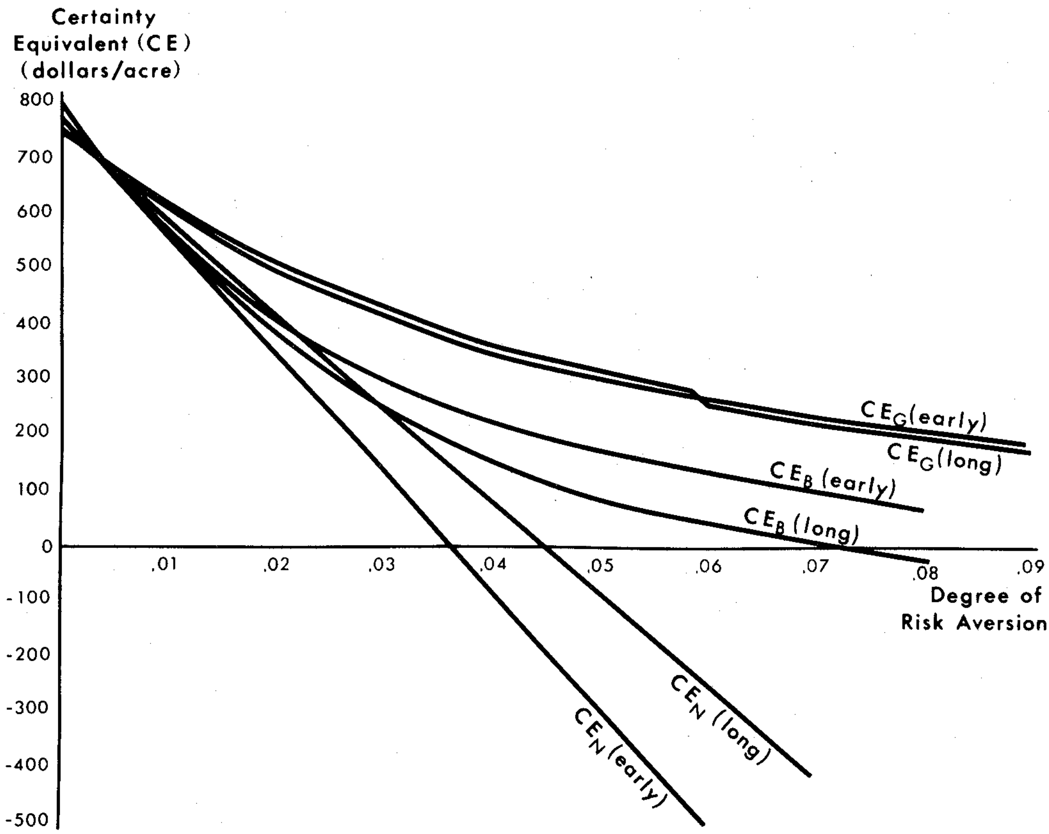

Figure 1. Certainty Equivalents for Early Termination and Long Season Cotton, Imperial Valley, California.

exceeds this amount. Hence, depending on the risk preferences of Imperial Valley growers, early termination may not be adopted even though it is more profitable on-average than current practice (long season).

It should be noted that research into alternative cotton pest control technologies for the Imperial Valley was begun due to increasing pest control costs over time. An analysis of historical control cost data (1966–80) for the pink bollworm, the primary pest, and secondary pests, primarily the tobacco budworm (Burrows *et al.*), indicates that these costs have increased in real terms at approximately six percent annually during this fifteen year period. If relative prices are approximately constant and if infestation/resistance levels continue to grow at this rate, current trends would support adoption of early termination for a much wider range of risk aversion ($r < .01$) within approximately five years regardless of the stochastic specification of technologies considered in Table 1.[2] This occurs because early termination largely avoids insecticide treatments and consequently also avoids resistance and secondary outbreaks which significantly increase costs over time.

[2] This can readily be computed by compounding variable costs at 6 percent per year, entering it into the certainty equivalent equations, and recalculating Table 2.

TABLE 2. Ranking of Pest Management Technologies for Cotton According to Degree of Constant Absolute Risk Aversion, Imperial Valley, California.

Early Termination Cotton / Long Season Cotton			If Yield Distribution is...		
			Normal	Gamma	Beta
			Early Termination is Preferred if... [a,b]		
If Yield Distribution is...	Normal	Early Termination is Preferred if...	$0 \leq r \leq .005$	$r \geq 0$	$0 \leq r < .005$ or $r \geq .03$
	Gamma		$0 \leq r \leq .004$	$0 \leq r < .008$ or $r > .06$	$0 \leq r < .004$
	Beta		$0 \leq r < .03$	$r \geq 0$	$r \geq 0$

[a] Results based on certainty equivalents from Table 1.
[b] The parameter, r, is the coefficient of absolute risk aversion. Long season cotton is preferred for values of r not in the ranges indicated.

Concluding Remarks

The importance of risk in pest control decisionmaking has been discussed often enough in the literature to suggest that risk should be incorporated when evaluating new pest control technologies. The EUMGF approach to stochastic efficiency developed by Yassour *et al.* is a convenient method for such evaluation. This paper utilizes this approach to compare a new pest control method for cotton (early termination) in California's Imperial Valley to current practice under normal, gamma, and beta distributed crop yield.

It is important to note that our conclusions depend on the adequacy of the experimental data used for analysis as well as simplifications inherent in our technical and behavioral postulates. Bearing in mind these limitations, our results suggest that early termination of cotton is more profitable than current practice but may or may not be adopted by growers in this area depending on their risk preferences and the actual distribution of crop yield. However, if the cost of pest control under current practice continues to increase at its present rate, the prospects for adoption of early termination will probably improve. For policy purposes, our results further suggest that research on short season/early termination management practices in order to reduce yield variability might be worthwhile.

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