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1. Introduction

There has been considerable interest in recent years in the opportunities

for switching from conventional pest control techniques based on the extensive

application of various chemical pesticides to the newer integrated pest manage-

ment (IPM) strategies which emphasise biological rather than chemical controls.

IPM offers a way to avoid many of the harmful environmental externalities

associated with conventional pest control techniques, yet its diffusion among

cotton growers has been relatively limited. Why is this? If one applies the

traditional economic tools associated with rational decision making under

uncertainty, one would have to explain this in terms of growers' risk prefer-

ences and the differential risk of IPM versus conventional control. In this

paper, we confront this explanation with data taken from a sample of cotton

growers in the San Joaquin Valley and find it to be inadequate. IPM does not

offer a less favorable risk-return tradeoff than conventional control techniques,

and we cannot find any systematic differences in risk preferences which might

explain why some growers have adopted IPM and others have not. It also seems

unlikely that the adoption or non-adoption of IPM can be explained by the use

of some criterion other than expected utility maximization. Instead, we believe

that the explanation lies in differences in the subjective perceptions of the

probability distributions of returns from the use of IPM and conventional controls.

If one looks at their subjective distributions, one finds that growers who

employ conventional controls and growers who employ IPM have contradictory and

inconsistent perceptions: each group perceives the returns from the control

strategy which it employs to be larger than the returns from the alternative strategy, although this is not consistent with the objective evidence. Thus, there appear to be systematic errors in the perceptions of the outcomes of the two control strategies. Moreover, the errors occur not in the perception of the outcomes of the current strategy, but rather in the assessment of the outcomes under the alternative control strategy.

These assertions will be documented below. We wish to emphasize here that they have important implications not only for public policy issues concerned with promoting the use of non-chemical pest control techniques, but also for the methodological issue of the validity of the economist's conventional model of rational decision making under uncertainty. That model takes the decision maker's subjective probability distributions as given exogenously, and focuses on differences in risk preferences as the explanation of why two decision makers would make a different choice from the 'same' choice set. Our findings suggest that there may be systematic biases in subjective probability distributions which have a more powerful influence on choices than differences in risk preferences, and that the subjective probability distributions may not in fact be exogenous, but rather may be endogenous and subject to the same factors as those which influence choices. An implication is that in future research greater attention must be paid to the process of expectations formation itself.

2. The Data

The data pertain to the output, inputs, costs, revenues and pesticide use of a random sample of 44 cotton growers in the San Joaquin Valley over the period 1970-1974; 28 of these growers used IPM and 16 used conventional chemical controls throughout the time period. The data were collected under the direction of Richard Norgaard, Wayne Willey and Darwin Hall with funding from the Ford Foundation,

USDA, EPA, NSF, and the Giannini Foundation of Agricultural Economics. Portions of the data have previously been analyzed by Willey and by Hall.

3. The Risk Preferences of Cotton Growers

Interviews were conducted with 38 growers to ascertain their utility functions for wealth. The Ramsey method of preference elicitation was employed to generate between 4 and 22 points on each grower's utility function. Various functional forms were fitted to these data, which embody a wide range of attitudes towards risk including: the linear (risk neutrality); the semi-log (decreasing risk aversion); the exponential (constant risk aversion or proneness); the quadratic, the power function and a function proposed by Keeney and Raiffa, which permit varying risk aversion or proneness; the logistic, which

imply risk proneness over the lower part of the wealth range and risk aversion over the upper part of the range, and which may be used to test Tversky and Kahneman's prospect theory of choice under uncertainty in which decision makers are risk prone for losses and risk averse for gains (i.e. the inflection point occurs at the current wealth level); and the cubic, which permits either uniform risk aversion or proneness over the relevant wealth range or non-uniform risk preferences (either convex-concave preferences as with the logistic, or concave-convex preferences). The exponential, power and logistic functions were fitted by non-linear least squares; the others were fitted by OLS. In each case, the estimated function was constrained to conform to the origin of the elicited utility scale. For each grower the selection of the best fitting functional form (i.e. the form which best represents the qualitative properties of his risk preferences) was made according to the standard $\bar{R}^2$ criterion, adjusted by the Box-Cox method for differences in the regressand.

The results are summarized in Table 1, in which the growers are classified according to the qualitative properties of their risk preferences. Five growers

Table 1. The number of growers with different types of risk preferences.

	UNIFORM RISK PREFERENCES								NON-UNIFORM PREFERENCES	
	Very Risk Averse	Risk Averse	Slightly Risk Averse	Risk Neutral	Slightly Risk Prone	Risk Prone	Very Risk Prone	Extremely Risk Prone	S-shaped[1]	Inverse S-shaped[2]
IPM Growers	1	2	2	3	2	2	4	5	1	2
CC Growers[3]	1	0	1	3	0	2	1	4	1	1
All Growers	2	2	3	6	2	4	5	9	2	3

1/ Risk prone, then risk averse.

2/ Risk averse, then risk prone.

3/ Conventional control (i.e. non-IPM).

have non-uniform preferences; of the remainder, 20 are risk prone to some degree, six are risk neutral, and 13 are risk averse to some degree. These proportions differ considerably from the findings of other studies, as summarized in Young, in which there is a predominant trend to risk aversion. For present purposes, the key question is whether or not there is a systematic difference between the risk preferences of growers who employ conventional control and those who employ IPM. This was tested in several ways. The growers were classified into two groups - those who are risk averse in any degree and those who are risk prone in any degree (the risk neutral and non-uniform risk preference cases were omitted) - and a contingeny table test was performed against IPM use. This test takes no account of the intensity of risk aversion/proneness. In order to allow for this, the values of the absolute risk aversion coefficients were compared using the randomization, Mann-Whitney and Kolmogorov-Smirnov two-sample non-parametric tests. All tests lead to the same conclusion: There is no evidence of any systematic differences in attitudes towards risk between the growers who use IPM and those who employ conventional control.[1]

4. The Actual Effects of IPM Use.

There are several peices of evidence which suggest that the use of IPM in place of conventional chemical controls does not reduce the returns from cotton production. Miranowski et al., USDA, and Taylor show that inputs of chemical pesticides could be reduced substantially with little or no effect on expected cotton yields. In a study of the use of IPM in corn rootworm control, Miranowski shows that IPM is superior to conventional chemical controls when judged both by expected profit maximization and by expected utility maximization with risk averse preferences. Hall studies essentially the same sample of growers as us, and concludes that expected cotton lint yields and profits are not

significantly different under IPM than under conventional controls. With a slightly different data set and methodology we reached the same conclusions, except that we found no difference in the variance of profits under the two strategies.[2] Our findings are summarized in the first two rows of Table 2.

5. The Perceived Effects of IPM Use.

In addition to data on the growers' actual input usage, expenditures, and yields over the period 1970-1974, we have data on the growers' subjective probability distributions of cotton yields, insecticide expenditures and pest damage under both IPM and conventional control strategies. These distributions were elicited in interviews using the PERT technique, which yields a three-parameter triangular distribution (the parameters are the median and the .05 and .95 percentiles). First we studied the relationship between the actual probability distributions of yields and insecticide expenditures over the period 1970-1974, and the subjective probability distributions (hereafter, s.p.d.) of these variables under the actual control strategy. A variety of tests was employed for this purpose, including: (1) For each grower separately, the Kolmogorov-Smirnov one-sample test to investigate whether the set of actual yields/expenditures could have come from the specified s.p.d.. (2) For each grower separately, constructing two-sided confidence intervals for the mean and variance of actual yields/expenditures and then inspecting whether the mean and variance of the s.p.d. fall in the respective confidence interval; and (3) For each group of growers, a paired comparison test of the means and variances of the actual and subjective probability distributions of all growers in the group. The tests yielded broadly consistent results, which are summarized in rows 3-6 of Table 2.[3] It will be seen that the s.p.d.'s of yields match the actual historical experience reasonably well, but not so for the s.p.d.'s of insecticide expenditures.

The means of these distributions tended to exceed those of the actual distribu-
tions, to about an equal extent for both IPM and non-IPM growers, which might
reflect expectations about future price increases for insecticides as a result
of the rise in petroleum prices just prior to the time of the interviews in
1975.

Next we compared the s.p.d.'s of yields and insecticide expenditures for
the two groups of growers. As with the comparison of actual yields and expendi-
tures between the two groups described in section 4, the tests were based on
ANOVA statistics and regression models. The results are shown in rows 7 and 8
of Table 2. For yields, there was no significant difference between the means
of the IPM and non-IPM growers' s.p.d.'s, which is consistent with the analysis
of actual yields summarized in rows 1 and 2 of Table 2. There was also no sig-
nificant difference between the variances of the s.p.d.'s of yields, which
conflicts with the analysis of the actual variances. Since there is some evidence
that IPM growers are more likely than non-IPM growers to overstate the variance
of their yields in their s.p.d.'s, this could explain why the two sets of dist-
ributions have similar variances. For the s.p.d.'s of insecticide expenditures,
both the means and the variances of the IPM growers' distributions were signifi-
cantly smaller than those of the non-IPM growers' distributions, which is con-
sistent with the analysis of the actual distributions.

Finally, for each grower we obtained the parameters of his implied s.p.d.
for yields, insecticide expenditures and partial profit under the actual and
alternative control strategies. The s.p.d.'s of yields and insecticides expenditures
under the actual strategy are those described above, and were elicited directly
in the interview. The s.p.d. of insecticides under the alternative strategy
was constructed from an s.p.d. for percent pest damage under the alternative
strategy, which was elicited in the interview. From the means and variances
of these distributions, the means and variances of the s.p.d. for partial profits

Table 2. Summary of results of comparisons of means and variances of actual and subjective probability distributions.

	Yields	Insecticide Expenditures	Profits	Row No.
Actual 1970-74	$\mu^{IPM} = \mu^{cc}$	$\mu^{IPM} < \mu^{cc}$	$\mu^{IPM} = \mu^{cc}$	1
	$\sigma^{IPM} < \sigma^{cc}$	$\sigma^{IPM} < \sigma^{cc}$	$\sigma^{IPM} = \sigma^{cc}$	2
Subjective				
IPM Growers	$\bar{\mu}^{IPM} = \mu^{IPM}$	$\bar{\mu}^{IPM} \geq \mu^{IPM}$		3
	$\bar{\sigma}^{IPM} \geq \sigma^{IPM}$	$\bar{\sigma}^{IPM} \geq \sigma^{IPM}$		4
CC Growers	$\bar{\mu}^{cc} = \mu^{cc}$	$\bar{\mu}^{cc} \geq \mu^{cc}$		5
	$\bar{\sigma}^{cc} = \sigma^{cc}$	$\bar{\sigma}^{cc} = \bar{\sigma}^{cc}$		6
Both Groups	$\bar{\mu}^{IPM} = \bar{\mu}^{cc}$	$\bar{\mu}^{IPM} < \bar{\mu}^{cc}$		7
	$\bar{\sigma}^{IPM} = \bar{\sigma}^{cc}$	$\bar{\sigma}^{IPM} < \bar{\sigma}^{cc}$		8

Note: μ^{IPM} is the mean of IPM growers' actual distributions under IPM.

$\bar{\mu}^{IPM}$ is the mean of IPM growers' subjective distributions under IPM.

μ^{cc} and $\bar{\mu}^{cc}$ are defined similarly for the conventional control case.

σ^{IPM}, $\bar{\sigma}^{IPM}$, σ^{cc} and $\bar{\sigma}^{cc}$ are variances of these distributions.

under both strategies was constructed from the formula: partial profit=yield x actual price in 1976 - all insecticide expenses. We are assuming that cotton prices and non-insecticide expenses would be the same under both control strategies.[4] The means and variances of each grower's s.p.d.'s for outcomes under the two control strategies were subjected to a paired-comparison test for each group of growers as a whole. The results are shown in Table 3. They may be compared with the results for the actual outcomes, which are shown in rows 1 and 2 of Table 2.

The s.p.d.'s of the two groups of growers present a striking contrast, both with one another and with the actual historical experience. The two sets of s.p.d.'s are entirely contradictory. For yields, IPM growers believe that IPM offers higher yields than conventional control, whereas non-IPM growers believe that conventional controls offer higher yields; The actual data-analyzed in Table 2 show no difference in yields. Similarly for profits. For insecticide expenditures the IPM growers believe that IPM offers lower insecticide expenditures, which is consistent with the historical experience, while the growers who employ conventional control believe that this offers lower insecticide expenditure. In short, each group of growers believes that its current strategy is better than the alternative, in terms of the means and variances of the s.p.d. How does this come about? Our analysis of Table 2 showed that each group's s.p.d.'s for yields under the current strategy match the actual historical data reasonably well. For insecticide expenses this is less true - each group tends to overestimate actual expenses, to an approximately equal degree for both groups. It appears, therefore, that each group judges its actual strategy better than the alternative primarily because it underestimates the yields and/or over- estimates the expenses associated with the alternative.

Table 3. Summary of results of paired comparison tests for means and variances of subjective probability distributions.

	Yields	Insecticide Expenditures	Partial Profits
IPM Growers	$\bar{\mu}^{IPM} > \bar{\mu}^{cc}$ $\bar{\sigma}^{IPM} < \bar{\sigma}^{cc}$	$\bar{\mu}^{IPM} < \bar{\mu}^{cc}$ * $\bar{\sigma}^{IPM} < \bar{\sigma}^{cc}$	$\bar{\mu}^{IPM} > \bar{\mu}^{cc}$ * $\bar{\sigma}^{IPM} = \bar{\sigma}^{cc}$
CC Growers	$\bar{\mu}^{IPM} < \bar{\mu}^{cc}$ * $\bar{\sigma}^{IPM} > \bar{\sigma}^{cc}$	$\bar{\mu}^{IPM} > \bar{\mu}^{cc}$ $\bar{\sigma}^{IPM} = \bar{\sigma}^{cc}$	$\bar{\mu}^{IPM} < \bar{\mu}^{cc}$ $\bar{\sigma}^{IPM} > \bar{\sigma}^{cc}$

Notes: (1) $\bar{\mu}^{IPM}$ is the mean of the subjective distributions under IPM of IPM growers in the first row, and of conventional control (CC) growers in the second row. Similarly for $\bar{\sigma}^{IPM}$, $\bar{\mu}^{cc}$ and $\bar{\sigma}^{cc}$.

(2) All tests are one-tailed tests and are at the .05 level except when there is an asterisk, in which case the result holds at the .10 level but not at the .05 level.

6. The Choice of an Optimal Strategy

Given the s.p.d.'s for partial profits under both control strategies, we investigated the choice of an optimal strategy for each grower individually under two decision criteria — expected profit maximization and expected utility maximization using the fitted utility functions. We found that both criteria predicted the actual choices equally well. Clearly, it is the nature of the subjective perceptions of outcomes rather than the type of choice creterion or the nature of risk preferences which explains actual use of IPM. For 35 of the 44 growers, given their s.p.d.'s, their current control strategy was superior to the alternative strategy by either criterion. For only nine growers — seven IPM and two non-IPM growers — the alternative strategy was better. Five of six of these cases seem reasonable in that either the two s.p.d.'s intersected, or the current control strategy was optimal if one overlooked the consultant fee component of insecticide costs. The other three or four cases seem less reasonable and would appear to imply irrational behavior as well as incorrect perceptions of yields and insecticide expenditures.

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