Voluntary Economic and Environmental Risk Tradeoffs in Crop Protection Decisions

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An indirect utility model is employed for measuring farmers' willingness to voluntarily accept yield losses for a reduction in environmental risk by decreasing pesticide use. Results support the hypothesis that farmers have self-described risk perceptions that enable them to make assessments of risk-yield tradeoffs. Policies designed to encourage and assist farmers making voluntary pesticide reductions can result in environmental risk reduction.

Policymakers in the past have used command and control regulation, taxes, legal solutions, and tradable permits to solve pollution problems. Currently, increasing emphasis is placed on voluntary compliance with environmental objectives. The newly instituted Pesticide Environmental Stewardship Program supports voluntary commitments to pesticide risk reduction through financial and technical support (U.S. Environmental Protection Agency 1996). The multistate Farm*A*Syst program helps farmers evaluate the environmental risk associated with their enterprises and develop cost-effective means of reducing them, with average voluntary investments of $800 per farm to reduce or eliminate water quality risks (Farm*A*Syst National Office 1996). Farm planning support programs for Idaho, Pennsylvania, New York, and the Great Lakes Basin teach farmers to use environmental auditing techniques in identifying risk and developing action plans that comply simultaneously with all relevant environmental regulations (Vickery and Lohr 1997).

In agriculture, voluntary adoption of alternative chemicals and chemical practices commonly has been explained by modeling observable characteristics of the farmer, the farm, the technology, information sources, and institutional arrangements. D'Souza, Cyphers, and Phipps (1993) presented a review of this literature.

Weaver's utility analysis (1996) of farmer adoption of sustainable practices included perceptions about environmental protection, economic capacity for reduced chemical use, and training requirements as explanatory factors. His results indicate that farmer beliefs and perceptions, which must be self-identified by farmers rather than observed, modify the economic decision. Weaver did not distinguish between purely voluntary and incentive-based voluntary participation, such as cost-sharing for soil conservation programs, nor did he model the risk tradeoffs implicit in compliance decisions.

Arora and Cason (1996) noted that little economic research on voluntary compliance was done prior to development and initial implementation of such approaches. They demonstrated that firms' participation in a purely voluntary toxic chemical reduction program is consistent with profit-maximizing behavior. Firm size and toxic release rates were positively related to participation, which was motivated in part by the cost savings of substituting nontoxic chemicals and in part by concern over consumer perceptions of a firm's environmental record.

We extend Arora and Cason's model (1996) to crop protection decisions and test whether farm size and chemical expenditures affect willingness to trade off economic and environmental risk. We also considered factors suggested by Weaver's work (1996), specifically, farm experience, education, and perceptions about environmental protection. Rather than compare the adoption of specific technologies, as most studies have attempted (Owens, Swinton, and van Ravenswaay 1997), we focus on the risk tradeoff itself, which derives from the farmer's utility function and thus modifies the adoption decision invariantly regardless of the

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technology choice. We explicitly consider risk tradeoffs, which underlie voluntary compliance decisions.

By identifying and quantifying risk perceptions that modify the economic crop protection decision, we can suggest design elements for voluntary environmental protection programs that will increase their probability of success. How strongly farmers value environmental and economic factors will affect the range of crop protection choices they are willing to consider implementing and the degree of environmental protection that can be expected to result from their decisions.

In this study, we quantify the willingness of farmers to trade yield losses for environmental gains. The value of an acceptable yield loss is indicative of belief that measurable risk reduction results from decreased chemical use. We use a utility difference model to value voluntary pesticide reductions by crop farmers in four midwestern states in the United States. Our empirical model describes farmers' decisions to reduce insecticide and herbicide applications in return for environmental benefits.

Valuing Risk Tradeoffs

Farmers' attitudes about chemical risk and the perceived advantages of reducing pesticide use have been ignored in research. The exclusion of lay opinion about risk due to chemical reduction is common, yet research that relies on expert opinion and observed data for risk usually exaggerates losses and ignores important sources of knowledge that could influence these estimates (Jaenicke 1997; Higley and Wintersteen 1996). Research fails to account for the environment-related and production-related benefits from pesticide reduction (Jaenicke 1997). Examples of the former include effects on wildlife, endangered species, and native plants. Examples of the latter include impacts on beneficial insects, livestock and crops, and operator health.

Pesticide reduction has two main risk consequences for farmers: potential gains in environmental quality and possible monetary losses associated with yield reduction. Use decisions trade off these risks. The true risk levels and their relationships to insecticide use are not known with certainty by the farmer. However, each farmer forms subjective estimates of the probabilities and values of decision outcomes, and these expectations are known with certainty to him or her. Of interest for the theoretical construct and empirical estimation is how this information may be elicited.

Viscusi and Evans (1990) highlighted the limitations of market data in estimating individual preferences for risk reduction, illustrated in figure 1. Let ABC represent the frontier of available farm enterprise returns—environmental risk combinations facing the producer. The producer selects the optimal production point B from this frontier, where the locus of expected utility (EU) is tangent to the enterprise returns frontier and the environmental risk-income combination is E_p, Y_p.

To measure the change in risk and income represented by a reduction in pesticide use, for example to E_{rp}, Y_{rp}, we need to map the entire EU locus. Market data and observed prices indicate only the tradeoff at the tangency of EU with the returns frontier. Viscusi and Evans (1990) noted that quasimarket data track response to changes in the farmer's risk condition, permitting estimation of the individual's utility function. We adopt the quasimarket approach to derive the underlying utility function that drives crop protection decisions, thus avoiding both limitations of market data and the need to specify a crop protection technology.

Cost of reducing chemical use is acceptable yield loss, measured as expected revenue loss. This value is the upper limit on willingness to pay for gains from pesticide reduction, since any lesser yield loss down to zero would also be acceptable if the same benefits were gained. Benefit to the farmer is protection of the environment, measured as the subjective rating of importance in protecting amenities from pesticide impacts.

In quasimarket studies, individuals have had dif-

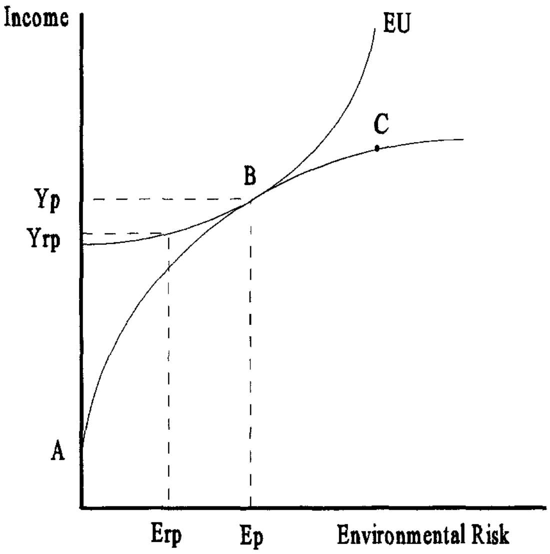

Figure 1. Environmental Risk and Farmer's Expected Utility Locus

ficulty assessing values for environmental goods that are not directly consumed as commodities or production inputs, because of lack of experience with the goods and disassociation of actions with environmental consequences (Diamond and Hausman 1993). Unrealistic attitudes about the affordability and method of payment for the perceived benefits of an environmental good also hinder valuation efforts (Mitchell and Carson 1989). An individual who recognizes the importance of an environmental good may offer a payment for the good that exceeds his or her budget constraint.

Survey evidence suggests that farmers may be better prepared than the general public to evaluate the risk tradeoff as they have more information about both benefits and costs of reducing pesticide use. Rockwell et al. (1991) confirmed that farmers are aware of their budget constraints and have experiential and science-based information on the yield risk from cutting back pesticide use. Also, farmers have demonstrated greater awareness of environmental impacts of management decisions, particularly for ground and surface water (Rockwell et al. 1991). Farmers are aware of the distinction between production-related and environment-related benefits of pesticide reduction and may be expected to value them accordingly (Jaenicke 1997). Quasimarket valuation provides an appropriate way to measure farmers' risk tradeoffs.

Decision Framework

Begin with the producer's indirect utility function defined over environmental goods and the choices of management practices including pesticide applications conditional on environmental risks. Let V_p be the state-dependent utility function when the producer maintains current applications with the current level of environmental risk at e_p. The indirect utility function depends on the producer's income level (Y), vectors of the individual's environmental attitudes (**A**), the individual's demographic and farm characteristics (**Z**), and regulatory and environmental conditions in the grower's state (**S**):

$$V_p = F(Y, \mathbf{A}, \mathbf{Z}, \mathbf{S} \mid e_p). \tag{1}$$

Let V_{rp} be the state-dependent utility function when the producer chooses a voluntary reduction in pesticide applications associated with reduced risk of environmental impacts to risk level e_{rp}. The compensated willingness to pay for the environmental good is derived from the utility difference model:

$$V_{rp}(Y - L^*, \mathbf{A}, \mathbf{Z}, \mathbf{S} \mid e_{rp}) = V_p(Y, \mathbf{A}, \mathbf{Z}, \mathbf{S} \mid e_p). \tag{2}$$

Equation (2) is derived from the utility difference model, such that $\Delta V = V_p - V_{rp}$, consistent with figure 1.

The acceptable yield loss (L^*) may be expressed as the dollar amount that equates the conditional ex ante indirect utility functions for the two choices where ΔV is the indirect utility difference. The empirical model for the acceptable yield loss for each producer depends systematically on the variables defined above:

$$L^* = \beta_0 + \boldsymbol{\beta}_1\mathbf{A} + \boldsymbol{\beta}_2\mathbf{Z} + \boldsymbol{\beta}_3\mathbf{S} + \eta^*. \tag{3}$$

Random and unobserved factors that influence yield loss appear in the error term denoted as η^*.

We specify marginal utility of income as constant across states of environmental quality and independent of income. McConnell (1990) noted that income is typically inferred from ranges and subject to differing levels of state and local taxes and its inclusion creates the potential for measurement error. This result was implemented by Cameron and Englin (1997), who used linearity of income in the indirect utility function to eliminate income from the utility-difference function. Monetary yield losses associated with reduced pesticides were not expected to significantly alter utility of income derived from farm operations in our model, where income is linearly specified. For these reasons, income was excluded from the monetary yield loss model in equation (3).

Holding indirect utility constant while environmental risk varies defines the yield loss L^* implicitly as a function of risk denoted as $L^*(e)$, where risk change is $e = e_p - e_{rp}$ (Harrington and Portney 1987). The total derivative of ΔV with respect to e is set equal to zero along the indifference curve so that

$$d\Delta V = \Delta V_L \, dL^*(e) + \Delta V_e de = 0 \tag{4}$$

$$\frac{dL^*(e)}{de} = -\frac{\Delta V_e}{\Delta V_L}.$$

In equation 4, ΔV_L represents the derivative of the utility difference model with respect to acceptable yield loss, and ΔV_e is the derivative with respect to changes in environmental risk. The term $dL^*(e)/de$ is the marginal willingness to pay for a decrease in environmental risk. Harrington and Portney (1987) emphasized that the marginal willingness to pay depends on the producer's indirect utility function. We model this function using environmental attitudes, farm characteristics, and state-level regulatory and environmental conditions.

Estimation Procedure

We implemented the model for valuing subjective risk tradeoffs by farmers using a quasimarket interview approach applied and validated by Viscusi and Evans (1990). Higley and Wintersteen (1996) confirmed that producers have experience in valuing environmental costs associated with insecticide and herbicide decisions in pest control. Farmers were asked to numerically rate the importance they place on avoiding risk for eleven environmental goods that could be affected by insecticide and herbicide use. Then they evaluated their acceptable yield loss in dollars per acre for using one less application of insecticides contingent on the reduction eliminating a moderate risk to the rate amenities. Throughout, we refer to "yield loss" even though it is measured in monetary units, for consistency with the questionnaire. A herbicide reduction response was generated following the same procedures. The definition of "moderate risk" was based on persistence and toxicity ratings for impacts on water quality and organisms (Higley and Wintersteen 1992). The elimination of the moderate risk by this action was presented as a certain probability.

The empirical structure in equation (3) is linked directly to the questionnaire presented to farmers, in which they were asked to value their acceptable yield loss. In this form, we can use the survey data to econometrically estimate the parameters that describe this relationship and test their statistical significance. We propose a system of equations to account for the possible linkage of the insecticide and herbicide decisions through the underlying utility function. Equation (3) indicates through β_1 that acceptable yield loss increases with intensity of environmental attitudes, measured as importance ratings of avoiding moderate risk to environmental amenities. The more strongly farmers feel about environmental protection, the greater their willingness to pay for environmental protection through yield losses.

We modeled equation (3) as a two-equation seemingly unrelated regression (SUR), with equations explaining acceptable yield losses for one-treatment reductions in insecticide and herbicide. The definitions of variables used in the model are presented in table 1. Mean values and standard deviations of the variables are shown in table 2. The dependent variables in the multivariate model are acceptable yield losses for reduced insecticide risk (*INSYLOSS*) and reduced herbicide risk (*HRBYLOSS*) associated with one-treatment reductions of each. The vector **Z** in equation (3) is composed of *ACRES* (acres farmed), *FARMYR* (years in farming), and *EDUC* (years of formal education). Linear and quadratic measures of total per acre expenditures on insecticides, *ITOTCOST, ITOTCOST2* and herbicides, *HTOTCOST, HTOTCOST2* were also included in **Z.** The same **Z** vector was included in both equations of the SUR.

The vector **A** contains two dimensions of the producer's environmental attitudes. For the insecticide reduction scenario, the variable *INSECN* represents an index for six environmental goods that affect yield risk through impacts on farm and human productivity. These goods are surface water, ground water, beneficial insects, harm to livestock/crops, acute toxicity to the farmer and others, and chronic toxicity to the farm family. *INSENV* is an index for five goods that affect risk to life support

Table 1. Description of Variables Used for Choice Model

Variable	Description
INSYLOSS	Acceptable yield loss to avoid moderate risks from insecticide ($/acre)
HRBYLOSS	Acceptable yield loss to avoid moderate risks from herbicide ($/acre)
ACRES	Number of acres farmed
FARMYR	Number of years in farming
EDUC	Years of formal education
ITOTCOST	Total per acre expenditure on insecticides in 1989 ($/acre)
HTOTCOST	Total per acre expenditure on herbicides in 1989 ($/acre)
TOTCOST2	Square of TOTCOST (ITOTCOST2, HTOTCOST2)
INSECN	Economic importance index for insecticide risk (sum of 6 factors)
HRBECN	Economic importance index for herbicide risk (sum of 6 factors) Importance of protecting surface water, ground water, beneficial insects, and livestock/crops, as well as importance of acute human health effects and chronic human health effects, rated from 1 to 10
INSENV	Environmental importance index of insecticide risk (sum of 5 factors)
HRBENV	Environmental importance index of herbicides (sum of 5 factors) Importance of protecting fish, birds, mammals, native plants, and endangered species rated from 1 to 10
ENVSCOR	Natural log of environmental score by state
AGPLSCOR	Natural log of agricultural pollution score by state

Table 2. Mean Values and Standard Errors of Independent Variables

Explanatory Variable	Mean Value	Standard Error
ACRES	570.39	546.73
FARMYR	26.43	13.30
EDUC	13.15	2.19
ITOTCOST	3.46	5.86
ITOTCOST2	46.30	329.22
HTOTCOST	12.80	10.32
HTOTCOST2	270.17	1409.40
INSECN	53.25	8.58
INSENV	38.98	10.12
HRBECN	52.50	9.12
HRBENV	38.22	10.64
ENVSCOR	8.83	0.05
AGPLSCOR	6.00	0.07

Number of observations = 1124.

and quality of life environmental functions. These goods are fish, birds, mammals, native plants, and endangered species. Both indexes are sums of the importance ratings, so that a respondent who rated all factors as very important (10) would have a value of 60 for *INSECN* and a value of 50 for *INSENV.* Similar ratings were elicited for the herbicide reductions and are defined as *HRBECN* and *HRBENV.* Both equations in the SUR contained an **A** vector, but only *INSECN* and *INSENV* were estimated in the insecticide risk model, while *HRBECN* and *HRBENV* were tested in the herbicide risk model. By differentiating the elements of **A** in the two-equation system, discrepancies in attitudes toward insecticide risk and herbicide risk may be detected.

The vector **S** in equation (3) contains the variables *ENVSCOR* and *AGPLSCOR.* These indexes reflect the environmental conditions and agricultural pollution levels in each state. Each producer from a given state has the same values for the two variables, so that any significant variation due to state conditions is detectable. The same **S** vector is included in both equations in the SUR.

Sample Description

To estimate the model, we used data from 1,124 questionnaires returned in a survey by Higley and Wintersteen (1992, 1996) of field crop producers in Illinois, Iowa, Nebraska, and Ohio. Corn and soybeans are the main crops grown in these states. The initial mailing was in early July 1990, and a reminder and duplicate survey form were mailed to each nonrespondent in early August 1990. Details of the survey administration are available in Higley and Wintersteen (1992, 1996).

Individual characteristics in the decision model include acres farmed, years in farming, and years of formal education. Respondents separately rated the importance of avoiding insecticide and herbicide risks for eleven environmental goods using a 10-point Likert scale, with 1 corresponding to "not important" and 10 corresponding to "very important." This scale has been validated in studies of risk perceptions held by consumers (Eom 1994) and by producers (Weaver 1996) and offers a simple and easily interpretable measure of risk attitudes. For insecticide risk and pesticide risk, respectively, the mean cumulative ratings were 92.9 and 92.1 in Illinois, 92.8 and 90.8 in Iowa, 93.1 and 91.4 in Nebraska, and 88.4 and 87.4 in Ohio, of possible ratings of 110. Higher ratings reflect greater importance of environmental risks in farmers' utility functions.

Since individual responses may be influenced by environmental conditions and regulations that vary by state, we supplemented the survey data with two indexes constructed from the 1991–92 Green Index (Hall and Kerr 1992). The Green Index ranks states on the basis of 256 indicators of pollution, quality of life, renewable and nonrenewable resource management, human health, environmental policies, and state Congressional voting. We summed the rankings for 256 indicators to obtain an environmental score variable for each state. The lower the value, the better the state ranks. The environmental scores were 7052 for Illinois, 6541 for Iowa, 7001 for Nebraska, and 7411 for Ohio. These compare with a minimum score of 4583 and a maximum score of 8658 for all fifty states.

The index of agricultural pollution is a subset of these indicators, with rankings for fourteen indicators of agricultural impacts on soil and water quality, agrichemical use, participation in conservation programs, and importance of agriculture to state economy. The agricultural pollution scores were 405 for Illinois, 414 for Iowa, 422 for Nebraska, and 342 for Ohio. For all fifty states, the minimum score was 193 and the maximum was 455. Both indexes enter the model in logarithmic form.

The farmers quantified acceptable yield losses per acre to reduce insecticide use by one application on all acreage and thereby avoid moderate risk for the eleven environmental amenities. A second scenario presented to the same respondents elicited acceptable yield losses associated with one less herbicide application. Respondents were provided information about the average costs for single treatments of insecticides ($7 to $15 per acre) and herbicides ($5 to $25 per acre) before being asked their willingness to pay. They were also asked how much they spent on insecticides and herbicides in 1989, including application costs. Reported expenditures averaged $3.46 per acre for insecticides and $12.80 for herbicides. The average insecticide cost fell outside the suggested range. While herbicides are typically used each year for corn and soybeans, the major crops grown in the region, insecticide use in any given year may vary depending on the effectiveness of crop rotations and integrated pest management (IPM) strategies.

The mean acceptable yield losses were $8.25 per acre for avoiding moderate insecticide risk to environmental amenities and $10.52 per acre for herbicide risk reduction. By state, average acceptable losses for avoiding insecticide risk were $7.98 in Illinois, $8.52 in Iowa, $8.35 in Nebraska, and $7.84 in Ohio. The largest value answered was $40 per acre and the smallest was $0. For avoiding herbicide risk, farmers averaged acceptable losses of $10.46 in Illinois, $10.92 in Iowa, $9.90 in Nebraska, and $10.09 in Ohio. The range of acceptable losses from reducing herbicide application was $0.00 to $50.00 per acre.

The summary results confirmed two critical perceptions. First, virtually all producers recognize the importance of environmental risks from both insecticides and herbicides. But some producers do not accept the premise that they should pay to help avoid environmental risks. For the sample of 1,124 respondents, 14% stated acceptable yield loss was zero for insecticide risk avoidance and 10% would accept zero yield loss for herbicide risk avoidance. This indicates an unwillingness to pay any environmental costs, with slightly more resisting payment for insecticide risk reduction. Higley and Wintersteen (1992, 1996) concluded from sample statistics that the acceptable yield loss values are not biased by a disproportionate number of environmentally concerned producers in the sample.

Results

Maximum likelihood estimates and their significance levels for the seemingly unrelated system of yield loss equations are presented in table 3. The estimated coefficients on *ITOTCOST* and *HTOTCOST* were significant and positive, while those on the quadratic terms *ITOTCOST2* and *HTOTCOST2* were negative. Farmers who spend more for pesticides are willing to accept higher yield losses to avoid moderate environmental risks. Acceptable yield losses for the sample peaked with insecticide expenditures of $45 per acre and herbicide expenditures of $97 per acre. Every additional dollar per acre spent on chemical crop protection increases the level of acceptable yield loss, by $0.073 per acre for insecticides and by $0.094 per acre for herbicides.

Table 3. Estimates from the Joint Model for Yield Loss-Environmental Risk Tradeoff

Explanatory Variable	Insecticide Tradeoff	Herbicide Tradeoff
ITOTCOST, HTOTCOST	0.079**	0.109***
	(2.060)	(3.783)
ITOTCOST2, HTOTCOST2	−0.0009	−0.0006***
	(−1.315)	(−2.750)
ACRES	−0.0006	−0.0003
	(−1.405)	(−0.675)
FARMYR	0.049***	0.042**
	(2.829)	(1.983)
EDUC	0.223**	0.013
	(2.109)	(0.100)
INSECN	0.017	
	(0.419)	
INSENV	0.089***	
	(2.952)	
HRBECN		0.070*
		(1.785)
HRBENV		0.068**
		(1.966)
ENVSCOR	−5.207	−9.522
	(−0.784)	(−1.119)
AGPLSCOR	−0.781	−1.638
	(−0.172)	(−0.296)
CONSTANT	50.644	91.600
	(0.630)	(0.936)
N = 1124	$\chi^2_{18} = 68.01$	

The dependent variable is yield loss (NSYLOSS and HRBYLOSS). Asymptotic t-statistics are in parenthese.

*indicates significance at the 0.10 confidence level. **indicates significance at the 0.05 confidence level. ***indicates significance at the 0.01 confidence level.

The critical value for the likelihood ratio statistics is 28.87 at 0.05 confidence level.

Since there is little variation in crop mix in the four states, there is little chance that large per unit price differences in chemicals are responsible for this result. Farmers who spend more may have better yields and so may be able to tolerate larger relative yield losses in return for environmental protection. Farm size in acreage has no effect on risk tradeoffs, suggesting voluntary chemical reduction is not scale-dependent.

Estimated coefficients on *FARMYR* and *EDUC* were positive and significant for the insecticide equation, but only *FARMYR* was significant for the herbicide tradeoff. More experienced, better-educated farmers accept greater yield losses to avoid environmental risks from insecticides. For herbicides, fewer alternatives have been proven effective so that education may have little effect on ability to substitute nonchemical methods (Benbrook 1996). These farmers risk greater losses in human capital from health effects of environmental damage than do less experienced, less educated farmers. More experience and education imply necessary skills and knowledge to adjust crop protection practices while reducing applications, and greater awareness of the effects on environmental goods.

INSECN was not a significant factor influencing willingness to pay for environmental protection through insecticide reduction, but *HRBECN* has a significant positive effect on the herbicide risk tradeoff. The mean sample value for *INSECN* was 53.2 and for *HRBECN* was 52.5, close to the maximum rating of 60. Avoiding risk to environmental goods that have productivity impacts is very important to farmers, but this concern does not alter acceptable yield losses for insecticide risk. Extensive water quality testing in the Midwest revealed that herbicides are a major contaminant, while insecticide pollution has not been significant. The positive effect on acceptable yield loss of a high importance rating of the *HRBECN* factors coupled with awareness of contamination by herbicides suggests credible risks to human and livestock health stimulate voluntary reduction in chemical use.

INSENV and *HRBENV* have significant positive influences on acceptable yield losses. The mean value for *INSENV* was 39.0 and for *HRBENV* was 38.2, compared with a maximum of 50, suggesting less agreement on the importance of these life-support factors than for the economic factors. Farmers who express strong support for protecting environmental goods are willing to pay more to avoid damage, even if there is no direct benefit to net returns for the farm.

A useful method to express the risk-yield loss tradeoff is in terms of the dollar value of the acceptable yield loss required per rating unit of risk. This is the value of a one-unit change in overall risk rating regardless of which underlying factor or combination of factors making up the economic and environmental risk indexes is responsible for the one-unit change in risk rating. We calculated this value for marginal changes in the two risk indexes based on equation (4).

The implicit value of a one-unit increase in importance rating of total risks at current levels of herbicide applications is $0.14 per acre and is approximately evenly divided between environmental and economic risks. This value is the marginal willingness to pay for risk reduction, based on the increased importance of risk. For insecticide applications the marginal willingness to pay for risk reduction is $0.10 per acre. The environmental risk component accounts for about 88% of this value.

From the emphasis on insect IPM research, a policymaker might reasonably expect that assistance programs targeting voluntary environmental risk reduction would best succeed with insecticide use. To the extent that yield losses incurred for insecticide reduction crowd out voluntary herbicide reduction, the cost-effectiveness of a program targeted toward reducing insecticide risk is lower than for an overall risk reduction program or a targeted herbicide risk reduction program. We calculated a farm level measure of the marginal willingness to pay for risk reduction by multiplying individual marginal risk valuation by the number of acres held by each producer. Summed and averaged for all farms, we found that the mean marginal value of risk reduction associated with lower herbicide use was $78.49 per farm and with decreased insecticide use was $57.77 per farm, with average farm size slightly over 570 acres.

Neither *ENVSCOR* nor *AGPLSCOR* significantly influenced acceptable yield loss. One explanation is that farmers' subjective risk tradeoff is framed without reference to the regulatory and environmental conditions in the state. While farmers may be aware of their state's situation, they do not determine their payments for environmental protection as if they were contributing to state level improvements. Existing state regulations and environmental conditions form a background for producer decisions but do not make farmers more or less likely to choose voluntary insecticide or herbicide reduction.

Cameron and Englin (1997) emphasized the importance of examining the robustness of valuations for environmental goods across alternative model specifications. They noted that willingness to pay estimates may differ systematically across respondents and that respondents who have some degree of experience with the good may provide more reliable valuations. We examined the effect of experience on farmers' acceptable yield loss by imposing a minimum level of pesticide expenditures on producers under the assumption that expenditures are correlated with familiarity with the chemical systems.

Higley and Wintersteen (1992) reported a typical range of expenditures per acre for both insecticides ($7 to $15) and herbicides ($5 to $25) for the sampled states. We included 173 producers who reported at least the minimum insecticide and herbicide expenditures in the restricted model and estimated the predicted acceptable yield loss for these experienced users. The predicted acceptable yield loss for reduced insecticide use from the full sample is $8.25 per acre and is only slightly higher at $8.85 per acre for experienced users. The predicted yield loss for the herbicide equation reveals the same pattern at $10.52 per acre for the full sample and $11.07 per acre for experienced users. Given the small differences between the full and experienced samples, it is probable that all farmers in the sample were knowledgeable of chemical methods and were capable of assessing the risk-yield loss tradeoff.

Conclusions

We apply an indirect utility model to demonstrate that farmers are willing to voluntarily reduce insecticide use, accepting yield losses for moderate reduction in environmental risk. The results indicate that more experienced, better-educated farmers, those who spend more on pesticides, and those who more highly rate protection of environmental goods will pay more. Estimation was based on data from 1,124 midwestern crop farmers and is generalizable to other producers who share similar characteristics. Our results show that farmers have self-described risk perceptions that enable them to make assessments of risk-yield loss tradeoffs, even when alternative crop protection methods are not explicitly offered. This suggests that fundamental attitudes about the relative importance of farm income and environmental protection are embodied in the farmer's utility function and these attitudes moderate insecticide and herbicide use decisions.

Policymakers who wish to encourage and assist farmers to make voluntary reductions in chemical use should determine barriers to such actions. First, uncertainty about insecticide and herbicide risks exists, whereas the scenario guarantees risk avoidance by reducing chemical use. Farmers may not believe the risk to environmental goods can be avoided by eliminating a single application, or they may believe current risk levels are low, rather than moderate. Research to determine economic and environmental risks and returns from reduction in insecticide use would provide a credible basis for making choices.

A second barrier is that farmers may feel they place themselves at a competitive disadvantage if they unilaterally reduce insecticide or herbicide use. The benefit of risk avoidance is shared by everyone, but producers who reduce chemical use bear the full cost. The questionnaire asked farmers to consider only their willingness to pay, in the absence of any contribution by other farmers. If they knew others would reduce chemicals by an equal amount, farmers might be motivated to pay less. Arora and Cason (1996) showed that publicity about and consumer awareness of voluntary compliance tend to increase participation rates. They recommended that these features be important design considerations for promotional programs. Several voluntary agricultural programs give highly publicized awards for exceptional performance (Vickery and Lohr 1997), which can encourage competition and raise the average and total willingness to pay for risk reduction.

Third, the crowding-out effect of encouraging environmental risk reduction, defined by the five factors in *INSENV* and *HRBENV,* at the expense of economic risk reduction, defined by the six factors in *INSECN* and *HRBECN,* should be avoided. With fewer alternatives to herbicide use available, and more evidence of pervasive contamination by herbicides, farmers tend to consider both aspects of risk in their willingness to pay for herbicide risk reduction. With insecticides, primarily environmental factors are being valued. Since herbicide risk reduction generates higher willingness to pay than does insecticide risk reduction, any program that focuses on birds, fish, mammalian wildlife, native plants, and endangered species will be less cost-effective than a broader emphasis encompassing human, insect, and livestock health risks. Most programs to assist in farm risk reduction address a range of potential risks (Vickery and Lohr 1997). Our research suggests that whole farm planning programs to assist in voluntary risk assessment and management will be highly successful in making agriculture more economically and environmentally sustainable in the twenty-first century.

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