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ABSTRACT---

An indirect utility model is employ 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.

KEY WORDS: pesticides, regulation, environmental policy, indirect utility

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Abstract

An indirect utility model is employ 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.

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Crop protection alternatives in the 21st century are evolving in response to public demand for dual goals of crop and environmental protection. Passage of the Food Quality Protection Act in 1996 could mean new restrictions on pesticide use, with tolerances tightened to meet the negligible health risk standards required by the law (Jaenicke, 1997). At the same time, alternative treatments such as bioengineered pest resistance are being challenged on safety grounds (Greenpeace International, 1997). Management changes hold promise for reducing environmental risk, but lack of management expertise and concern over yield reductions are barriers to widespread adoption (Jaenicke, 1997). Emerging research will focus on systems that combine chemical, biological and management strategies for protection of crops and human and environmental health (Council for Agricultural Science and Technology [CAST], 1995). More choices will be available, testing farmers' capacity to assess environmental and economic risk tradeoffs in order to select appropriate systems. We quantify these risk tradeoffs under current crop protection options for Midwest farmers and relate the results to new strategies for environmental protection.

Policy makers in the past have used command and control regulation, taxes, legal solutions and tradeable permits to solve pollution problems. Now 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). Other programs help farmers evaluate the environmental risk associated with their enterprises and develop means of reducing them. The Farm*A*Syst program documented participation by 30,000 farmers in 29 states, with average voluntary investment of $800 per farm to reduce or eliminate water quality risks through self-identified resource management changes (Farm*A*Syst National Office, 1996). The Great Lakes Basin Comprehensive Farm Planning program, the Idaho One Plan, the Pennsylvania One Plan, and the New York City Watershed Agriculture Program are farm planning support programs. Farmers use environmental auditing techniques to identify risk and develop action plans that comply simultaneously with all relevant environmental regulations (Vickery and Lohr, 1997).

Arora and Cason (1996) noted that little economic research on voluntary compliance was done prior to development and initial implementation of such approaches. 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) present a review of this literature. Weaver's (1996) utility analysis 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. We extend this research by explicitly considering risk tradeoffs, which underlie voluntary compliance decisions.

Weaver (1996) did not distinguish between purely voluntary and incentive-based voluntary participation, such as the case of cost-sharing for soil conservation programs. Arora and Cason (1996) demonstrated 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 cost savings of substituting nontoxic chemicals and by concern over consumer perceptions of the firm's environmental record. We extend this model to crop protection decisions and test whether farm size and chemical expenditures affect willingness to trade off economic and environmental risk. Rather than compare 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 technology choice.

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 U.S. 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 perceived advantages of reducing pesticide use have been mainly 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). Much 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 risk consequences for farmers, potential gains in environmental quality and possible yield loss, resulting in monetary loss to the operation. 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 is how this information may be elicited.

Viscusi and Evans (1990) highlighted the limitations of market data in estimating individual preferences for risk reduction. For example, hedonic wage studies estimate the average tradeoff of risk and increased wages but provide no information on the impact of individual utility functions. Figure 1 illustrates the source of this limitation using the scenario of the farm producer.

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 EU is tangent to the enterprise returns frontier. Market data and observed prices can provide evidence on the slope of the tangency with the frontier ABC. Information about the shape of the producer's utility function is available only for the rate of tradeoff at the tangency with the returns frontier. Viscusi and Evans (1990) noted that a strength of quasimarket data obtained by survey is that it tracks a change in the farmer’s risk condition, permitting estimation of individual utility functions.

The tradeoff between environmental benefits and yield loss is valued through the farmer's maximized utility function. The attitudes a farmer expresses reveal this underlying utility function and the expectations about risks of costs and benefits from reducing pesticide applications. The utility function determines the choice among crop protection options. Modeling this function avoids the discrepancy between market choices and utility functions noted by Viscusi and Evans (1990).

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 difficulty assessing values for environmental goods that are not directly consumed as commodities or production inputs, due to 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, G, 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)

(1) $$V_p = F(Y, A, Z, S \mid e_p) \quad .$$

Let V_{np} 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_{np}. The compensated willingness to pay for the environmental good is derived from the utility difference model

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

The acceptable yield loss (L*) is 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:

(3) $$L^* = \beta_0 + \beta_1 A + \beta_2 Z + \beta_3 S + \eta^* \quad .$$

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. Monetary yield losses associated with reduced pesticides were not expected to significantly alter utility of income derived from farm operations. Econometric tests also confirmed that the marginal utility of income was constant, so 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 $e = e_p - e_{np}$ (Harrington and Portney, 1987). The total derivative of ΔV with respect to e is set equal to zero along the indifference curve so that

$$d\Delta V = \Delta V_L dL^*(e) + \Delta V_e de = 0$$

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

This term 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.

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 for using one less application of insecticides contingent on the reduction eliminating a moderate risk to the rated amenities. 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. The more strongly farmers feel about environmental protection, the greater their willingness to pay for environmental protection through yield losses.

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 11 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. The mean cumulative ratings were 92.9 for insecticide risk and 92.1 for herbicide risk 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.

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 1991-1992 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 14 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 avoid moderate risk for the 11 environmental amenities. A second scenario 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 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. The acceptable yield loss was zero for 14 percent of the sample for insecticide risk avoidance and 10 percent for herbicides, indicating an unwillingness to pay any environmental costs. Higley and Wintersteen (1992, 1996) concluded from sample statistics that bias in these values due to a disproportionate number of environmentally concerned producers was unlikely.

Results

The definitions of variables used in the model are presented in Table 2. The dependent variables in the multivariate model are acceptable yield losses for reduced insecticide risk (INSYLOSS) and reduced herbicide risk (HRBYLOSS). The vector Z in equation 3 is composed of ACRES, FARMYR, and EDUC. Linear and quadratric measures of total per acre expenditures on insecticides, ITOTCOST, ITOTCOST2 and herbicides, HTOTCOST, HTOTCOST2 were also included.

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 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.

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. These scores were discussed in the previous section.

Maximum likelihood estimates for the seemingly unrelated system of yield loss equations are presented in Table 3. We tested the hypothesis of constant marginal utility of income across states of environmental quality variables. The likelihood ratio test for the restricted and unrestricted models yielded a calculated χ^2_2 value of 1.912, which did not exceed the critical value of 5.99 at the 95 percent confidence level. The income coefficients were not significantly different from zero and were omitted from the model.

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 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.

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 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. These farmers risk greater losses in human capital from health effects of environmental damage than 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 unit of risk. We calculate this value for marginal changes in the economic and environmental risk indexes based on equation 4. The implicit value of environmental and economic risks at current levels of herbicide applications is $0.14 per acre and is approximately evenly divided between environmental and economic risks. For insecticide applications the marginal willingness to pay for risk reduction is $0.10 per acre. The environmental risk component accounts for about 88 percent of this value.

A policy maker might reasonably expect that assistance programs targeting voluntary environmental risk reduction would best succeed with insecticide use. To the extent that willingness to pay though insecticide reduction crowds out voluntary herbicide reduction, the risk gains per unit of crop protection forgone is lower than for a n overall risk reduction program that would have a greater impact on herbicide use. We calculated a farm level measure of the marginal risk valuation for each producer by multiplying this value by the number of acres held by each producer. The average farm level value of risk reductions associated with lower herbicide use $78.49 and was $57.77 for decreased insecticide use.

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 are 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 exclude producers who report pesticide expenditures that fall outside this range from the model and estimate the predicted acceptable yield loss from the seemingly unrelated model. The predicted acceptable yield losses for one less insecticide or herbicide application for the full sample and for the more restricted experienced user model are very close. The predicted acceptable yield loss for reduced insecticide use from the full model is $8.25 and is only slightly higher at $8.85 value for experienced users. The predicted yield loss for the herbicide model reveals the same pattern at $10.52 for the full sample and $11.07 for experienced users. In the full sample, 14 percent reported zero expenditures on insecticides and 10 percent recalled zero expenditures on herbicides in 1989. Crop rotations, participation in set aside programs or conservation reserve, organic production methods, fallowing or grazing, and other factors could account for these individuals. Given the small differences between the full and experienced samples, it is probable that all these farmers were knowledgeable of chemical methods and were capable of assessing the risk-yield loss trade off.

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 there are fundamental attitudes about the relative importance of farm income and environmental protection that are embodied in the farmer's utility function and that moderate insecticide and herbicide use decisions.

Policy makers 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 are 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 risk reduction. With insecticides, primarily environmental factors are being valued. Since herbicide risk reduction generates higher willingness to pay than insecticide risk reduction, any program that focusses 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 21st century.

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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, livestock/crops, 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	

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	χ^2_{18}	68.01

The dependent variable is yield loss (INSYLOSS and HRBYLOSS). Asymptotic t-statistics are in parentheses. Asterisk indicates significance at the 0.10 confidence level. The critical value for the likelihood ratio statistic is 28.87 at 0.05 confidence level.

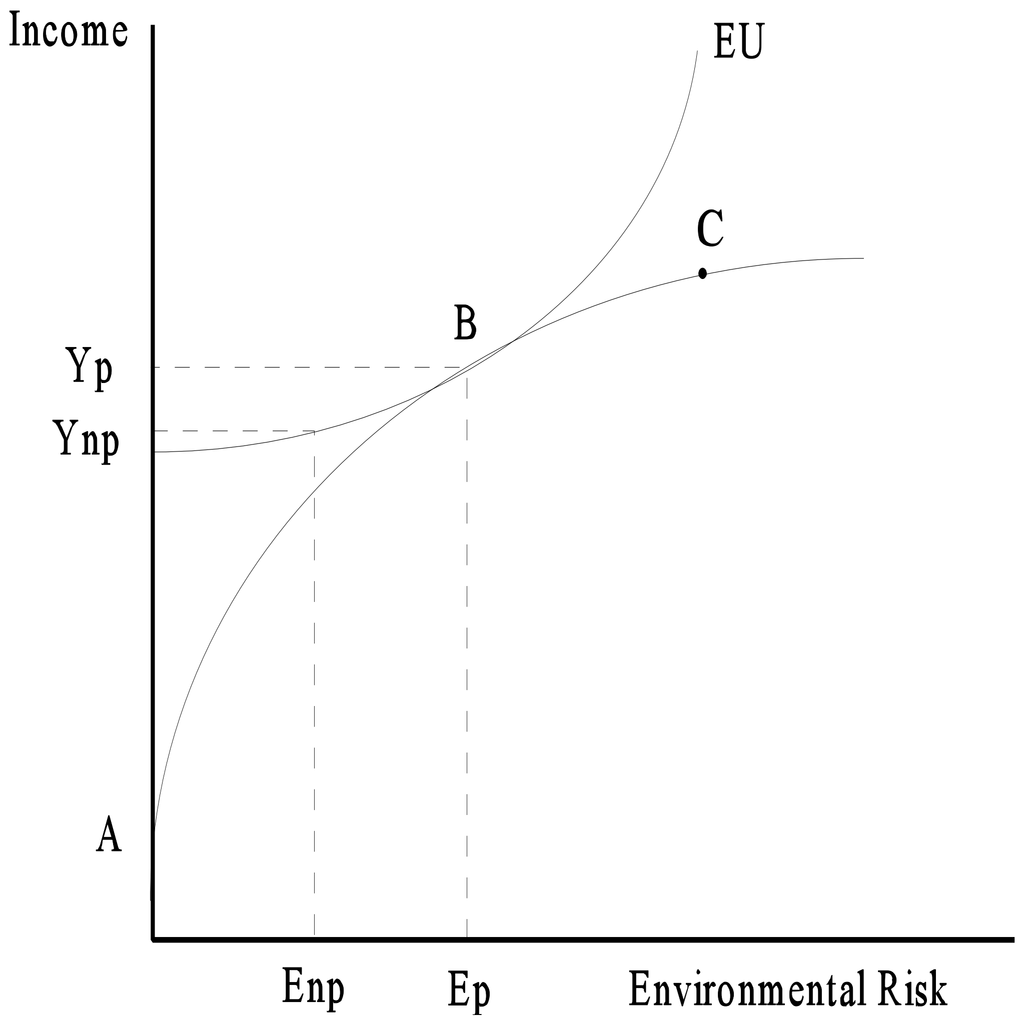

Figure 1. Environmental Risk and Farmer’s Expected Utility Locus