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QUANTIFYING AND MANAGING RISK IN AGRICULTURE

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Managing risk in agriculture is a topic of continuing interest in the United States. A complex risk environment has emerged over the past decade reflecting the farm sector's growing sensitivity to forces in the general economy, government policy and international markets. This environment should reward strong skills in production, marketing and financial management, particularly for operators of commercial farms. Risk management skills are an important component of superior management in each of these areas.

Fortunately a large body of conceptual and applied research on quantifying and managing risk in agriculture has been developed. Many conceptual developments in risk analysis contributed to the evaluation of work by agricultural economists. Von Neumann and Morgenstern revived Bernoulli's expected utility analysis. They proved that if an individual's behavior conforms to certain axioms an ordinal utility function can be formulated which reflects the decision maker's preferences for risky prospects. Savage elaborated subjective probability concepts and their relationship to expected utility. Arrow, and Pratt developed refined measures of risk aversion that provided for interpersonal comparison of risk attitudes and contributed greatly to empirical analyses of risk preferences. Portfolio theory was developed by Markowitz; Tobin; and others. Markowitz; Hanoch and Levy; Hadar and Russell; and Meyer made major contributions to the development of risk efficiency criteria that partially order risky choices for decision makers. Magnusson; and Sandmo made pioneering contributions in extending neoclassical production theory to deal with risk. Each of these developments has had an important influence on risk analysis by agricultural economists.

Approximately 40 years ago Earl Heady observed that risk and dynamics of the firm was a neglected area of farm management research. The development of research dealing with risk since that time has been dramatic. Jensen's survey of the literature cites numerous studies completed during the 1950's and 1960's on the formulation of expectations, measuring farmer's risk attitudes and managerial characteristics, and the evaluation of various strategies farmers could use in responding to uncertainty (Jensen). Several methodologies have been used to estimate risk preferences of producers in developed and developing countries. Game theory, Bayesian analysis, risk programming, simulation analyses and stochastic dominance criteria have been applied to risk analysis in agriculture. Three books that summarize important parts of the contribution agricultural economists made to firm level risk analysis are Anderson, Dillon and Hardaker (1977), Risk Management in Agriculture, edited by Barry (1984), and Robison and Barry (1986).

The risk considerations in aggregate policy analyses have received much less emphasis than farm level applications. Two approaches that have been used to incorporate the aggregate effect of risk aversion in empirical analyses are the programming approach (Hazell and Scandizzo) and the econometric approaches (Just, Hueth, and Schmitz). Both approaches continue to be used in applied policy analyses, but their use has not become as routine as many of the risk analyses at the micro level. More research is needed to understand farmer's response to policies and the implications for structure of the agricultural sector.

The purpose of this paper is to review relevant portions of the risk literature and propose an agenda of applied risk research. More specifically, the paper discusses the major sources of risk in agriculture, summarizes several methods of quantifying risk, summarizes the literature on estimates of agricultural producers' risk preferences, and briefly discusses alternative methods to manage risk. The applied research agenda given in the final section is included to promote discussion of ways that we can aid decision makers apply what has been learned. The discussion focuses on these topics as they relate to agricultural producing units. Many of the same procedures can be applied to firms in processing and distribution as well as to the analysis of aggregate policy issues. The comments are developed from my experience, primarily in the United States, and what I read of work in other areas of the world. The reader will need to determine how these comments apply to the Republic of South Africa and other areas of interest.

The terms risk and uncertainty are used interchangeably throughout this discussion. By either risk or uncertainty, I mean that the action a decision maker selects has alternative outcomes. The decision maker may or may not know the full range of alternative outcomes, but the decision maker uses the available data to identify possible outcomes and estimate subjective personal probabilities of their occurrence.

SOURCES OF RISK

Economic research is typically concerned with estimating the risk of a monetary outcome. The gross margin of an individual crop or livestock enterprise within the business and either the net cash flow or net farm income of the total business are typically the outcomes of concern on an annual basis. Over longer periods of time, consumption plus changes in wealth are commonly considered the consequence of interest.[1/]

[1/] A more detailed discussion of defining the consequence of interest is given elsewhere (Eidman).

Agricultural producers face many uncertainties that can affect these monetary outcomes. The external environment of the production unit has several major dimensions, each of which can be considered a source of uncertainty. Five major dimensions commonly identified are: technological, climatic, social, political, and economic. Each of these dimensions represents an important source of risk for agricultural producers.[2/]

There are many factors of change operating individually and in combination within these five dimensions that may contribute to producer risk. The availability of new technology is typically uncertain with respect to its timing, the input-output coefficients, and the human capital required to utilize it. Consumer acceptanceand hence demand for the commodity produced with the new technology may also be uncertain. For example, dairy and hog farmers in the U.S. currently face these uncertainties as they consider adoption of growth hormones (bovine somatotropin and porcine somatotropin) to enhance the production of milk and pork.

Uncertain weather is often the first source of risk farmers mention. It is important in both the short-run and the long-run. Concerns about changing climate (e.g., world warming) represent an additional source of long-run risk.

Changing values and attitudes of employees, input suppliers, bankers, purchasers of products and society in general translate into lifestyle changes which affect the demand for agricultural products and pressures to change the ways food can be produced. For example, consumer demand for residue-free and humanly raised commodities appears to be increasing in both the European Economic Community and the U.S. The European Economic Community has recently added two priorities to its common Agricultural Policy: human health and farm animal welfare (Lilwall). Pressure from Swedish consumers and taxpayers led their government to enact laws in 1988 having the objective to protect farm animal welfare.

National and local governments legislate on many matters that influence profitable operation of the business. These include wage and price controls, safety and health standards for employees, environmental standards, input subsidies, product price subsidies, marketing organizations and tax subsidies. The potential for changes in these

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[2/]The strategic management literature typically includes an appraisal of both the general and the industry environments. In addition to the five areas mentioned for the general environment, an appraisal of the industry environment emphasizes an evaluation of (1) product and service demands, (2) the availability and cost of inputs, and (3) the organization's competitive position. These factors are included within the five dimensions listed here to shorten the presentation. See a standard text such as Jauch and Glueck Chapters 3 and 4 for a more detailed discussion of an organization's environmental analysis.

institutional restrictions represents an important source of both short-run and longer-run risk for agricultural producers.

Unexpected change in major economic variables is an important source of uncertainty. Unexpected changes in the inflation (deflation) rate, interest rates, exchange rates, and tax rates are important economic variables affecting the risk farmers face.

These and other factors of change operate through the external environment to affect the technology that is available for use. They affect laws, regulations and societal norms that limit the organization and operation of the production unit. They operate through the market to affect the price levels of inputs and products.

A major challenge in applied risk research is to characterize the important factors of change in a manner useful for decision making. Some decisions are short-run in nature. We can treat the underlying technical and economic relationships--production functions, supply relationships and demand functions--as constant for these short-run analyses. Risk for the short-run can be estimated as the stochastic variation in prices, production and income given these relationships. More factors of change operate over the longer-run. Some may cause changes in the underlying relationships as well as alter the size of the stochastic elements associated with the relationships. It is my observation that we have tended to estimate what I am calling short-run production, price and income risk in previous studies. Many of our longer-run studies that consider risk have assumed these are constant over time, which probably understates the magnitude of the actual risk.

Characterizing Risk

The appropriate means of characterizing risk depends on the decision rule to be used. Two classes of decision rules are commonly discussed in the current agricultural risk literature: safety-first rules and expected utility maximization. The safety-first rules satisfy a risk constraint first and a profit oriented objective second. The risk concept implied by the safety-first model is commonly described as chance of loss or down-side risk, which is consistent with both the dictionary definition and popular usage. Several types of safety-first rules have been suggested (Pyle and Turnovsky). One rule assumes the decision maker maximizes expected returns ($\bar{E}$) subject to a constraint that the probability of a return less than or equal to a specified lower disaster level (d) will not exceed a specified probability a. This rule can be stated as

$$\begin{aligned} &\text{Maximize } \bar{E} \\ &\text{Subject to } P(E \leq d) \leq a \end{aligned} \qquad (1)$$

If the decision maker is a farm operator, the lower level of income might be an amount sufficient to pay cash operating expenses, family living, taxes and interest (but not principal) payments on debt. An important point to notice is this and most other safety-first rules require estimates of probability distributions of the outcome. One might argue that probabilistic information could be developed for only the appropriate range of the outcome variable. It may be difficult, however, to accurately estimate part of a probability distribution without estimating the total distribution.

Both maximization of expected value and maximization of expected utility require information on the probability of occurrence for the full range of the outcome variable. The index for maximization of expected returns is the summation of the monetary returns Y_{ij} weighted by their respective probabilities $p(S_i)$. The expected value index for the j^{th} action $E(A_j)$ is given by:

$$E(A_j) = \sum_{i=1}^{m} p(S_i)\, Y_{ij} \qquad (2)$$

The choice with the largest value of $E(A_j)$ ($j = 1,\ldots,n$) is preferred. Daniel Bernoulli proposed the expected utility model in the 1700's as being more descriptive of people's choices under uncertainty than the expected value model. Expected utility explained how the marginal worth of a unit of income at a low level could be valued differently than an additional unit of income at a high level. Von Neumann and Morgenstern proved that if an individual's behavior conforms to certain axioms, an ordinal utility function can be derived to assign utility values to potential incomes. The expected utility for the j^{th} action $U(A_j)$ is given by:

$$U(A_j) = \sum_{i-1}^{m} U(Y_{ij})\, p\,(S_i) \qquad (3)$$

The choice with the largest value $U(A_j)$ ($j=1,\ldots,n$) is preferred.

Both types of decision rules require information on the probability distribution over the full range of the outcome variable. The required probability distributions of prices, yields and net incomes can be represented in several alternative ways. Four methods commonly used are illustrated with the hypothetical yield data in Table 1. Assume that the data are obtained from the farmer's records and they have been appropriately detrended to allow for changes in technology. The data in Table 1 could be used to form either a probability density function (PDF) or a cumulative distribution function (CDF). For example, the data on corn yield could be displayed as a simple histogram (Figure 1a). The histogram is a graphical estimate of the plot of the density function. Similarly, the empirical distribution function can be plotted from the sample data to provide an indication of the cumulative distribution function. The user may want to smooth the empirical distribution to allow for a wider range of outcomes than are exhibited in the observed data and to smooth some of the irregularities that typically occur in a small sample of observations. An example of a smoothed empirical CDF using a procedure described by King (1989) is illustrated for the corn yield data in Figure 1b. A third method of representing probability distributions is to estimate the moments of the distribution. The mean, standard deviation and skewness are given in Table 1 for the two crops. Many decision models rely on estimates of the standard deviation (or variance) as the measure of dispersion or risk. The standard deviation is likely to be more acceptable as a single measure of dispersion in distributions that are symmetrical than those that are positively or negatively skewed. When a random variable is positively skewed, the probability is greater than .50 that a particular outcome will be below the mean. For example, these data suggest corn yields are negatively skewed, while wheat is more symmetrical. A fourth method is to select a probability distribution and estimate its parameters. For example, the decision maker might consider representing the probability of wheat yields with a normal distribution having an expected yield of 43.44 and a standard deviation of 5.95. The normal CDF with these parameters is shown in Figure 1d. A goodness-of-fit test could be used to examine how well the fitted distribution in Figure 1d represents the observed data. Procedures for conducting goodness-of-fit tests are given in standard discussions of estimating the parameters of probability distributions. For example, see Law and Kelton, pages 192-204. A simple visual inspection of the histogram of corn yields suggests a distribution allowing for negative skew, such as the Beta, may provide a better fit than the normal distribution.

METHODS TO QUANTIFY RISK

The probability distributions of prices, production levels and net income are typically obtained through a combination of modeling and encoding. The modeling process includes defining the relevant variables and characterizing their relationships in a formal model. For example, the annual gross margin of a single crop enterprise might be modeled as:

$$(P \cdot Y - VC)\,A = GM \qquad (4)$$

where P = product price per unit of output,
Y = yield per hectare,
VC = variable cost per hectare,
A = number of hectares, and
GM = the gross margin for the A hectares

The variables in the model can be divided into decision variables (those the decision maker can choose the values of, such as A) and variables that are beyond the decision makers control. Both P and Y are typically beyond the control of agricultural producers. Some variables, such as VC, may be partially under the decision makers' control. The farmer may control the quantity of many variable inputs applied, but the quantity of some yield related inputs and the input prices are often beyond the operator's control. This problem can be solved by dividing VC into appropriate component parts and restructuring the model.

Uncertainty is incorporated into the analysis by assigning probability distributions to the important uncontrolled variables. The philosophy of subjective probability indicates the probability assessment should reflect the decision maker's information about a given quantity or event. The process of extracting and quantifying individual judgment about uncertain variables is referred to as encoding (Spetzler and Stael von Holstein). The decision maker may rely on the analysis of a set of historic observations (such as past yields) or the judgment of an expert in forming his/her judgment about the uncertain variable.

Following this broad definition of encoding, there are three basic methods of quantifying risk that are commonly used in agricultural risk analysis. They are empirical, elicited and logically derived.

Based on Empirical Data

Many analysts and farmers faced with the task of encoding production or price risk begin by searching for what they feel is an appropriate set of historic data to use as the basis of their assessment. Pioneering work in the estimation of price, production and income variability was completed by Heady, Kehrberg and Jebe). This and a landmark study by Carter and Dean identified a number of important issues in using historic yield and price data as the basis for probability encoding. Three of these are the appropriate length of historic period from which data should be used, the source of the data, and the appropriate method to process the data.

One of these issues is the source of data. They argue and more recent studies document that production and price variability tend to be greater at the farm level than for the average yield of a larger geographic area such as a county or state. This indicates farm level data should be used if possible to estimate farm level production and price risk.

Second, an appropriate detrending method should be used to remove the predictable change in the yield or price. Earlier studies used relatively simple linear and polynomial detrending methods as an estimate of the predictable change in yield or price over time. More frequent changes in technology and economic conditions have encouraged analysts to use more elaborate methods to remove the systematic component. Monetary series, such as prices, are usually expressed in monetary values of current purchasing power. Some authors recommend developing the expected change in a price series as a sequence of one-step ahead forecasts, where the forecasts are based on data available to the decision maker at the time the expectation would have been formed and with a forecasting device that is updated each period (Young). Either a moving time trend or a moving autoregression model can be specified to calculate the expected change in a manner meeting these conditions.

Elicited Distributions

There has been a great deal of interest in eliciting personal probabilities from farmers and other decision makers as a basis to analyze risky decisions. The basic premise of the personalistic school is that the probability an individual attaches to a particular event expresses the individual's "degree of belief" in that event. When these "degrees of belief" are assessed in a quantitative and coherent manner, the assessed probabilities conform to the axioms of probability (Savage).

Hogarth reviews much of the psychological research debating whether human subjects can express their degrees of belief in the required manner. He concludes in part that substantive experts can make meaningful assessments in situations where they make forecasts over a period of trials and receive feedback on the accuracy of their prediction. However, he also acknowledges there are many examples of experts giving erroneous predictions. Furthermore, Hogarth's assessment of the available research is that naive assessors find expressing degrees of belief in a quantitative manner "an unusual and exacting task." This sobering appraisal suggests we cannot easily fill our need for accurate probability predictions through direct elicitation. Applied work will require continued reliance on direct elicitation when the data for other methods are not available, however.

The literature on common modes of judgment subjects use and the resulting implications for bias in the elicited probabilities is both extensive and interesting (Spetzler and Stael von Holstein). This literature emphasizes the importance of motivating and conditioning the subject, structuring the variable in an appropriate manner, and verifying the elicited distribution with the subject. Motivation and conditioning introduces the subject to the encoding task and attempts to determine if sources of motivational bias might be present. The subject is also asked to state the most important basis for the judgment and what sources of data or models are being used in forming the responses. The variable must be defined as an unambiguous variable that is not controlled by the decision maker. It must be clearly defined in terms of quantity, unit, quality, date and location. For example, if a probability distribution of a commodity price is being elicited, it is important to specify the unit on a scale (bushel, ton, kilogram, etc.) meaningful to the subject.

Various methods have been proposed for the encoding process (Anderson, Dillon and Hardaker; Hogarth; Spetzler and Stael von Holstein; and Nelson, Casler and Walker). A common recommendation is to begin by asking for extreme values and then for scenarios that might lead to outcomes outside of the extremes provided. This approach helps identify conditions that the subject has taken as given in providing the assessment. Procedures have been recommended to verify the results with the subject. Plotting the resulting distribution and having the subject inspect it visually is one step in verifying elicited probabilities. More rigorous verification is provided by selecting pairs of events having the same elicited probability of occurrence and asking the subject if these events are considered equally likely.

Relatively few studies eliciting probability distributions from farmers have been reported in the literature, perhaps because many researchers have doubted the ability of elicitation procedures to provide a reliable representation of the subjects beliefs. Adherence to these recommendations on motivation, conditioning, verification and structuring of the variables has the potential to improve the accuracy of elicited distributions.

A recent study compared elicited yield distributions with those estimated from historical data (Skees). The study found farmers were able to assess the expected yield more accurately than the dispersion. However, the discussion also noted that "farmers appear to be surprisingly consistent (between crops) in the degree that they over or underestimate both expected values and standard deviations." The later finding suggests calibration methods could be applied to correct their elicited distributions.

Logically Derived

Logically derived probabilities are typically associated with games of chance rather than the applications of interest in agricultural risk analysis. One example of logically derived probabilities that might be used in agricultural risk management is the use of options market data to assess the probability distribution of commodity prices.

A commodity option is a contract to purchase or sell a given quantity of the commodity at an exercise price stated in the contract. A contract conveying the right to buy is a "call" option. The individual purchasing the call (put) contract pays a fee for the right to buy (sell) a specified amount of the commodity at the exercise price.

Gardner observed that option selling prices generate implicit information of the market's assessment of the variability of commodity prices. His article gives an option pricing formula and outlines a procedure to derive the implied variance of the price distribution. The procedure assumes the futures market price for the commodity at time T can be interpreted as the expected price at time T and that the option contract price is the present value of the option contract. The procedure uniquely determines the variance based on the option price, the exercise price of the option contract, the futures price, the price of a risk-free bond for the appropriate period and the time until expiration. By assuming the mathematical form of the distribution, the procedure can be used to assess the implied probability distributions.

Fackler and King apply this procedure to options based probability assessments of four agricultural commodities and provide a means of evaluating the reliability of such assessments. Their evaluation is somewhat preliminary given the recent development of the options markets. The reliability of the option-based probability assessment for two of the commodities, corn and live cattle, however, suggests this may be a useful method of encoding price distributions when options market data are available.

Evaluating Encoded Distributions

A natural question to raise is, how good is a probability assessor? Calibration or reliability, one measure of goodness, is concerned with the degree to which an assessor's probability corresponds to the relative frequency that eventually occurs (Bunn; Winkler). They suggest an ideal probability assessor should have a record that shows for occasions when an X percent probability was assessed, the frequency of occurrence was approximately X percent. Furthermore, they suggest users of probability assessments would like this to hold for the full range of probability levels. If the value of the assessed probabilities is plotted against the frequency of occurrence of all events with that assessed probability, an assessor meeting this criterion would plot as a straight line. More typically, events occur Y percent of the time when probabilities of X percent were assessed. Plotting Y against X gives the assessor's calibration function. The closer the calibration is to a straight line, the better calibrated is the assessor (Figure 2).

The calibration process also provides an opportunity to correct the estimates when systematic bias in previous assessment is detected. The procedure, presented in Bunn, fits a calibration function and adjusts the assessed distribution for the observed systematic bias. Examples of calibration in agricultural assessments are presented by Fackler and King.

A more thorough evaluation of an estimator is provided by scoring rules. Bunn notes that good calibration by itself is not a sufficient condition for an estimator to be valuable. The ideal probability appraiser would always give probability of zero or one and would always be correct. For example, predicting a high commodity price with a probability of 1 when it occurs and 0 when it does not occur is likely to be of greater value than predicting that a high price will occur with probability of .33 on three occasions and having the high price occur once. Scoring rules use a penalty function reflecting how far an assessor differs from the estimates made by a perfect predictor. Proper scoring rules are those that encourage honesty on the part of the appraiser. Winkler lists several proper scoring rules. Bunn; and Winkler provide illustrations of the procedure. Bessler and Moore discuss their application to agricultural forecasts.

Multivariate Distributions

In many applications the distributions of stochastic variables are not independent. There are three methods to include the effect of multivariate distributions on the outcome variable. One is to model away the correlation. For example, if the yield and price in equation 4 are correlated, one could replace these two variables with their product, gross returns, and estimate the probability distribution of gross returns. This approach may provide an acceptable solution in some cases, but may present difficulties in encoding the distribution for the combined variable.

A second approach is to encode conditional distributions. Using the example of P and Y in equation 4, this would require encoding the distribution of one variable, say P, conditional on each of several alternative levels of Y. Limited data availability and the difficulty of eliciting conditional probability assessments frequently limit the opportunity to use this approach.

Historic data series on yields, prices and other state variables can be used to estimate correlations (Lin, Dean and Moore). The data series should be appropriately conditioned as discussed above and the conditioned data used to estimate the required correlation coefficients. These correlation coefficients can be used with the encoded univariate distributions to estimate the appropriate multivariate distributions (Law and Kelton, Ch. 7; and King, 1989).

RISK ATTITUDES

Much empirical work has focused on measuring the risk attitudes of agricultural producers. Some of these studies have been primarily methodological in nature, measuring the risk attitudes of a relatively small number of nonrandomly selected producers. Others have attempted to estimate risk preferences for a larger sample to obtain an estimate of the distribution of risk preferences for the population of producers. Several approaches used in making these estimates are mentioned here: (1) direct elicitation of utility functions, (2) the risk interval approach, (3) experimental methods, and (4) observed economic behavior. In addition to a better understanding of the methodological advantages and disadvantages of the four approaches, these studies have provided an important empirical base for applied research.

Direct Elicitation Methods

Direct elicitation of utility (DEU) functions involves direct questioning of decision makers to specify their risk attitudes. Several elicitation procedures, all requiring the decision maker to respond to hypothetical gambles involving monetary gains and losses, are described elsewhere (Officer and Halter; and Anderson, Dillon and Hardaker). Each of the elicitation procedures yields a series of points in utility-monetary space that can be used to estimate utility as a function of monetary outcome. DEU has been criticized because of the lack of realism in the game setting, interviewer bias that can creep into the elicitation procedure, and the lack of time for respondents to study the hypothetical choices (Binswanger; and Robison, Barry, Kliebenstein and Patrick). Much can be done to reduce the effect of these problems (Anderson, Dillon and Hardaker; and Hildreth and Knowles). However, it is a relatively expensive method of obtaining data on risk attitudes.

Risk Interval Approach

King and Robison (1981 a,b) proposed an interval measure of risk attitudes. The approach requires the decision maker to choose among pairs of probability density functions of monetary outcomes. The procedure treats constant absolute risk aversion over a small range of monetary outcome as an acceptable approximation of the decision maker's actual risk aversion. The procedure calculates the boundary level of absolute risk aversion that would make the decision maker indifferent between the two distributions. The individual's response indicates whether their level of risk aversion is above or below the boundary levels. By asking the decision maker to choose between appropriately selected pairs of distributions, the range that includes the decision maker's risk aversion function is determined.

Experimental Methods

Binswanger, dissatisfied with the interviewer bias he observed in applying the DEU to heads of households in rural India, developed an experimental approach. Gaming situations conducted over a period of time with financial compensation provide an incentive for the decision maker to increase and protect their wealth. The use of financial compensation and the opportunity to make the choices over a longer period of time respond to some of the criticism of DEU. The cost of providing meaningful financial payoffs to commercial farmers in developed countries has restricted its area of use.

Observed Economic Behavior

The observed economic behavior (OEB) approach derives estimates of risk attitudes by comparing actual behavior of decision makers and the behavior predicted by an empirical model of the decision environment. Brink and McCarl developed a linear risk programming model of the annual crop selection problem for central Indiana farms. The risk aversion parameter in the model was adjusted until the cropping program selected by the model corresponded to the actual cropping program chosen by the decision maker. Econometric modeling approaches have been used to estimate the risk preferences of decision makers based on observed behavior (Antle). OEB has the advantage of using data on actual decisions rather than hypothetical choices. It is also considered to be less expensive when estimating risk attitudes for a large sample of decision makers. OEB is criticized because it attributes all differences between the actual decision and the decision recommended by the model to risk attitude. Thus, any difference between the decision maker's understanding of the decision environment and that depicted by the model is included in the estimates of the decision maker's risk attitude.

The empirical results indicate commercial farmers in the U.S. are predominantly risk neutral to slightly risk averse at mean annual income levels, with much smaller proportions exhibiting strong risk aversion and slight risk preference. The empirical measures of the Arrow-Pratt risk aversion coefficient obtained from studies by Lin, Dean and Moore of six large-scale California farm operators and Hildreth and Knowles of four Minnesota farm operators ranged from -.0002 to .0012. King and Robison (1981b) produced risk coefficients within the same range for Michigan farmers. In studies of larger samples of producers, Wilson and Eidman found 44 percent of Minnesota swine producers were risk averse while 34 percent were risk neutral and 22 percent were risk preferring. Tauer found similar percentages for a sample of 72 New York dairy farmers. He found 34 percent were risk averse, 39 percent risk neutral and 26 percent risk preferring. These data provide a reasonably consistent picture of risk preferences for commercial family and larger farms in the U.S. Officer and

Halter provide results for 5 Australian Wool Growers that are consistent with the U.S. estimates.

The empirical estimates of producer risk preferences in developing countries are also somewhat mixed. Dillon and Scandizzo found that most, but not all, small farmers and share croppers in Northeast Brazil exhibited risk neutral and risk averse preference. They also noted that the proportion of risk averse respondents increased when the family's subsistence was not assured. In contrast, Binswanger and Sillers comparing studies of risk preference for small farmers in India, the Philippines, El-Salvador and Thailand feel the data suggest that the incidence of risk neutrality and risk preference in peasant farming is quite low. Their data also indicate few LDC farmers are extremely risk averse. They argue that it is reasonable to hypothesize peasant farmers are moderately risk averse. Antle used an econometric model to estimate risk preferences for a sample of 282 rice farmers in India. The econometric estimates of partial Arrow-Pratt risk aversion are in the same range as those obtained with the experimental method.

METHODS OF MANAGING RISK

It is convenient to list and briefly describe methods of managing risk by area of responsibility: production, marketing and finance. Doing so emphasizes the actions individual operators can take in responding to the risk environment. In addition to private responses, it is important to recognize the role public policy plays, both in the need for risk management and in the opportunities available to the operator to formulate a risk management strategy. The following discussion briefly deals with these four areas.

The available evidence indicates that farmers use a combination of methods to manage risk on their individual farms (Patrick, 1984). The challenge farm operators and those advising them face is to develop an integrated approach to risk management that is appropriate for the operator's financial situation and risk preferences.

The evaluation of methods and combinations of methods to manage risk has been a very popular area of research. The work can be divided into two parts, conceptual and empirical. The conceptual research uses models of the decision environment to deduce the decision maker's response and indicate how this optimal response may be affected by differences in debt level, risk preferences, the risk environment and other factors. This work provides a rich source of hypotheses concerning the appropriate use of many methods of managing risk. Much of this research, as it applies to agricultural producers, is summarized by Robison and Barry. The empirical studies evaluate the impact of applying risk management methods to specific farming situations. Many of these empirical studies completed within the U.S. are cited in the book edited by Barry. The discussion in this paper cites a few empirical studies as examples of completed research. Space does not permit either a summary of the conceptual work or a more complete summary of the empirical findings.

Production Responses

Risk Reducing Inputs. Farmers frequently select the technical inputs and the system of production to reduce risk. Irrigation is frequently cited as an input that reduces production risk in arid regions. Harris and Mapp reported that expected net returns of irrigated sorghum in Oklahoma are more than double nonirrigated expected net returns, while the variance of irrigated net returns is significantly smaller than dryland returns. Similar, but less dramatic results have been reported for subhumid and humid regions. Burt and Stauber reported that irrigating corn in Missouri increased expected gross returns by 34 percent and reduced the standard deviation by 50 percent. Studies in Indiana and Georgia have shown much smaller increases in expected net returns, but large reductions in variability of net returns (Apland; McCarl and Miller; and Tew, Musser and Boggess.

Farmers often invest in additional machinery capacity to complete tasks in a timely manner during years of unfavorable weather. Tenant farmers may over mechanize both to stabilize output and to reduce the risk of losing their rented land. Antibiotics in livestock feed, and pesticides used in crop production may be routinely used though not always required. Planting several varieties, may reduce possible losses from weather, insects or disease. In general, these actions are designed to reduce yield and net return variability, but in many cases they also reduce the expected net return.

Information and Control. One of the most effective ways to reduce production risk is to develop appropriate information and control systems for the major crop and livestock enterprises. The principles of developing such systems are outlined by Boehlje and Eidman. There has been a great deal of interest in developing such systems for crop and livestock producers in the U.S. Commercial concerns, including the farmers' cooperatives, are offering pest management and irrigation scheduling services. These services scout fields and make recommendations to producers for appropriate pest control and irrigation application. These activities recommend a response to the farmer based on the data collected. The recommendations replace the routine applications mentioned under risk reducing inputs. Similarly, services are being offered to livestock producers that monitor the performance of livestock and recommend appropriate responses related to nutrition, disease control, the breeding program, housing, and other husbandry areas to avoid substandard performance if possible and to improve substandard performance when it occurs.

The availability of relatively low cost microcomputers and the development of certain information technologies is leading to further development of information and control systems in both the public and private sectors. The merging of computers with electromechanical sensing devices makes possible the automation of data collection and process controls. Typically a sensor monitors data, such as temperature or quantity of products. The data are stored on a computer for later use by the manager or they may be processed by a computer algorithm and action taken immediately through actuating another electromechanical device. Process control activities are currently being used in agricultural enterprises that are easily monitored, such as confinement livestock enterprises and greenhouse operations.

The development of expert systems is a second information technology that may be of use in reducing production risk. An expert system is a computer based algorithm which allows a problem to be addressed in much the same way that a human expert would seek a solution. Most of these systems store the knowledge obtained from human experts in the form of rules of thumb. The expert's rules constrain the search of alternatives by guiding the program toward the most likely solution, making the procedure more efficient than a random search. The most promising immediate applications for expert systems appear to be in the management of crop and livestock production where undesired performance can result from a range of sources including genetics, nutrition, disease, insects and the environment. Production control systems will detect substandard performance. Expert systems may be useful in identifying the reason for the poor performance. More time is needed to determine how effective they will be in reducing production risk.

A number of studies, typically of an interdisciplinary nature, have been completed to evaluate alternative control strategies for specific inputs. For example, King, Lybecker, Schweizer and Zimdahl evaluated strategies to control grass and broadleaf weeds for continuous corn in Colorado. They found a flexible strategy based on observed conditions had the largest annualized net return for low and high initial weed seed numbers. Furthermore, the flexible strategy did not have a significantly greater standard deviation than the second best alternative. Bosch and Eidman evaluated the benefits of using alternative irrigation strategies with each of four measures of soil water levels. They found that 64 percent of the benefits to perfect soil water information would be obtained using relatively inexpensive soil water readings and a "checkbook system." The evaluation showed that more accurate soil water information permitted applying less irrigation water on the average with little increase in expected net returns and some decrease in variability of net returns.

<u>Diversification</u>. Diversification involves combining enterprises to reduce variability of net income. The principles of diversification indicate the greatest reduction in risk through diversification occurs when the returns from the enterprises are negatively correlated, but some reduction in risk will generally occur unless enterprise returns are perfectly correlated.

A number of studies confirm the risk reducing benefits of diversification. For example, Patrick (1979) reported the variability of average gross income from a combination of corn, soybeans and wheat on Indiana farms was lower than either a corn and soybean combination or specialization in corn. He found, however, that adding wheat as the third enterprise reduced variability less than adding soybeans as the second enterprise. Similarly, Hanson and Thompson reported Minnesota farmers who combined cash grain and beef feeding during the 1966-75 period had lower variability of cash income than specialized producers.

There are other opportunities to diversify farming operations. Farmers in areas with highly variable weather conditions and few profitable alternative crops may consider geographic dispersion of their operations. Producing the same crop(s) on a geographically dispersed land base allows the operator to "average out" some of the within-year variation. If this can be accomplished without too great an increase in costs, it may be an effective means of reducing production risk.

Farmers can also diversify by allocating some of their resources to nonfarm activities. Farmers may find either working off of the farm or operating a nonfarm business, in addition to operating a farm, is an effective means of diversifying. This may be particularly advantageous where opportunities for diversification with crop and livestock enterprises are not promising.

Marketing Responses

Methods to reduce the input and product price risk depend to a large extent on the institutional structure surrounding the determination of these prices. Marketing orders, commodity programs and government action in input and product markets may significantly alter the amount of price risk and the opportunities to reduce it. The alternatives discussed refer to those commonly used by U.S. farmers.

Select Commodities with Low Price Risk. Farmers may be able to identify commodities with relatively low price variability. In many countries, low price variability often has been associated with commodities having substantial regulation of the market. The price farmers receive for milk in the U.S. has been regulated by marketing order, reducing price movements. Prices of certain grains have had low variability during periods when commodity programs have established minimum prices. Participation in government programs for such commodities in the U.S. typically assures producers they will receive a minimum price level with the possibility of selling at higher prices if market conditions provided the opportunity.

Forward Contracting. Farmers have the opportunity to contract both for future delivery of some inputs, and the future sale of many livestock and crop commodities. Input suppliers using such contracts agree to sell inputs at a specified price for delivery to the farmer at a future date. Similarly, grain elevators and livestock buyers may offer a forward contract to purchase a specified amount of the commodity at a designated location for a stated price. Such contracts are typically available for a period of 1 to 15 months into the future. The businesses offering the contract to farmers hedge their position in the futures market to reduce their risk. The producer signing a forward contract has usually not eliminated all price risk. The producer will have to sell any excess production at the market price and, in the event of a production shortfall, make up the shortage by purchasing the amount required to fulfill the contract terms.

Hedging. A farmer producing a commodity that is traded on the futures market has the opportunity to price the commodity by selling a futures contract. Farmers typically sell the commodity on the local cash market and buy back the futures contract prior to the end of the specified delivery period. The importance of basis and basis risk is a major distinction between forward contracting and hedging. The basis is the difference between the futures price and the local market price. The basis has a typical pattern in each local area, but the pattern can vary and the basis risk is born by the contractor. Other disadvantages of hedging are the limited availability of contracts, their discrete size, brokerage fees and the money required for margin calls.

Market Information

Farmers receive market information from both the public and private sectors. The federal government places major emphasis on providing periodic estimates of availability (production, imports and carryover) and use (for domestic purposes and export) of the major commodities. The land grant system focuses on the implication of these and other data for future price movements and procedures farmers can use in making marketing decisions. The private sector provides information in the same area as the public sector, but emphasizes advice for pricing decisions. The use of market information from these sources is an important method of managing price risk.

A recent survey of 149 producers in 12 states obtained data on the use of their marketing strategies (Patrick, 1984). Over 90 percent indicated they use market information in making management decisions. Seventy-five to 78 percent said they use government commodity programs, spreading of sales and forward contracting. Only 19 percent indicate they use hedging, although the percentage increased from 11 percent for small and medium producers to 27 percent for large and very large farms.

Financial Responses

It is useful to distinguish between business and financial risk as components of the firm's total risk. Business risk is commonly defined as the inherent uncertainty in the firm independent of the way it is financed. Business risk includes those types of risk that would be present with 100 percent equity financing. The major sources in any production period are price and production uncertainty although, as noted earlier in the paper, a number of other sources may affect price and production uncertainty over a period of time. Financial risk is the added variability of net returns to owner's equity that results from financial obligations associated with debt financing. Uncertain interest rates--an uncertain input price--represent a major component of financial risk. The nonprice sources of financial risk include differing loan limits, security requirements and maturities over time. For purposes of this discussion, we can think of total risk as the sum of business risk and financial risk.

Farmers financial responses to risk include liquidity management, formal insurance and various methods of controlling resources used in the operation of the business. These responses affect both the asset and the liability side of the balance sheet. In most cases they are interrelated with production and market responses the firm can use. Barry and Baker describe the three liquidity management strategies listed below and provide a summary of the research on their use by U.S. farmers. Formal insurance and three methods of reducing risk through financial measures complete this listing.

Holding Assets for Sale to Meet Cash Demands. Farmers typically hold cash and some highly liquid assets that can be converted to cash without impairing the ongoing operation. The sale of grain and forage not required for livestock production, as well as market livestock ready for slaughter, are among the first sources used to meet cash demands.

Other assets including growing crops, livestock on feed, breeding stock, machinery, equipment and real estate are considered less liquid because they would have to be sold over a period of time and their sale may involve significant transaction costs. Furthermore, their sale would interrupt the normal operation of the business. However, willingness to liquidate assets to meet financial obligations during a time of crisis can be an important response to risk.

Maintaining Liquid Credit Reserves. Farmers rely heavily on developing a favorable debt/asset ratio and a strong working relationship with their commercial lenders. Doing so provides credit reserves that can be used during periods of financial stress through deferment of principal payments, refinancing of existing loans and obtaining additional loans to meet cash commitments. Using credit reserves to meet their needs avoids the costs associated with liquidating assets when the funds are needed. Utilizing credit reserves also involves some costs. In addition to the interest payments on the additional borrowing, reducing credit reserves may increase the interest rate on existing debt. It may also increase noninterest costs in the form of loan fees, appraisal fees and minimum deposits.

Managing the Pace of Investments and Withdrawals. Controlling withdrawals by owners of the business for consumption, payment of taxes and other uses is an important method of controlling financial risk. U.S. farmers are more dependent on cash to meet family living requirements than their counterparts a generation or two ago. Taxes must also be paid in a timely manner. However, farm operators typically have some opportunity to delay the replacement of consumer durables, expenditures for leisure activities and to make investments in nonfarm assets. Exercising control over these discretionary expenditures is an important method of maintaining liquidity.

Pacing capital investments and withdrawals in a manner allowing the firm to build equity and liquid credit reserves is an effective method of managing financial risk. Postponing investments in new assets and replacement of existing capital assets reduce the interest and noninterest costs associated with a higher proportion of debt capital. Deferring the investment may reduce productivity and earnings and increase business risk. The challenge in applying this method of controlling risk is to pace investments in a manner that reduces business risk by at least as much as the investment increases financial risk.

The interaction of business and financial risks can be illustrated with irrigation investments. Like the studies mentioned earlier, Boggess reported that irrigated production of corn, soybeans and peanuts in Florida reduced production risk. The higher levels of purchased inputs and the higher yields increased cost and price risk, but they were more than offset by reductions in yield risk. Thus, business risk was lower for irrigated than nonirrigated production. However, he demonstrates that investment in an irrigation system for some crops, soils and financial situations may increase financial risk sufficiently to more than offset the decrease in business risk.

Formal Insurance. Farmers are able to transfer the risk associated with some events to an insuring party. Examples include losses due to fire, storms, accident, and low crop yields. Commercial insurers charge a premium that includes the expected loss and the cost of administering the company.

In some cases, government subsidies are provided to lower premiums, making the purchase of insurance more attractive. For example, multiple peril crop insurance is currently being offered for about 40 crops in the U.S., although not all crops are insurable in all counties. Premiums and indemnities are based on a ten-year yield history obtained from the farmer's production records. The producer's coverage level depends on the production guarantee and the price election level selected. The production level can be 50, 65 or 75 percent of the average yield. The producer also selects one of three price levels.

The insurance policies are sold to farmers by private companies. The private companies offering multiple peril crop insurance reinsure with the government. The premiums for 50 and 65 percent levels are subsidized at 30 percent. The same dollar amount of subsidy is paid for the 75 percent level as the 65 percent production level.

Leasing Assets. Leasing is an effective means of gaining control of capital assets without incurring the financial risk associated with debt financing. Various capital assets including breeding stock, machinery and equipment, buildings, storage facilities and land are commonly leased. Nonland assets are typically leased for a fixed cash payment. Leasing arrangements available for land include fixed cash, variable cash, and share leasing. The availability of leasing arrangements increases the alternatives a producer has to control the size of the firm and the total risk. For example, expanding the firm by adding additional land used for crop production increases business risk. Financing the land with debt capital will probably increase financial risk. Expanding the farm with an equal area of land leased on a fixed cash arrangement contributes in the same manner to business risk as land ownership, but it will have less effect on financial risk. A crop-share lease divides the increased business and financial risk of the fixed cash lease between the land owner and the operator. In a competitive market for land rental, the expected lease payment will be less for a fixed cash lease than a crop-share lease, reflecting the difference in risk sharing.

Resource Providing Contracts. Several forms of vertical integration are used widely in agricultural production. Each form has unique risk and return characteristics. One of these forms, the resource providing contract, has been used extensively in poultry production and has become increasingly popular in swine production during the current decade. Under a resource providing contract the producer typically furnishes the real estate (land and facilities) equipment and the labor required for production. The off-farm contractor furnishes the poultry, livestock or crop seed and the other purchased inputs. They also provide management advice and make the marketing decisions. The producer typically receives a payment based on the amount of physical production with additional incentive payments for high levels of efficiency and/or product quality.

Livestock producers with existing facilities can reduce the business risk associated with livestock production by shifting from self-financing the enterprise to production with a resource providing contract. In many cases, producers are encouraged to construct new facilities that meet required specifications. In exchange, the producer receives a guarantee that the opportunity to produce under contract will be available for a specified number of years, which is typically much less than the expected life of the facilities. In this case, the financing of the new facilities may significantly increase the financial risk and the total risk of the farmer's business. Thus, producing under a resource providing contract may be a method of reducing risk for some farmers, but not others.

Public Methods

Many aspects of public policy influence the risk agricultural producers face. In some cases the public policy measures may provide stability and largely replace the need for producers to use methods to control certain types of risk. Several examples that illustrate the effect of public policy on agricultural risk are mentioned in this section.

Farm commodity programs. In the U.S. these programs have intervened in the market in several ways. Establishing acreage allotments, removal of stocks from the market during low price periods with later sale, and providing direct payments to producers are three of the methods that have been used. Gardner, Just, Kramer and Pope note that such policies reduce the dispersion of farm prices and increase the average price farmers receive for the controlled products. They show that the impact on output of the controlled product depends on the provisions of the programs. Thus, the effect on the market price of the controlled commodity and the effect on nonsupported commodities the farmers might produce is unclear, making the total impact on income variability of the farm unclear.

Subsidized Credit. Farmers Home Administration provides subsidized loans to farmers unable to obtain credit at reasonable rates from commercial lenders. They also provide disaster-emergency loans in areas designated as disaster areas due to drought, floods, and other natural disasters. These programs have increased the supply and reduced the cost of credit to low-input farmers. Thus, the programs have probably increased output and reduced expected prices. However, the availability of subsidized credit programs reduces the need for operators to exercise other methods of risk management. They can be thought of as part of the liquid capital the firm can access. Furthermore, farmers with subsidized interest rate loans are shifting some of the financial risk to the federal government.

Subsidized Water. Large federal irrigation projects provide water at below market prices to many farmers in arid areas of the U.S. Federally funded projects have reduced uncertainty of water supplies and yield. The federal subsidies have encouraged greater use of irrigation water, more production and lower output prices.

A PROPOSED RESEARCH AGENDA

A review of previous research suggests that we have developed a cadre of agricultural economists familiar with the methods to estimate risk preferences, quantify risk and apply decision analysis to agricultural problems. The research conducted also provides an improved understanding of producers risk preferences and the magnitude of risk for some problems.

Educational efforts to move the concepts and methods of risk analysis into the hands of farmers also have received some emphasis. In addition to efforts by many individual research and extension economists, USDA funded a project conducted jointly by two of the land grant universities to provide teaching materials for introducing and illustrating decision analysis to farmers (Nelson, Casler and Walker). The project developed five teaching modules on risk management concepts and several computerized decision aids to apply the concepts to specific decisions. These materials were distributed to state farm management extension specialists and used in meetings with county agents and farmers. Additional computerized decision aids for specific decisions continue to be developed over time. However, a recent survey indicates only a small proportion of farm management decision aids formally include decision making under uncertainty (Knight, Kubiak and McCarl). Apparently the major educational activities utilizing risk concepts are those dealing with the outlook for commodity prices and some programs dealing with crop insurance. Although the need to consider risk is often noted in other educational activities, formal consideration in a quantitative manner is apparently the exception rather than the rule. An important, although not surprising, lesson from these efforts is that producers are more receptive to decision analysis when it is applied to a problem they consider important in managing their operation. This point has important implications for the way we structure a program of applied research.

Both additional basic and applied research is needed to make these tools available to decision makers in the agricultural sector. New developments in basic research can be incorporated as they become available. The focus here is on an applied research and development agenda.

Several components appear to be important for an applied research agenda designed to make decision analysis available for use in agricultural decision making at the farm level. They are: (1) learn more about how farmers perceive problems and how they make decisions, (2) develop software that is user friendly to support decision makers for risk analyses, (3) work with other scientists as required to develop an appropriate data base, including estimates of production and price risk, for analyses at the firm level, and (4) provide educational programs and appropriate support for the users. One method to focus this agenda on problems of importance to producers is to begin by identifying a farm type with important risk considerations and work with a sample of farms of this type. Doing so should enable a research team to focus their efforts sufficiently to make some progress and to receive frequent feedback from users. As they work through the four parts with one farm type, consideration can be given to identifying a second farm type and repeating the process. Some of the work that might be completed under each of the components for a given farm type is described below.

Problem Perception and Making Decision

Economists commonly recommend that farmers follow a rather specific procedure of planning and control. For example, see Boehlje and Eidman. A plan is developed to achieve certain goals and the status of the operation is monitored over time. The feedback from monitoring is compared to standards specified in the plan. The monitoring identifies substandard performance (problems) in the operation. Similarly, monitoring the environment for unexpected changes that will prevent achieving goals with the current plan suggests additional problems needing attention.

Decision analysis under uncertainty is based on a rational model of decision making that requires estimation of risk and the use of risk preferences. The analysis becomes rather complex as the number of choices considered increases. An alternative model of decision making, the behavioral model, emphasizes the process of how decisions are actually made. In contrast to maximization of expected utility, behavioral models typically assume that people have limited ability to process data. They also assume that the data are processed in serial rather than parallel fashion. That is, decision makers think about things one-at-a-time rather than simultaneously. The models often rely on multiple goals with satisfying levels to select the desired action. Reflecting on the behavioral model suggests we should investigate what decision makers are doing before we rush out to tell them what they should be doing.

Farmers typically use a combination of formal and informal planning and control systems. Understanding how these systems are being used and the way risk is currently incorporated in making decisions is an important starting point. Professor King argues that research is needed to learn more about how farmers identify problems, formulate these problems and make decisions to provide a basis for developing decision support systems (King, 1988). More specifically, he recommends studies to: (1) determine how managers perceive the content and structure of formal plans and how these plans relate to control systems, (2) determine how farm operators structure problems, and (3) study the decision making processes used by farmers. Investigating these issues should identify problem areas in planning and control. It should also indicate the sources of risk producers perceive to be important and provide new insight into how decisions are made. Each of these areas is important in structuring a decision support system.

Develop Software for a Decision Support System

Sprague and Carlson (p 4) define decision support systems (DSS) as "interactive computer-based systems that help decision makers use data and models to solve unstructured problems." DSS have four major characteristics. First they emphasize support for, not the replacement of, decision makers. Second, they are intended for use in an interactive manner by decision makers. Third, they integrate both data and models, giving users easy access to data and the tools needed to answer important questions. Fourth, they are designed for use in decision situations that require both computer and human support. Planning and control models that include consideration of risk will require computational support and input from the decision makers to be useful. The computational burden for risk analyses is great enough that a computer based system will be required.

The magnitude of the software development task depends to a significant extent on the planning and control systems producers are already using. It may be possible to develop software for risk analysis that complements current planning and control systems. However, when relatively informal systems are in place, a more complete development may be required to integrate risk analysis. That is, more formal procedures to project cash flows, income levels, and net worth changes of alternative plans may be needed to make quantitative risk analysis relevant. Similarly, it may be difficult to make formal risk analysis relevant to control decisions unless a formal control system is in place. Thus, the development of software has the potential of becoming a major undertaking in situations where producers are currently using informal planning and control procedures.

Software should provide users with flexibility to assess the risk associated with a particular action and also assess the impact of risk on the enterprise or total business. Models developed using a portfolio approach can provide this flexibility. The ARMS model, which allows consideration of price and yield risk for up to four crops, is a prototype that can be used as an example (King, 1988).

Develop an Appropriate Data Base

The data base will need to include the physical and financial quantities required for a user to apply the decision support system. This will include the appropriate price, quantity and cost data required for planning. It will also include appropriate physical and financial control standards. In addition, the appropriate risk estimates must be prepared.

Developing appropriate risk estimates for decision analysis is a time-consuming and technical task. Producers may feel they have neither the statistical expertise nor access to relevant empirical data to estimate appropriate distributions and the required correlations. Forcing a decision maker to base analyses on hurriedly developed risk estimates may erode confidence in the entire analysis.

Research is needed to estimate an appropriate and consistent set of distributions for the problem(s) being analyzed. Estimates of production risk for a given commodity should be made conditional on important variables, such as soil type, the production system and the control system. Preparing these estimates requires interdisciplinary cooperation between economics and the appropriate biological and physical sciences, both to select the appropriate condition variables, and to select the best available data.

When the DSS is being developed to analyze long-run decisions, the matter of estimating long-run risk becomes important. As noted, the methods to quantify risk discussed earlier in the paper are better suited to estimate short-run than long-run risk. Perhaps the best way to characterize the longer-run uncertainty is to develop a set of scenarios that captures the range in the uncertainty apparent in the firm's external environment.

Scenarios consist of a set of statements about future events and trends surrounding some underlying theme. One or more critical events and trends (such as changes in technology, market demand or laws) are identified and given specific values or descriptions. Then related events and trends must be identified to consider the indirect impacts. Finally, these statements must be translated into the expected market prices for inputs and outputs and the changes in institutional restrictions that producers will face. The development of scenarios is difficult both because of the lack of scientific guidelines to follow in their preparation and because they need to consider the full range of environmental factors (technological, social, political, economic and climatic). Furthermore, the statements within one scenario about these environmental factors must be consistent with the theme and each other. However, the development of a small number of "good" scenarios is an important part of the data base producers will want when evaluating the risk of long-run situations. Willis provides guidelines to use in developing and evaluating scenarios.

Educational and Support Programs

After a decision support system has been developed and tested, potential users must be trained in its application. Training programs with agricultural producers will have to focus on the rudiments of decision analysis, including enough discussion of probability concepts to make users comfortable with the DSS. Of course, they will need to be trained in the mechanics of using the system and the flexibility it provides in analyzing problems.

A DSS of the type described is likely to require a significant level of support to keep it operational. In addition to supporting the computer efforts, the data base of cost, return, and probability data, and scenarios for long-run planning will require periodic updating as technical and economic conditions change.

A great deal of related research also will be needed to support this four-stage process. Three areas come to mind. One, a general understanding of the magnitude and range of producers' risk preferences may be important in designing a decision support system. Such estimates could be developed using the risk interval approach. Two, an evaluation of risk strategies for representative producing units may be important in developing educational programs on risk management. An evaluation of appropriate combinations of production, marketing and financial strategies may be particularly beneficial to producers beginning to develop an integrated risk management strategy. Three, research will also be needed on methods to estimate price and yield risk and to design long-run scenarios. While research in each of these three areas is important, experience suggests that completing it without development of the DSS described above is unlikely to move risk analysis much closer to agricultural producers.

Macro Level Research

We have noted that government policy may influence the magnitude of risk at the producer level and that some programs provide opportunities for producers to reduce or shift risk to another party. An appropriate research program in this area is highly dependent on the policy agenda of the country. It does appear, however, that knowledge of producers' risk preferences is an important component of such a program. A second is development of models to analyze the impact of policy alternatives on producers' risk. A third component is development of models to analyze producers' response to policies that alter risk levels. Accomplishing these three components will comprise a major research program. Developing a more detailed agenda in the policy area is the topic of another paper.

Table 1. Hypothetical Corn and Wheat Yield Data

Year	Yield in Bushels per Acre Corn	Wheat
1977	116.1	34.4
1978	147.3	38.9
1979	129.5	42.4
1980	104.9	43.6
1981	116.1	41.8
1982	124.5	48.7
1983	89.3	42.3
1984	109.0	53.8
1985	135.0	37.4
1986	99.8	46.1
1987	127.2	47.8
1988	77.4	46.8
Mean	114.90	43.44
Std. Deviation	18.99	5.95
Coef. of Variation	0.17	0.14
Coef. of Skewness	-0.23	0.03

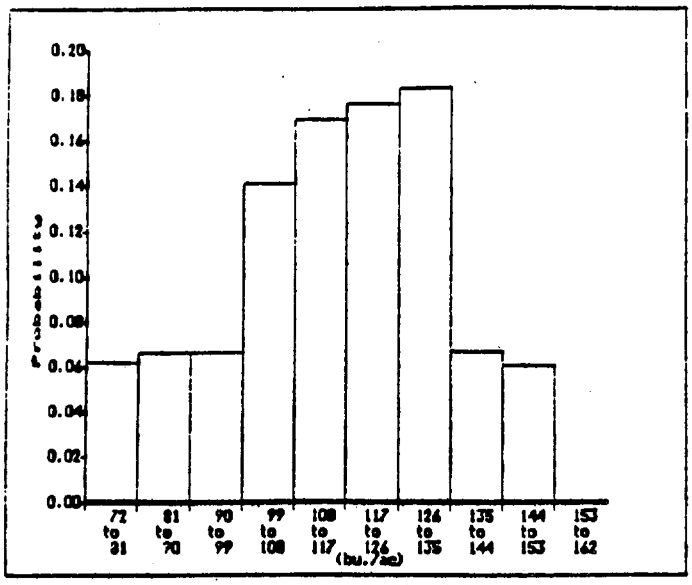

Figure 1a. Histogram of Corn Yields.

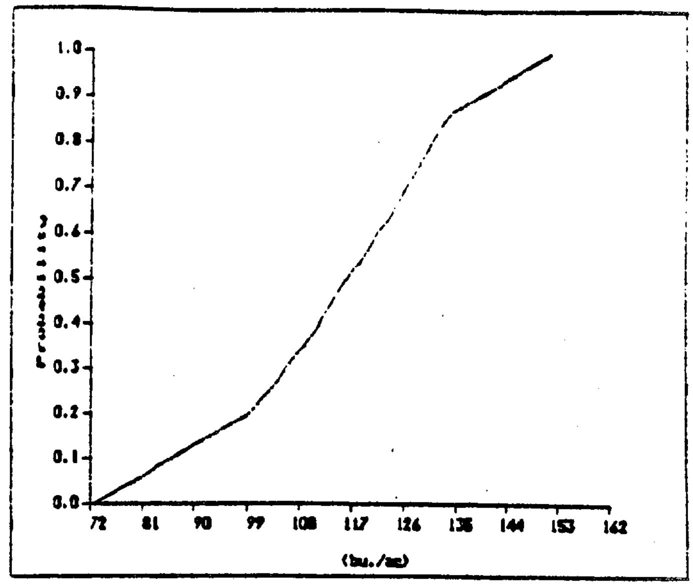

Figure 1b. Smoothed Cumulative Distribution Function of Corn Yields.

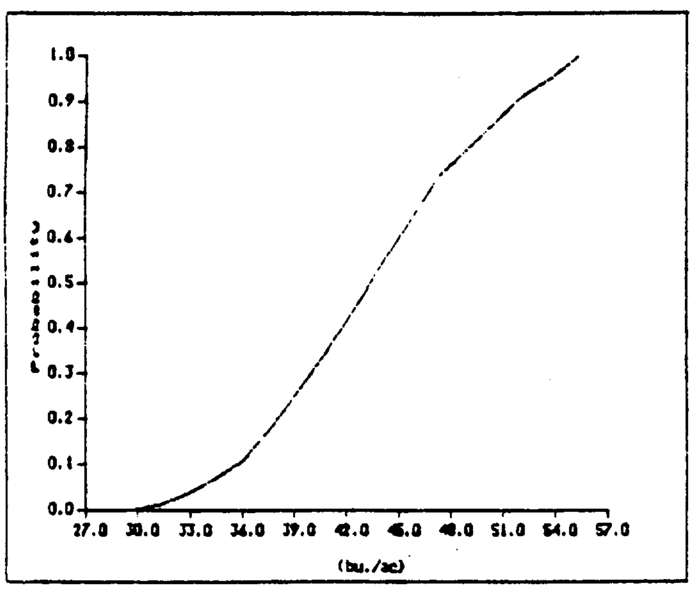

Figure 1c. Smoothed Cumulative Distribution Function of Wheat Yields.

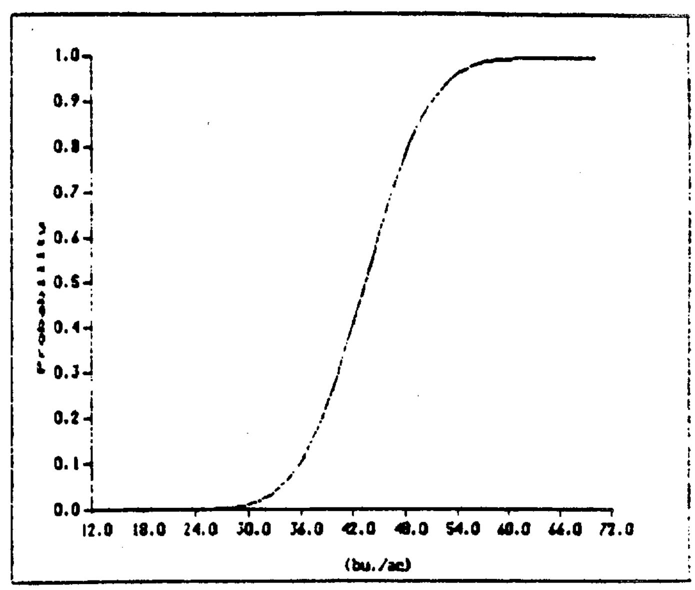

Figure 1d. Fitted Normal Cumulative Distribution Function of Wheat Yields.

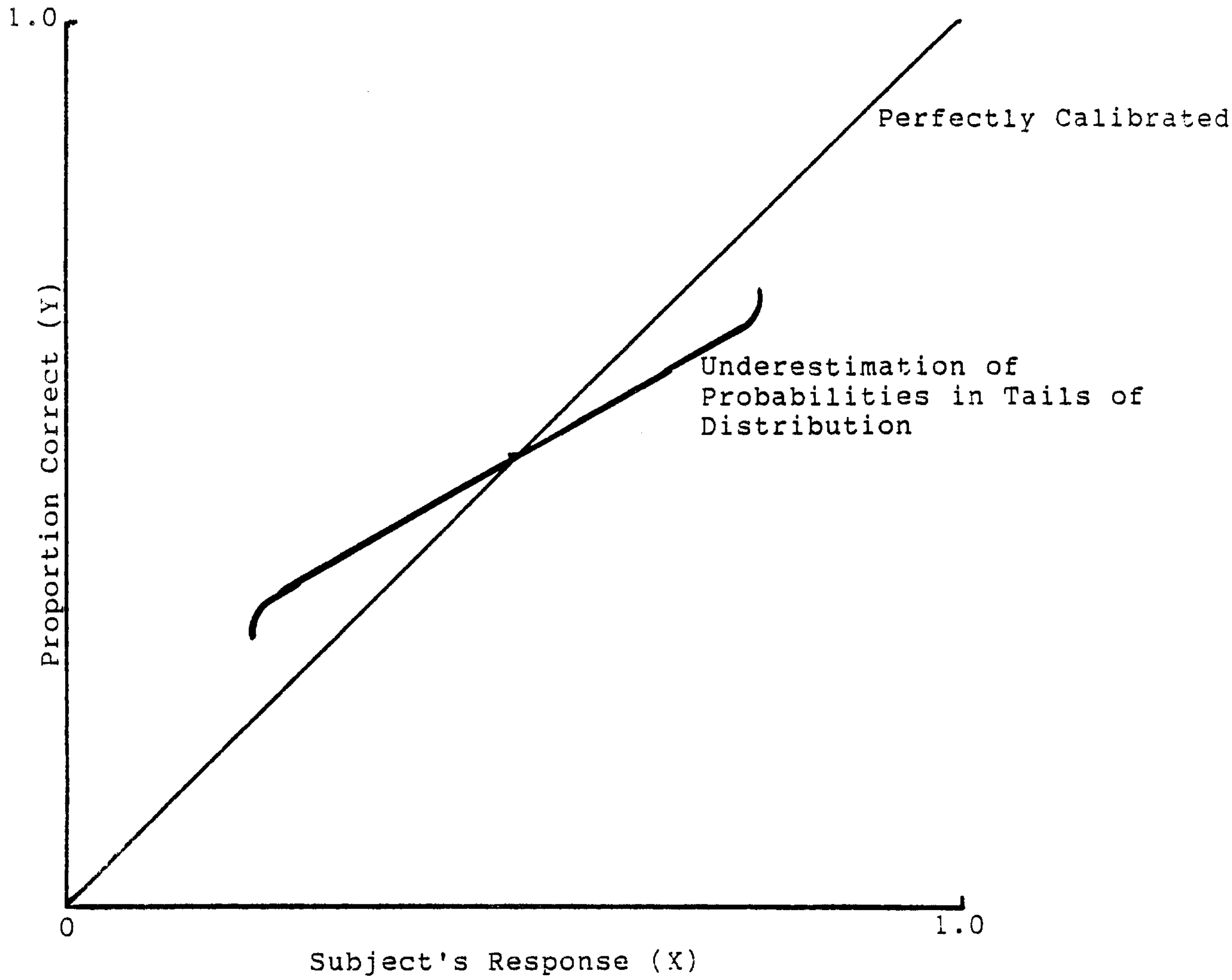

Figure 2: Calibration Functions

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