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Risk and Agriculture

Some Issues and Evidence

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As a subfield in economics, agricultural economics has an unusual genesis and hence an unusual orientation. In production, its roots are found in the study of agronomy and horticulture. Out of these disciplines grew studies and training in farm management. As Marshall's (1920) marginal analysis reached its climax, agricultural economics was just beginning to emerge as a discipline in land-grant colleges throughout the United States. It embraced marginal economic analysis, comparative advantage, and competition as important insights into market behavior. A hard-fought view began to emerge that the behavior of those involved in agriculture throughout the world was consistent with these basic economic concepts (summarized nicely in Schultz 1980). Yet, agricultural economics has always strived to help family farms (in the United States or abroad) understand more fully their economic environment. Thus, there has always been a normative dimension to agricultural economics as well (similar, perhaps, to finance in a business school). In most other fields of economics, economists are not so presumptuous as to suggest to economic agents how they should optimize—unless it is the government.

Today, agricultural economics considers a broad set of issues and behavior about resources, consumers, the environment, and policy about food and fiber using the full range of current economic concepts and methods. Likely second only to finance, agricultural economics has embraced risk concepts as an essential ingredient to understanding and prescribing behavior. It was an early entry into experimental economics by measuring individual risk preferences and subjective probabilities across a relatively broad set of agents (see Young et al. 1979;

Nelson and Bessler 1989). The purpose of this chapter is to highlight a few selective but central concepts, issues, and contributions about agricultural behavior under risk. Although the central paradigm of economic behavior is called *expected utility maximization*, the distinctions among various models of behavior under risk will not be important. Indeed, the relevant concepts and issues can be portrayed as a choice among distributions based upon the mean (a measure of central tendency) and the variance (a measure of dispersion). Such models can often be rationalized as maximization of expected utility (Meyer 1987). The main normative and positive issues are about choices that reduce risk but, even more fundamentally, raise expected utility. It would be impossible to cover all of the relevant topics, but this chapter will address some issues central to agricultural economic research on risk (see Robison and Barry 1987; Just and Pope 2002; and Caswell 1995 for more in-depth discussions).

It is useful to state at least my perception of a few generally relevant economic facts about agriculture that serve as background:

- 1) Agricultural production is atomistic and is generally placed on international markets. However, demand for raw agricultural products is much more concentrated than final consumer demand for food products. This implies that farms and final consumers are generally price takers with international shocks readily transmitted to agricultural markets. There is often an underlying suspicion by many agricultural producers that markets are unfair to them because of this alleged asymmetric market power.
- 2) Farm products have relatively price-inelastic demand and supplies. Income elasticities of demand for many raw food goods are relatively low compared to manufactures and services. Much has been made of the inelastic demands and supplies in agriculture, implying that shocks have greater price and income consequences than in many sectors.
- 3) Production is heavily constrained by biological processes that have long lags between the point in time in which a decision is made and its ultimate consequences. This is particularly notable in livestock production but is prevalent throughout agriculture.

- 4) Production is heavily seasonal with definitive intra-seasonal stages of production.
- 5) Investment decisions tend to have long physical and economic lives. Land often has low alternative uses, except near cities.
- 6) Weather, disease, and pests (vicissitudes of nature) are direct and pervasive in agriculture.
- 7) Government policy is omnipresent and often intrusive in market outcomes (e.g., the Common Agricultural Policy in the European Union, target prices, and subsidies in the United States). In developed countries, policy generally attempts to raise farm incomes and often raises consumer prices. In developing countries, policy often attempts to lower consumer prices.
- 8) Most of the demands on factors of production (inputs) in crops are inherently spiked rather than distributed uniformly throughout the season. This may imply an incentive to choose productive activities that don't compete for resources at a given point in time.
- 9) Institutions for the ownership of factors of production and the organization of production vary widely throughout the world.
- 10) Evidence seems to suggest that yields are generally increasing over time but that deviations about this trend are random (not bunched). However, prices are highly correlated (thus, bunched) in adjacent time periods.

It is also useful to briefly state some stylized facts about U.S. agriculture.

- 1) Production occurs in predominantly single or family-run enterprises. Despite ever-increasingly larger farms, the last agricultural census shows that over 85 percent of farms are "family farms," and true corporations (beyond small family-held corporations) make up only 0.4 percent of producers (Allen and Lueck 1998).
- 2) Structural changes in livestock production have been dramatic and often resemble manufacturing with large scale and substantial division of labor. There is substantial contract farming where

farmers supply only some of the inputs and are paid incentive contracts for producing.

- 3) Production is increasingly specialized during the post-war period, but multi-output production is still common. There appear now to be substantial returns to specialization of production. There is widespread innovation with continual technical progress, and there are large numbers of strains of a given crop or livestock available for production with different inherent characteristics.
- 4) Many farms rent and own land; thus, contracting for the services of land is ubiquitous.
- 5) Crop insurance and disaster relief have been the center of policy debates in recent decades; price supports and production controls were central in earlier times.
- 6) An interesting aspect of U.S. agricultural data is that there are little farm level data available to researchers. There is a small set of selective (not random) panels in a few states, but the data are often of limited value for the questions studied and they are not widely available. This constrains the kind of evidence that is accumulated (Just and Pope 2001).

DIVERSIFICATION AS A RESPONSE TO RISK

Since at least the early 1950s, risk reduction through diversification has received considerable attention. On the prescriptive side, agricultural economists studied and proposed various diversification strategies to reduce risk. However, there was a rather serious policy aspect to this research. If farmers have significant opportunities to reduce their risk, then perhaps some of the rationale for agricultural policy needs to be rethought. The basic incentive for diversification is widely known and can be discovered with a simple thought experiment. Suppose that the variance of the net income from a 1,000-acre corn farm is a number labeled σ^2 , while the expected return from the farm is labeled μ . If another crop exists—say, soybeans, which has an

identical and independent distribution to corn—then as Samuelson (1967) has shown, the optimal choice for a risk-averse individual is to plant 500 acres in each crop. Using variance to illustrate, this perfect diversification will reduce the variance of income from σ^2 , when specialized in corn, to $\sigma^2/2$ when the farm is diversified. The variance of farm income is reduced in half by diversification, and a risk-averse producer would presumably find this attractive. This is the incentive for diversification: low returns in one enterprise may be mitigated by high returns in the second enterprise. Indeed, if there are N identically and independently distributed enterprise returns, the variance can be further reduced to σ^2/N by putting $500/N$ acres in each enterprise (this assumes that there are no economies or diseconomies of scale). In cases of more general distributional settings (uneven means, variances, and nonzero covariances), there is a marginal benefit from diversification (reduction of the variance) and a marginal cost (reduction in expected or average income by not specializing in the activity or enterprise with the largest expected return).

The standard approach to economic behavior up to 1950 implied specialization: choose the enterprise with the highest expected return. This is equivalent to maximizing any increasing function of expected wealth or maximizing

$$(6.1) U = u(W_0 + \mu),$$

where μ is expected net income from farming and W_0 is initial certain wealth. Thus, if confronted with the choice of producing corn, which is expected to yield \$25 per acre, and hay, which is expected to yield \$15 per acre, a prudent farmer maximizing expected wealth would specialize in the production of corn. However, in 1952, E.O. Heady argued that farmers likely had distaste for risk (risk aversion) as measured by the variability or variance of net income. Given estimates of individual enterprise variances and covariances, farmers can analytically choose the crop or enterprise combination that minimizes total farm variance of income. This procedure focuses on the benefits from diversification and highly favors diversification rather than specialization as an optimal decision. Knowing that enterprise expected returns will likely be unequal, Heady also discussed choices that minimize variance for a

given expected income appropriate for any mean-variance utility function of the form

$$(6.2) U = u(W_0 + \mu, \sigma^2),$$

where μ is expected farm income and enters utility u positively, σ^2 is the variance of farm income, and U is utility (expected utility). In this chapter, an individual is “risk responsive” when one includes the variance in a maximization such as in Equation (6.2). A person is “risk-averse” when increased variance reduces utility. In the summary in Young et al. (1979), most of the individual farmers whose preferences were elicited were not risk-neutral for some decisions—a majority were risk-averse, and some were mixed, meaning that for some decisions a person might be risk-averse and for others risk preferring or neutral.

In Heady’s analysis, expected farm income is: $\mu = h_1\pi_1 + h_2\pi_2$, where h is the proportion of total land or investment in enterprise 1 and π_1 and π_2 are expected returns per unit of land or investment on enterprises 1 and 2 respectively. Similarly, the variance of farm income for two enterprises is

$$(6.3) \sigma^2 = h^2\sigma_1^2 + (1-h)^2\sigma_2^2 + 2h(1-h)\sigma_{12},$$

where σ_1^2 is the variance of enterprise, 1 income and σ_2^2 is the variance of enterprise 2 income, and σ_{12} is the covariance of the two incomes. Heady found that if a typical Iowa corn farm diversified by halving corn acreage and correspondingly increasing hay production, variance of income could be reduced substantially without a significant reduction of expected income. This is because the correlation between hay and corn income is relatively small, 0.45. Thus, large random draws in one crop’s income are often offset with low random draws in the other crops income. This incentive becomes most pronounced for enterprises whose outcomes tend to be independent or are negatively correlated with similar means. When expected returns are very different in the two enterprises, then specialization of production becomes more likely.

Subsequent writers added the possibility of renting in or out land (Johnson 1967). In this case, the square root of the variance or the stan-

standard deviation of income can be linearly reduced by choosing to produce fewer (or less) risky enterprises and engaging in more safe activities. Examples of the latter are cash lease of land and investing in a risk-free asset in the case of capital. In cases where the cash lease or risk-free rate exceeds the expected return from risky enterprises, then specialization in the risk-free asset is predicted under risk aversion (see Equation (6.2)). In cases where the expected risky return exceeds the cash lease rate, firms combine the two according to their tastes for risk (risk aversion). A similar conclusion can be obtained for investment capital among risk-free and risky assets.

Many authors attempted to use quadratic programming or an equivalent mathematical programming model to identify the risk-efficient (minimizing variance for a given mean) set of enterprise choices for farms, regions, or countries. The main advantage is that quadratic programming models of farms could integrate many production constraints on firm behavior. For example, perhaps machinery and labor supplies were limited throughout the months of a growing season. In addition, they could include many policy constraints or incentives, such as land set-asides. However, the normative and positive content (what farms should do and what they do) of these models is only as good as the models themselves. Failure to reflect individual preferences, beliefs, or constraints will yield recommendations or insights that may be irrelevant to a decision maker. Additional effort is needed to understand what decision makers actually do in their response to risk.

Lin, Dean, and Moore (1974) attempted to test whether programming models incorporating response to risk (variance) were better than risk-neutral models. Using elicitation techniques, the preference functions of a small set of farmers were estimated. Many of these preference functions implied that the mean and variance of incomes should enter into farmers' objective functions. Mathematical programming models using these general objective functions were superior at predicting what farmers actually did when compared to models based solely on maximizing expected farm income. Though by today's standards the techniques and evidence used to advance their argument might be rather unconvincing, it was and is an important paper in positive economics, convincing many that risk was fundamental to understanding behavior in agriculture. This paper confirmed empirically

what other researchers had suspected: “risk aversion was superior to risk neutrality for explaining behavior” (e.g., Officer and Halter 1968).

Spatial Diversification

Soon after Heady’s work, Emery Castle (1954) noted that area diversification was almost as important as crop diversification. Indeed, spatial diversification apparently has been a successful strategy for risk reduction since medieval times (McCloskey 1976). Formulae for the variance across farms always involve the covariance (see Equation (3)) or correlation, which is the covariance divided by the product of the square root of the variances. Spatial diversification becomes particularly useful if the correlation across farms is sharply reduced as distance between the plots increases.

Jensen (1961) argued that spatial diversification was an important managerial technique open to dryland farms in the Great Plains because of idiosyncratic weather across areas. Thompson and Wilson (1994) argued that one of the primary reasons that Mexican ejido communal farmers resisted privatization of grazing land is that yields are variable with highly idiosyncratic weather patterns. Farmers could readily reduce the variance of their yields by scattering production spatially. Of course, spatial diversification has a cost in terms of expected return (increased travel costs), but apparently the benefits are sufficient to make it viable.

Davis et al. (1997) found that the correlation between yields of different peach orchards decreased 2.28 percent for each mile of separation, which could be a significant factor in the pattern of operation. It should also be mentioned that larger farms often have a significant advantage due to very subtle advantages in diversification. Many farms, such as orchards, have different responses at different elevations. Thus, a farm can in some cases gain a significant reduction in the variance while having contiguous plots by diversifying by elevation. However, more research is required to know how extensively spatial diversification techniques are used.

Econometric Models of Risk Response

There was an increasing awareness in the decade of the 1970s that the evidence via programming models of risk-averse or risk-responsive behavior was not on sound statistical footing. In mathematical programming models, parameters are usually estimated and treated as exact. Hence, there was not a readily deducible metric to decide when something like the null hypothesis of “no aversion or risk response” could be rejected. As with other fields of econometrics, programming models gave way to the search for econometric evidence. These models often made very simple assumptions about constraints, but the results were more easily amenable to inference. The ability to incorporate more complex constraints on behavior in econometric models may imply that more of the old programming constraints will find their way into econometric models (Andrews 2001).

For over four decades, agricultural economists had been using computers to estimate short run supply functions essentially of the form

$$(6.4) \quad A = b_0 + b_1\mu_p + b_2z,$$

where μ_p is the expected price (or yield, or both) of the crop or livestock, A would be acreage or supply, z represents other variables, and the $b_0 - b_2$ are constants to be estimated econometrically. One prominent example of such an approach is the adaptive expectation model discussed in undergraduate econometrics texts. The coefficient of b_1 is presumed to be positive and the larger the magnitude of b_1 , the more elastic is the supply.

Around 1970, some argued that this approach was limiting because it didn't capture risk response. Behrman (1968) incorporated risk response in agriculture as he studied crop production in Thailand. This is a large and careful study. More importantly, a regression was estimated of the following form:

$$(6.5) \quad A = b_0 + b_1\mu_p + b_2\sigma_p^2 + b_3z,$$

where μ_p is an estimate of expected price (yield or both), σ_p^2 is an estimate of the variance (or standard deviation) of price, yield, or both, z represents other variables (for example, the means and variances of

substitutes and complements), and the $b_0 - b_3$ are constants to be estimated econometrically. Behrman found that in a preponderance of the cases, b_1 was estimated to be positive and statistically different from zero, indicating that supply curves are upward-sloping in expected price. In a majority of cases, b_2 was estimated to be negative and statistically different from zero. This was particularly true for upland crops that are sold on the market, unlike rice, which is often consumed by the farm family. Behrman concludes that “The estimated responses to the relative standard deviations do provide further support, however, for the hypothesis that the agricultural sectors in underdeveloped countries respond negatively to risks” (p. 336). Six years later, another work on risk response was very influential. Just (1974), using a Bayesian approach, formalized the estimation and specification of the mean and variance of revenue, including complementary and substitute crops, and estimated an acreage response model like Equation (6.4) for counties in California. He concluded that there was convincing statistical evidence that b_2 is negative for many crops. Thus, it appeared that risk response was not limited to developing countries.

A number of papers during the next three decades sought to determine whether a model like Equation (6.5) captures something that Equation (6.4) does not. Indeed, there has been mounting evidence of risk-responsive behavior across many commodities, countries, and aggregations. Table 6.1 summarizes a sample of these studies. Though the elasticities measuring risk response are often low in absolute value (column 5), they usually have the expected sign (negative), and risk coefficients are statistically significant (column 3). In some cases, the response to the risk of competing crops can be captured (column 4). For example, more corn acreage may be planted when the risk in soybeans increases. Various measures of risk can be constructed (column 6), and this issue continues to be a matter of research and controversy. In many cases, both μ_p and σ_p^2 are estimated using weights of past observations. This is called *adaptive* in the table. In this case, risk is measured by a backward looking mechanism; surprises in the past affect the expectation of the future variance of price, yields, or revenue per acre.

To illustrate, μ_p might be a weighting of the previous three years of prices with weights summing to one. Similarly, σ_p^2 is estimated by weighting the last three years of squared deviations about μ_p (Chavas

and Holt 1996). More sophisticated single-equation approaches use long memory geometrically declining weights (Just 1974), ARCH/GARCH with conditional or time varying variances, and/or rational risk (Aradhyula and Holt 1989; Myers 1989; Holt and Aradhyula 1990, 1998; Holt and Moschini 1992). Rational risk implies that the mean and variances implied by the model match the market data given available information. One must build up a structural model of the supply and the demand side of the market to yield expected price and the variance of price given available information. Then, the restrictions implied by the rational expectation hypothesis must be imposed. One of the most impressive but complex applications of rational risk is found in Holt and Aradhyula (1998), where a carefully specified model of the broiler market is estimated. Risk-responsive behavior was evident. More complicated still would be to estimate a complete model of production or supply and inputs demanded (factor demands), such as chemicals, labor, land, and machinery and product supply using rational expectations of the first two moments of price. A number of authors have estimated such models without explicit complicated expectational schemes and found evidence of risk-responsive behavior (Antle 1987; Chavas and Holt 1996; Love and Buccola 1991; Saha, Shumway, and Talpaz 1994; Coyle 1999).

In summary, the available econometric evidence suggests that firms rebalance their production portfolios such that when the perceived risks of an enterprise increase, farms substitute toward less risky enterprises. Taken as a whole, this evidence is very persuasive that these models capture something. However, for some, there are still reservations about the explanation of risk aversion for these risk effects. That is, is it possible that Equation (6.5) merely picks up a nonlinearity, lags, or aggregation problems (e.g., Pope 1981)? Part of the reason for this skepticism is the very success of the approach. When Equation (6.5) is applied to highly aggregated data where risk measures are substantially compromised and/or in markets where reasonably good futures markets exist, it still seems to work well. The question then is not one of insufficient evidence, but of interpretation of the evidence.

Table 6.1 Selected Risk Response Studies

Author	Dependent variable	Significant negative own risk coefficient ^a	Significant cross risk coefficient	Own risk elasticity (short run) ^b	Risk measure ^c
Behrman (1968)	Rice, corn, casaba, A ^d	Yes	N.A. ^e	Small but negative	3-year std. dev. (moving)
Just (1974)	Grain, cotton, A	Yes	Yes	Not calculated	Adaptive like (infinite)
Lin (1977)	Wheat, A	Yes	N.A.	Not calculated	3-year std. dev.
Estes et al. (1981)	Potato, A	Yes	N.A.	Not calculated	Adaptive
Hurt and Garcia	Sow farrowing	Yes	Yes	-0.47 to -0.56	Adaptive
Brorsen, Chavas, and Grant (1985)	Wheat margins (f-m & m-r) ^f	Yes	N.A.	Not calculated	Adaptive
Aradhyula and Holt (1989)	Broilers	Yes	Yes	-0.045	GARCH rational
Holt and Aradhyula (1990)	Broilers	Yes		0.232, -0.012, -0.046	GARCH
Chavas and Holt (1996)	Corn and soybean, A	Yes	No	Not reported	Adaptive
Love and Buccola (1991)	Corn and soybean system, A	Yes	No	N.A.	Yes
Pope and Just (1991)	Potato and sugar beet, A	Yes	Yes	Not reported	Adaptive
von Massow and Weersink (1993)	White beans, corn soybeans, wheat, A	Yes	Yes	-0.073 to -0.220	Adaptive
Saha, Shumway, and Talpaz (1994)	Wheat system	Yes	N.A.	N.A.	N.A.

Holt (1994)	Corn, A	Yes	Yes	-0.018	Rational
Duffy, Shalishali, and Kinnucan (1994)	Cotton, corn, and soybean, A	Yes	No	Not reported	Adaptive
Krause, Lee, and Koo (1995)	Wheat, A	Yes	N.A.	-0.062 to 0.003	Adaptive
Krause and Koo (1996)	Wheat, barley, flaxseed, and oil sunflower, A	Yes	Yes	-0.05 to -0.01	Adaptive
Tronstad and McNeill (1989)	Sow farrowing	Yes	Yes	-0.0013 to -0.164	Downside
Bar-Shira, Just, and Zilberman (1997)	Crop system	Yes	Yes	N.A.	Adaptive
Coyle (1999)	Crops and livestock system	Yes	No	Not reported	Adaptive

^a Often a single paper includes a variety of specifications. “Yes” means that some of the risk parameters were significant.

^b Often a single paper includes a variety of specifications. Thus, the elasticities reported are an attempt to convey approximate risk response.

^c Adaptive here is used very loosely. It is intended to imply a weighting scheme where the weights sum to one. Some “adaptive” used polynomial lags rather than geometric declining; some use simple fixed weighting schemes.

^d A = crop acreage or similar spatial measure.

^e N.A. means “not applicable.”

^f f-m and m-r are margins: respectively, farm to mill and mill to retail.

SOURCE: Author’s calculations from selected cited references.

Other Forms of Diversification

Another risk-reducing activity is to diversify family labor. Mishra and Goodwin (1997) find a significant positive relationship between the coefficient of variation of farm income (standard deviation divided by the mean) and off-farm employment. Thus, when farm income is more variable, one risk-reducing strategy is to apply more of one's labor portfolio to safer off-farm income-generating activities. Further, farm operators who receive large payments from government farm programs are less likely to supply off-farm labor. Both of these findings are consistent with farmers balancing risks in a portfolio generated by owner labor and owner capital.

Not only can a farmer self-insure through reducing labor allocations to risky endeavors, but capital can be allocated to safe investments as well. Mishra and Morehart (2001) calculate that off-farm financial assets in 1995 for the United States were 18 percent of total assets for farm families. This is up from 14 percent in 1990. Thus, farms are becoming more diversified outside of agriculture. One way to view these data is that agriculture is more risky so farmers are increasingly diversifying outside of agriculture in order to reduce the risk of total wealth or income. Perhaps recent market events have reversed that trend.

Diversification and Farm Size

Because the foundation of much agricultural policy in the United States historically has hinged on the survival of the family farm, one issue of concern is the relationship of scale and risk. Unlike the portfolio approach, there may be substantial economies of scale in production; that is, as a farm produces more of a particular crop, marginal and average costs of production fall. Economies of scope may also arise, meaning there are cost advantages to diversification. Part of the reason for such economies of scope is that there are inputs that are productive across products. For example, a tractor can be utilized to produce a variety of crops, especially when they don't compete at the same time for services. Economies of scope imply that expected utility with two products is greater than expected utility when specialized. These can come from the diversification motive discussed above or from cost

advantages from public-like inputs. Economies of scale promote specialization while economies of scope promote diversification. Thus, there are three relevant effects: diversification in response to risk with no scale effects, scale economies in enterprises, and economies of scope due to cost advantages in jointly producing two or more products.

Attempting to empirically untangle these three effects is difficult, and there is not a satisfactory conclusion. Econometric studies provide some evidence that larger farms are more diversified, *ceteris paribus*. Further, wealthier farms, *ceteris paribus*, have less diversification (Pope 1976; Pope and Prescott 1980; Dunn and Williams 2000; Zenger and Schurle 1981). Pope (1976), using factor analysis for California farms, found evidence that there is a combination of minimum efficient scale and economies of scope due to spreading the services of fixed inputs across time.

However, looking broadly across this literature, one is struck by the large volume of prescriptive literature on optimal diversification and the relatively small set that positively examines behavior. Though there is little doubt that the principles of diversification are always potentially important, exactly where they are used is still a matter of some debate. For example, perhaps farm diversification across enterprises due to risk aversion is relatively unimportant in explaining farm behavior.

If initially an optimal portfolio of actions or investments is chosen, then policy that reduces the risk in a particular agricultural commodity will see greater supply of that commodity (and at the expense of others). Thus, a well-meaning policy attempting to assist wheat farmers in the northern plains because of variable profitability may have the unintended consequence of increased production and greater demand for help in the future. Further, it is apparent that behavioral and market responses to risk may be diminished in response to a public policy that attempts to reduce risk. For example, diversification may fall if the government provides a safety net for farms.

RISK REDUCTION AND INPUT USE

One can surely view the entire portfolio choice as one of choosing inputs, such as land allocations for crops. However, one aspect of input choice applies to specialized or diversified farms and asks what the distributional consequences are of input choice. To illustrate the issue, suppose that a farm is specialized in the production of corn. Corn has a production function that depends on an input, h . Both its mean output and the variance of output depend on h . That is, $\mu = \mu(h)$; $\sigma^2 = \sigma^2(h)$. What might a farmer do in choosing how much of this input to apply? Just as in diversification, there is a marginal benefit in that expected output would increase. For example, if fertilizer is applied, we expect it to raise output or to have a positive expected marginal product generally. At some point, it is expected that additional fertilizer will diminish output (negative expected marginal product). If the farmer's only concern were expected profit μ , the farmer would choose fertilizer such that the expected marginal benefit equaled the cost (price) per unit of the fertilizer. In which case, economists say that a farm chooses inputs such that the expected marginal revenue product is equal to marginal factor price. That is, the marginal benefit of input use is equal to its marginal cost.

However, if the farmer is risk-averse, there is concern with how increasing input allocations might alter the variance of profit. If the decision maker is risk-averse, then increasing the variance of profit will reduce utility. The important question is how each input contributes to expected profit and the variance of profit at the margin. We will call inputs that reduce the variance of profits at the margin *risk-reducing*, while inputs that increase the variance of profits are *risk-increasing*. If an input is risk-reducing and the farm is risk-averse, there will be an additional marginal benefit from using more of it than would be implied by maximizing expected profit. This is a self-insuring technique. Firms might have more machinery or labor than would seem advisable based upon average marginal product because using more of it reduces risk. Farms might use more pesticides than would seem profitable on average because of its self-insuring capabilities. A little reflection shows that irrigation may perform that function. Irrigation often virtually lops off the lower tail of the distribution of yields; nec-

essarily, it reduces the variance (and raises the average) of crop yields. However, land is likely risk-increasing under this definition: adding more acres of corn increases the variance of profits (and expected profit). The policy significance of describing agricultural technology is apparent. If agricultural decision makers believe that the environment is more risky, then they may use more of inputs that lead to degradation of the environment when the inputs are risk-reducing.

The motivation for answering the question about how inputs affect the distribution of output comes from two sources. First, it is relevant to prescribing optimal input use to farms. It is particularly relevant in developing countries. If a modern variety of a crop is chosen, there are often very large variations in output if there are modest variations in inputs like fertilizer. This is often in contrast to native varieties, which have a number of resistances to input variations. Secondly, there are many environmental issues regarding the use of modern chemicals.

Roumasset (1976) considered rice production in the Philippines in 1971–1972 and found that the green revolution was not as successful as expected. Farmers often adopted “miracle rice” varieties, but they did not use the recommended amount of nitrogenous fertilizer. It was hypothesized that less than the recommended level of fertilizer was used because of risk aversion. After estimating risk preference functions and the random properties of technology, Roumasset discovered that risk neutrality was more consistent with observed behavior than was risk aversion, contrary to the Officer and Halter (1968) and Lin, Dean, and Moore (1974) conclusion that risk aversion often explained behavior better than risk neutrality.

As mentioned earlier, most attention was focused on chemical inputs. The empirical results were often mixed, but there is no reason for inputs to behave similarly across soil qualities, climatic conditions, and crops. Secondly, results vary because of many methodological issues associated with functional forms and estimation of higher order moments. Regev, Gotsch, and Rieder (1997) found significant evidence that fungicides are risk-increasing at low levels of rainfall, but found no conclusive evidence of nitrogen being risk-reducing or risk-increasing. Horowitz and Lichtenberg (1993) found evidence that fertilizer and pesticides may be risk-reducing. Mixed results on pesticides are found in Carlson (1979), Horowitz and Lichtenberg (1994), and Hurd (1994). There seems to be a growing consensus that there is no

evidence that pesticides are risk-reducing. Thus far, agricultural economists are only beginning to build a consistent body of findings upon which to infer a coherent set of stylized facts about risk-reducing/increasing inputs (Antle 1983; Griffiths and Anderson 1982; Hall and Moffit 1985; Just and Pope 1979). The most clear-cut evidence seems to come from experimental plots commonly studied by agricultural experiment stations throughout the world, but there are questions about how these data apply to actual farming experience under less controlled situations.

CROP INSURANCE

As economists have thought about the new economics of uncertainty, one of the early insights was that insurance markets rationally could not exist unless coercion was involved or unless there was free choice with significant risk aversion. Excluding coercion, a risk-neutral person will maximize expected wealth and therefore will pay at most the expected loss due to acts of nature. That is, if there is a 0.001 probability that fire will destroy a \$200,000 building in a given year, the largest insurance premium a risk-neutral individual would pay is the expected loss, $E(L)$, which equals \$200. Insurance provision involves marketing, adjusting, and other monitoring costs denoted by c . Let this total cost of insurance provision be $C = c + E(L)$. No insurance market could exist unless people are willing to pay at least C for insurance. The amount an individual is willing to pay beyond $E(L)$ is called the risk premium, ρ . The risk premium is zero for risk-neutral individuals and positive for those who are risk-averse. Thus, a risk-averse individual is willing and able to purchase insurance if the provision costs are less than the premium, or $c \leq \rho$. The left side of the inequality is the supply price, and the right side is the demand price. No insurance market can exist (for $c > 0$) without compulsion unless market participants are risk-averse such that they are willing to pay for the costs, c . Any risk-averse individual would surely purchase "fair insurance" where the insurance premium is equal to the expected loss. This is a simple initial insight into a necessary condition for the existence of an insurance market.

A second insight comes from the notion of insurability. Insurers generally are thought to have little exposure to risk if they have a large number of independent contracts. In this case, the payouts (indemnities) will thus be remarkably predictable (low variance). This is evident from the law of large numbers in probability. Using this indemnity data, the insurance product can be readily priced and most of the competitive assumptions can ensue. These conditions for insurability hold for life insurance and fire insurance. These conditions rarely hold for acts of nature to agriculture (hail insurance is an exception), which can often be catastrophic. Insurers of acts of nature in the Midwest would have a highly correlated portfolio if the insured losses were due to drought. Thus, the liabilities could be large one year and low the next, implying a high variance of the return. This may mean that the probability of ruin for an insurer would be substantial, leading to risk-responsive behavior by insuring firms (Duncan and Myers 2000). However, there are reinsurance markets and other means to trade away some of the risk in a risky undertaking.

It appears that no multiple-peril private crop insurance markets have emerged (e.g., see Glauber and Collins 2002). Due either to issues of insurability or just plain old rent seeking, policy has focused in recent decades on the provision of federally organized and provided crop insurance. To illustrate the essence of the program, a farm might select the 0.75 option. When yields are 75 percent of approved program yield, this triggers a payment from the government.

In 1980, the “Crop Insurance Improvement Act” was passed in the United States, allowing the private sector to sell multiple-peril federal crop insurance (MPCI) with a subsidized premium. Since that time, five additional acts have been passed to extend and reform the federal program. Federal subsidies have risen to around \$1.4 billion. Liabilities have grown sevenfold since 1980 to around \$35 billion, also showing the tremendous growth in the program. During the 1980s and much of the 1990s, the ratio of indemnities/total premiums (ignoring the government subsidy) or loss ratio was greater than 1, indicating that the program was actuarially unsound. Because of enormous policy interest in the program, significant amounts of intellectual effort, computer time, and ink were spent studying crop insurance.

Crop insurance has also been a focus of international attention as countries around the world study the viability of similar programs

(both Canada and Japan have programs similar to the United States; see the bibliography of Coble and Knight 2002). Because of the federal subsidy, this insurance is more than “fair” to some farmers. Thus, even a risk-neutral farmer may strictly prefer the insurance. Thus, risk tools are relevant, but insurance purchase isn’t *prima facie* evidence of risk aversion, as it would be in a laissez-faire market for insurance.

There are many possible reasons for the excess losses, including that government may wish to transfer wealth to agriculture. However, using the best available actuarial methods, there are good reasons to expect the program to fail. At least part of the answer is well known to economists. When farmers have more information than those setting the rates (asymmetric information), moral hazard and adverse selection may occur. These will be explored conceptually first and then empirically.

Adverse Selection

Suppose that rate makers have access to average actuarial data and set what is known as a pooled rate, that rate where the average loss ratio is 1. Suppose also that there is heterogeneity; that is, some farms have a high probability of loss below the insured level, while other farms have a low probability of loss. Farms that are good risks (low probability of a payout) in that the probability of yields falling below the threshold value is low, will find the price of insurance too high because it is based upon the average farm’s probability. They will not purchase the insurance. Farms that are poor risks will find the average rate attractive and will self-select into the insurance program. Thus, risks that are adverse to the long-run viability of the program select in and low risks select out. This implies that the government will lose money and may wish to raise rates. If rates are raised, some of the good-risk farms will exit the program. Again, the program will lose money.

The incentives to purchase insurance are now threefold under risk-aversion: 1) the incentive to participate based upon an increase in expected profit due to the subsidy, 2) an incentive due to risk aversion (reduced risk), and 3) an incentive due adverse selection. One way to calculate the three effects is as follows: the first calculates the increase in expected profit from being insured, the second calculates the difference in the risk premium due to being insured, and the third follows from the increase in expected indemnity due to adverse selection. Each

of these provides incentive to participate. The greater the subsidy, the larger the first incentive. Greater risk aversion implies greater incentive to purchase insurance. Finally, for the adverse selection effect, higher-risk firms will benefit because of larger expected indemnities than typical. The third incentive will imply that the expected loss to insurers increases with participation in insurance by high-risk producers.

Adverse selection need not be a problem if the insurance provider can monitor or know the nature of the heterogeneous firm. Experience rating is an example of trying to adjust premiums for the type of firm demanding insurance.

Moral Hazard

Moral hazard implies another type of asymmetric information. Here, knowledge of the insured's actions is hidden from the insurer when comparing pre- and post-insurance behavior. The most extreme form of hidden action is arson, but more subtle behaviors involve taking inappropriate care or effort. Antitheft devices might not be purchased if a car is fully insured. Regarding health insurance, an insured person might see a doctor more often than if uninsured. For MCPI, the opportunities to change behavior if insured are many. Thus, a fourth incentive to purchase insurance relates to moral hazard: fewer inputs may be applied when insured. This will save costs and will increase the probability of collecting indemnity payments. Again, if the provider can monitor behavior and pay indemnities according to deviations from best practice, moral hazard need not be an issue. Monitoring is expensive and difficult to do, except for obvious behaviors.

Many policy proposals have tried to deal with the moral hazard problem. One such program makes payments based upon area yields rather than individual yields. In this case, adverse selection and moral hazard are virtually eliminated. However, the amount of insurance that an individual receives is dependent on how the farm outcomes are correlated with the area outcomes. If a farm risk is largely idiosyncratic, then the areawide insurance will provide little benefit to the farm.

Empirical Results

Consider first the demand for insurance. Empirical work on crop insurance demand has used simulation methods assuming particular characteristics and risk preferences of the farm (e.g., Kramer and Pope 1982; Mapp and Jeter 1988) or econometric techniques (e.g., Gardner and Kramer 1986; Goodwin 1993; Barnett and Skees 1995; Richards 2000; Vandever and Loehman 1994; Coble et al. 1996). A central question is how does the demand for insurance respond to various characteristics of the farm and the contract and insurance premiums? These studies find that the demand for crop insurance is very price (premium) inelastic despite wide variation in crops, regions, subsidies, and in the nature of the program (contract). The 1998 ad hoc disaster relief bill provided for an additional 30 percent of subsidies for premium subsidy. Studying this change, Coble and Barnett (1999) find the price elasticity of demand to be approximately 0.65 in terms of acres insured. That is, a 1 percent decrease in premiums would increase acres insured by 0.65 percent.

Empirical work on moral hazard and adverse selection is much more difficult than measuring insurance demand elasticities. A number of studies find substantial scope for or direct evidence of adverse selection (Goodwin 1994; Ker and McGowan 2000; Luo, Skees, and Marchant 1994; Just, Calvin, and Quiggin 1999). Adverse selection is a large problem in the program for at least three reasons. First, farmers can choose to participate knowing early spring soil moisture and weather forecasts. For example, soil moisture at enrollment and long-run weather forecasts can be beneficial. Using El Niño/La Niña weather patterns can exacerbate the adverse selection problem for insurers (Ker and McGowan 2000). This implies that farmers often have more information than rate makers. Second, there is great heterogeneity, and farmers may choose to insure particular parcels of their land. Third, the U.S. program is marked by procedures that imply large difficulties. For example, a farm without an approved yield history could use the county average. If a farm's yields were substantially lower than this average, there would be a large indemnity paid and relatively small premium received, leading to program losses.

Regarding moral hazard, Horowitz and Lichtenberg (1993) estimated chemical use for Midwest corn producers. They estimated that

insurance participation in MPCCI led to increased use of nitrogen, herbicides, and pesticides. Smith and Goodwin (1996) examined Kansas dryland wheat production and obtained opposite results. Firms purchasing insurance significantly reduced total chemical input. Babcock and Hennessy (1996) argued that using reasonable measures of risk aversion and estimates of technology, insurance implied very modest reductions in fertilizer usage. Coble et al. (1996) found evidence of increased yield shortfalls for those insured. Taken as a whole, these results suggest that moral hazard is a potentially serious problem.

There is also research that substantiates that the uninsured behave differently from the insured, but that does not attribute this to a particular explanation. Quiggin, Karagiannis, and Stanton (1993) examined typical revenue and input share equations and noted that revenue was statistically less for insured farms. No corresponding significant results were found for inputs. The impacts on crops grown (likely moral hazard) are substantial and likely clearer. Glauber (1999) estimates that a revenue insurance program for North Dakota durum wheat producers led to a 25 percent increase in production. Wu (1999) estimates that crop insurance for corn causes corn acreage to increase. Keaton, Skees, and Long (1999) estimate that a 10 percent increase in crop insurance participation increased an increased planted area of 6 major crops of 5.9 million acres. This is an unusually large response and likely overestimates the response to crop insurance alone (Glauber and Collins 2002). Goodwin and Vandever (2000) estimate a 2.2–3.3 percent increase in corn and soybean acreage planted. Orden (2001) estimates that that would increase production by 0.28–4.1 percent. Finally, if production increases, price must fall. Babcock and Hart (2000) conclude that the elimination of crop insurance subsidies for corn would increase price by \$0.02–\$0.16 per bushel.

To summarize, it seems that there is every expectation to believe that adverse selection and moral hazard will be a problem in the MPCCI. The dates allowed for enrollment, the fact that separate fields can be enrolled, and the difficulties of monitoring complex behavior all contribute to these possibilities. Though the empirical research is not as broad and uniform as desired, the available evidence suggests that the two economic problems identified with provision of insurance under asymmetric information are alive and well in MPCCI (Coble and Knight 2002).

As this section concludes, a question arises: Should the government be insuring yields in the first place? First, if the elasticity of demand is unity, yields may vary considerably but total revenue (price times quantity) is fixed. This suggests that if policy wants to provide some safety net for farms rather than transfer wealth to them, then revenue insurance may be a preferred policy to yield insurance. Second, it is far from clear that there is a strong demand for agricultural crop insurance. This is to be distinguished from a strong demand for a subsidy or transfer to farmers.

HEDGING/FORWARD MARKETS

As discussed in virtually every textbook on economic theory or practice, hedging can reduce exposure to risk. Examples abound of markets for risk. Many commodities are listed on the Chicago Board of Trade, and a number of instruments are relevant. Though using futures markets is available, there is no reason to suspect that this is the efficient mechanism to trade risk. Often the efficient mechanism for a farm to shed risk is a forward contract. A forward contract is merely a contract at a negotiated price today for delivery in the future. A futures market is an organized forward market specifying delivery at a particular date, quantity, and grade of the commodity at a specified place (e.g., Chicago). However, the basic advantages and risks of farm hedging can be told equivalently with either a forward or a futures market. I shall use the latter because it is commonly discussed in most texts in microeconomics.

A farmer plants corn in the spring and knows that the futures price is \$3.00 for September corn. This is the current price for future delivery of corn in September. If the futures price converges to the actual price of corn on the spot market, then when fall comes, both prices will be equal. These prices might be equal to \$4.00 or \$2.00. They are random when viewed from the point of view of the farmer in the spring.

Now consider the following three transactions for a bushel of corn assuming the fall price is $\$x$:

	Spot	Futures
Sell (spring)		\$3.00
Sell (fall)	$\$x$	
Buy (fall)		$-\$x$

Summing yields $+\$3.00$. The farmer, by placing the hedge, has received a certain $\$3.00$ for corn rather than the random price $\$x$. If risk-averse and if the futures market is fair or unbiased (expected spot is the futures price), farmers would surely prefer to use the futures market. The farmer could forget risk aversion and use the certain $\$3.00$ price signal to decide how much acreage to plant in corn. Summarizing and generalizing the above example, farm profit using the futures market can be described equivalently as:

$$(6.6) \text{ profit} = \text{total revenue in the spot market} - \text{costs of production} + (\text{futures price} - \text{spot price}) \times (\text{quantity of output hedged}),$$

or equivalently,

$$(6.7) \text{ profit} = (\text{unhedged output}) \times (\text{spot price}) - \text{costs of production} + (\text{hedged output}) \times (\text{futures price}),$$

when the futures price converges to the spot price at any point in time.

The example and concepts discussed above bring about four important issues. First, the separation result of production from hedging does not extend to the amount hedged; it depends on the magnitude of risk aversion. However, when production itself is uncertain, the farmer does not know how much of her crop is hedged by a given quantity sold forward in the spring. Second, there is basis risk where basis is the difference between the spot price and the futures price at any point in time and in the place where production takes place. Third, how should a hedge change over time in reaction to new information and what are the time series properties of prices? Dynamic or rolling hedges are an important issue. Finally, there may be substantial trans-

actions costs in using the futures market (fees/margin calls etc.). These issues are reviewed in sequence.

The Hedge

When production is certain, when there is no basis risk, and when firms are risk-averse, one of the first observations involving the optimal hedge is that it will be less (greater) than output produced as the expected spot price is greater (less) than the futures price. This states that in order for a risk-averse firm to be rewarded for risk taking by selling more futures contracts than it has output (speculating), it must be true that the futures price is greater than expected spot price. When the futures or forward price predicts unbiasedly the spot price, output will be completely hedged because there is no incentive to speculate in either the cash or futures markets. Thus, a key question is whether futures or forward prices unbiasedly predict spot prices. The available evidence is mixed. However, across many commodities and countries, my reading of the evidence suggests that when spot prices are not longer than 3–6 months out, futures prices are unbiased estimates of future spot prices.

Production Uncertainty

When production is uncertain, the correlation between production and price uncertainty is crucial to any analysis. For a farmer producing in the corn-belt, this correlation is likely significantly negative. To illustrate why this covariance matters, consider a common description of technology where production shocks enter production multiplicatively. When expected production is expanded, the marginal benefit in terms of expected profit is expected price plus the covariance between the production shock and price. Because we presume this covariance is negative, firms will produce less output because the more output produced, the greater the reduction in profit on average. Further, increasing the scale of production will increase the variance because the variance of profit is proportional to the scale squared. Now we ask how the possibility of a forward or futures contract affects hedging and production choice.

Many authors have used mean-variance notions to calculate the optimal hedge when both production and the price of output are uncertain. Because price and production tend to be negatively correlated, the optimal hedge under risk aversion is generally found to be less than expected farm production.

Dynamics

The optimal dynamic hedge depends crucially on the evolution of prices (time-series properties) and whether they are unbiased. If prices are unbiased and production is certain, then reasonably simple dynamics are implied in the optimal hedge (or ratio of hedge to production) in most cases (Myers and Hanson 1996). When production is uncertain, then strong assumptions are required in order to make much headway on solving the problem (see references in Myers and Hanson).

Use of Futures and Forward Markets

Moschini and Hennessy (2001), citing a report from the U.S. General Accounting Office (1999), state that the available evidence is that farmers use futures markets some but use forward markets frequently. For farmers with sales exceeding \$100,000, forward contracts were used by 55 percent of farms and futures contracts or options were used by 32 percent of farms. Patrick, Musser, and Eckman (1998) surveyed large, well-educated, progressive Indiana farmers over a three-year period on their use of forward and futures markets. Those who used some form of forward contracts exceeded 75 percent. Use of futures markets to hedge was limited to less than 25 percent for corn and soybeans and usually was less than 15 percent. My interpretation of the general tone of much agricultural extension work seems to be: “futures are a risk reduction tool that has been under-exploited.” However, it is a very costly and imperfect mechanism for trading risk compared to forward contracts—particularly where a large purchasing entity can use the futures market to “lock in” price and then extend forward contracts to farmers.

FOOD SAFETY

Consumer confidence about food safety has fallen precipitously in recent times (Kramer 1990). This is likely due to highly publicized occurrences in the 1980s and 1990s. The Alar and Chilean grapefruit scares are examples of concern about chemical residues on produce. In 1993, an *Escherichia coli* outbreak in several fast-food restaurants sickened hundreds of people and resulted in four deaths. In the summer of 1997, there was a much-publicized case where 25 million pounds of hamburger were produced with suspected *E. coli* contamination. The Centers for Disease Control and Prevention (CDC) estimate that between 6.5 and 33 million people in the United States become ill each year from food-borne pathogens, and that up to 9,000 die (Buzby et al. 1998). Of these cases of illness, more than 4,000 deaths may be associated with meat and poultry products. In addition, chemical residues from fertilizer, herbicides, and pesticides may pose long-term risks to the public.

Safety policy is concerned with the delivery of existing foods within some level of confidence that it is safe. It also extends to new foodstuffs such as genetically modified organisms. We expect that the usual marginal benefit–marginal cost calculations inform decision making: absent externalities, the optimal level of care or safety is where the marginal private benefit equals marginal private costs. The marginal benefit could be modeled with expected utility or a mean variance utility and the willingness to pay for each additional unit increase in safety. Apparently, however, there are significant externalities to other firms and consumers if a firm chooses a low level of safety. Thus, because the optimal level of safety is where marginal social benefit equals marginal social cost, private incentives as embodied in supply and demand may not lead to the social optimum. Contrary to the rhetoric often heard, this optimum will most often allow for some contamination/risk.

Though measurement of each of these entities is not easy to do well, there have been numerous attempts to shed light on the costs and benefits of a policy proposal. The costs are relatively easy to conceptualize and calculate. These are the additional costs to firms when safety is efficiently increased. For a recent policy change by the Food Safety

and Inspection Service (FSIS) called Hazard Analysis and Critical Control Points (HACCP), the costs are estimated to be at least \$100 million annually. Antle (2000), studying meat-processing plants, argues that these estimated costs are much too small due to the loss in productive efficiency involved in complying with the HACCP regulations. Any attempt to measure the costs of a regulation must count both the direct costs of the program and the indirect costs due to the loss in productive efficiency.

Many estimates of the benefits have been much larger: \$3.7 billion–\$19.1 billion, depending on quantity and type of pathogens ameliorated and assumptions about the value of life. Cutting some corners, the conceptual notion of willingness to pay (WTP) for food safety can be illustrated using Equation (6.2) for a consumer. Let a consumer be given a choice between two probability distributions. The current distribution possessed has a mean of \$100 and a variance of a 500. The second distribution has a mean of \$96 and a variance of 400. The WTP is the value that equates the following utilities:

$$U(100,500) = U(96 - WTP, 400).$$

(A more realistic depiction would embody not two means or variances but two probability distributions of contamination.) It is the purchase or demand price for the second probability distribution given that the individual possesses the first one. In general, it can be positive or negative. The Food Safety and Inspection Service estimates of the yearly public benefits using the cost of illness method (discussed below) are \$990 million–\$3.7 billion. This wide range of numbers immediately suggests the difficulty of measuring consumer benefits for the United States.

The four methods used to estimate benefits are: 1) ask people in a survey (contingent valuation, or CV method) how they would value an increase in safety, 2) use experimental auctions to try to evaluate consumer's willingness to pay for improved safety (experimental method), 3) use cost of illness or liability as measure of consumer benefits, and 4) direct econometric estimation of the shift in demand functions controlling for other factors (Caswell 1998; Buzby et al. 1998).

A few introductory comments will serve as background. Attempts to measure econometrically the effects of food safety on consumer

demand are fraught with measurement problems and often cannot apply to a prospective program. If one had measures of food characteristics, including safety attributes, then a regression of price on food characteristics (hedonic regression) could yield the WTP for safety changes. For example, as safety varied, the economist could measure the effect on price. This marginal effect on price could be used to infer WTP. However, one seldom has such data. Yet, it may be possible to measure the impact of information or safety on demand. Further, some economists make a distinction between safety claims by a manufacturer and scientific supportable claims. That is, if a manufacturer labels eggs with a particularly low probability of *Salmonella*, and charges \$ x more for them, is that the correct measure of the social value of improved safety irrespective of scientific evidence of efficacy?

Applications of the Methods

In the first method, surveys elicit a response to a hypothetical environment. For example, one might propose a baseline probability of food poisoning and severity and ask the respondent what they would be willing to pay for a particular scenario of risk/severity reduction. This is conceptually the most direct and appealing method, although there may not be sufficient incentives and context for respondents to be truthful. The second method need not rely on hypothetical scenarios, but the experiment may not be representative of actual decision making by the population at large (a sampling problem), or the experiment itself may not represent the complexity of the environment and choice. The third method often is not necessarily linked to WTP or social value. For example, the cost of illness may not include pain and suffering and may miss the long-term consequences of illness on growth and development. Liability may be a better measure, but it is not very helpful for a prospective evaluation of a policy. Either the cost of illness or producer liability likely underreports the WTP for improved food safety.

The empirical findings are interesting but often do not yet yield a precise and consistent pattern (Shogren et al. 1999). Buzby et al. (1998) discuss the following CV experiment. Store A is a conventional U.S. grocery outlet, but store B eliminates or reduces, through testing, the amount of pesticide residues on fresh produce. Store A is called

pesticide-free and store B is set to government residue standards. Demographic variables and a risk index that the respondent estimates are included in the regressions. The only demographic variable that was statistically significant was gender: women are more likely to shop at store B and have a higher WTP. As expected, those who estimated the risks from residues as being high were also more likely to shop at store B and have a higher WTP. The median weekly WTPs for a government standard store and a pesticide-free store were \$5.31 per week and \$5.88, respectively. Buzby, Ready, and Skees (1995) used CV to measure the costs and benefits of eliminating a post-harvest chemical sodium *ortho*-phenylphenate (SOPP) from use on Florida grapefruit designated for the fresh markets. Sodium *ortho*-phenylphenate is a fungicide that reduces molds and rots but is perceived by consumers to have health risks. After calculating the costs (lost fruit) to the industry from the ban, CV is used to calculate the WTP. Average WTP was between \$0.19 and \$0.28, depending on what one assumed about the WTP to nonrespondents. On average, respondents are willing to pay about 38 percent more for SOPP-free grapefruit. Regression analysis found no significant evidence that household size, race, or gender affected WTP. More affluent and older people were found to have a lower WTP. van Ravenswaay and Hoehn (1991) found that consumers were willing to pay about 17 percent of the current purchase price to avoid Alar in fresh apples.

In a typical experimental market, participants are given a choice between a chicken sandwich with the usual chance of contamination by *Salmonella* (probability of contamination may not be specified) if purchased at a local outlet and a sandwich that is screened and is reported to have 1/1,000,000 chance of contamination. Bids are in increments over the price of the sandwich with the usual risk of contamination. Similar experiments have been done in Arkansas, Massachusetts, Iowa, and California. Incentives are put in place to obtain relevant bids. In Arkansas and Massachusetts, average bids often exceeded \$1, but in Iowa, California, and Kansas the average was approximately \$0.55 or less for a given run of the experiment. It is unclear how one extrapolates this to a countrywide cost/benefit calculation which includes non-student participants.

The essence of the methodological difficulty involving eliciting WTP is found in the excellent experimental study of Shogren et al.

(1999). They designed an experiment where subjects chose irradiated or nonirradiated chicken breasts. The price of nonirradiated chicken breasts was held constant at \$2.88/lb. The price of the irradiated chicken breasts varied from a 10 percent discount (\$2.59/lb.) to a 20 percent premium (\$3.45/lb.). The first experiment involved actual retail market trials with clear labeling and prominent display of USDA summary data on food irradiation. In the second experiment, an experimental auction was conducted. A budget of \$30 was offered, and the participants were asked to spend approximately \$5.00 and keep the rest. Briefly, after providing each participant with the USDA summary data on irradiation, each participant responded with their preferred choice. The final experiment was a random sample of 400 households where the survey requested information on purchase behavior given the same choices as in the retail and experimental markets. In the latter case, a much more rich set of attitudinal, experience, and demographic data were available to the researchers.

There was general agreement among all three approaches in that the demand for irradiated chicken is downward sloping. However, informing market participants with the best available scientific information (which is generally supportive to higher health and safety with irradiation) led a significant percentage of customers to demand a 10 percent discount on irradiated chicken. Further, in this category (requiring a 10 percent discount), there was a reasonably large (greater than 33 percent) difference among the three methods in the percentage that would purchase the treated chicken. The nature and explanation of these anomalies are part of an ongoing debate (e.g., Bockstael 1999). When it comes to the value of human life and safety, there are many methodological and policy issues (Hooker, Nayga, and Siebert 1999). The concluding question arising from these experiments is: "Based upon available information, is consumer sovereignty to be respected even if tastes and preferences conflict with accepted scientific evidence?"

The last method is based upon secondary data. Henneberry, Piewthonggam, and Qiang (1999) tried to measure a risk information variable and placed it in a system of demands for 14 major fresh produce categories. The risk information variable was seldom statistically significant but suggested an average percentage elasticity of 0.05–0.07 percent due to a marginal decrease in risk information. For example, a

1 percent increase in the risk information index reduced crucifers, carrots, and foliage consumption by an average of 0.07 percent. However, if high-frequency data are used with a specific risk, it appears that one can establish through event studies the impact of contamination on prices. For example, for specific USDA *E. coli* O157:H7 recalls, McKenzie and M.R. Thomsen (2001) established that prices (using daily prices) for boneless beef react significantly to the recalls. This is the most likely category affected by the bacteria. However, no such relationship can be established for the more aggregative categories of live cattle and boxed beef prices.

CONCLUSION

It is a daunting task to try to summarize the content of risk research in agriculture. Large areas of agricultural economic research have been neglected: adoption of technology, storage, grading and standards, contracting, environmental risks, finance, and others. Risk research pervades agricultural economic research because risk is pervasive in agriculture. Biological and physical processes (such as weather) are so complex that risk is often treated as endemic. This is not the only way to view research. Perhaps more investment should be made to understand these biological processes so that deterministic methods can be coherently employed. My conclusion is that risk research in agricultural economics has been a very fruitful intellectual endeavor. However, as is likely apparent throughout this chapter, I am not sure that the profession has invested sufficient attention to carefully measuring behavior. Normative prescriptions to government or individuals are likely to mislead if there is no firm grounding in behavioral social science knowledge. To be sure, there are some risk-related stylized facts such as the econometric response of enterprise choices to changing risk. However, there is much more work to be done in order to understand whether many current interpretations of research results based on aggregate data rests on firm micro-foundations.

References

- Allen, D.W., and D.L. Lueck. 1998. "The Nature of the Farm." *Journal of Law and Economics* 41(2): 343–386.
- Andrews D.W.K. 2001. "Testing When a Parameter is on the Boundary of the Maintained Hypothesis." *Econometrica* 69(3): 683–734.
- Antle, J.M. 1983. "Testing the Stochastic Structure of Production: A Flexible Moment-based Approach." *Journal of Business and Economic Statistics* 1(3): 192–201.
- . 1987. "Econometric Estimation of Producers' Risk Attitudes." *American Journal of Agricultural Economics* 69(3): 509–522.
- . 2000. "No Such Thing as a Free Safe Lunch: The Cost of Food Safety Regulation in the Meat Industry." *American Journal of Agricultural Economics* 82(2): 310–322.
- Aradhya, S., and M. Holt. 1989. "Risk Behavior and Rational Expectations in the U.S. Broiler Market." *American Journal of Agricultural Economics* 71(4): 892–902.
- Babcock, B.A., and D.A. Hennessy. 1996. "Input Demand Under Yield and Revenue Insurance." *American Journal of Agricultural Economics* 78(2): 416–427.
- Babcock, B., and C. Hart. 2000. "A Second Look at Subsidies and Supply." *Iowa Agricultural Review* 6(4): 3.
- Barnett, B.J., and J.R. Skees. 1995. "Region and Crop Specific Models of the Demand for Federal Multiple Peril Crop Insurance." *Journal of Insurance Issues* 19(2): 47–65.
- Bar-Shira, Z., Just, R.E., and D. Zilberman. 1997. "Estimation of Farmer's Risk Attitude: An Econometric Approach." *Agricultural Economics* 17: (2–3): 211–222.
- Behrman, J.R. 1968. *Supply Response in Underdeveloped Agriculture: A Case Study of Four Major Crops in Thailand, 1937–63*. Amsterdam: North-Holland Publishing Co.
- Bockstael, N. 1999. "Valuing the Benefits of Microbial Food Safety Risk Reduction: Discussion." *American Journal of Agricultural Economics* 81(5): 1200–1204.
- Borsen, W. B., Chavas, J-P, and W. R. Grant. 1985. "Marketing Margins and Price Uncertainty: The Case of the U. S. Wheat Market." *American Journal of Agricultural Economics* 67(3): 521–528.
- Buzby, J.C., R.C. Ready, and J. Skees. 1995. "Contingent Valuation in Food Policy Analysis: A Case Study of a Pesticide-Residue Risk Reduction." *Journal of Agricultural and Applied Economics* 27(2): 613–625.

- Buzby, J.C., J.A. Fox, R.C. Ready, and S.R. Crutchfield. 1998. "Measuring Consumer Benefits of Food Safety Risk Reduction." *Journal of Agricultural and Applied Economics* 30(1): 69–82.
- Carlson, G.A. 1979. "Insurance, Information, and Organizational Options in Pest Management." *Ann. Rev. Phytopath.* 17: 149–161.
- Castle, E. 1954. "Flexibility and Diversification as a Measure of Meeting Price and Yield Uncertainty in Western Kansas." *JFE* 36: 273–284.
- Caswell, J.A., ed. 1995. *Valuing Food Safety and Nutrition*. Boulder: Westview Press.
- . 1998. "Valuing the Benefits and Costs of Improved Food Safety and Nutrition." *The Australian Journal of Agricultural and Resource Economics* 42(4): 409–424.
- Chavas, J.P., and M.T. Holt. 1996. "Economic Behavior under Uncertainty: A Joint Analysis of Risk Preferences and Technology." *Review of Economics and Statistics* 78(2): 329–335.
- Coble, K.H., and B.J. Barnett. 1999. "Preliminary Evidence of Crop Insurance Demand Elasticity from the 1999 Response to Additional Subsidies." Department of Agricultural Economics, Mississippi State University. Available at: <<http://www.agecon.msstate.edu/risk/documents>>.
- Coble, K.H., and T.O. Knight. 2002. "Crop Insurance as a Tool for Price and Yield Risk Management." In *A Comprehensive Assessment of the Role of Risk in U.S. Agriculture*, R.E. Just and R.D. Pope, eds. Boston: Kluwer Academic Publisher, pp. 445–468.
- Coble, K.H., T.O. Knight, R.D. Pope, and J. Williams. 1996. "Modeling Farm-Level Crop Insurance Demand with Panel Data." *American Journal of Agricultural Economics* 78(2): 439–447.
- Coyle, B. 1999. "Risk Aversion and Yield Uncertainty in Duality Models of Production: A Mean-Variance Approach." *American Journal of Agricultural Economics* 81(3): 553–567.
- Davis, S.B., T.J. Price, M. Wetzstein, and M.W. Rieger. 1997. "Reducing Yield Variation in Peach Orchards by Geographic Scattering." *American Journal of Agricultural Economics* 79(4): 1119–1126.
- Duffy, P. A., Shalishali, K. and H. W. Kinnucan. 1994. "Acreage Response under Farm Programs for Major Southeastern Field Crops." *Journal of Agricultural and Applied Economics* 26(2): 367–378.
- Duncan, J. and R.J. Myers. 2000. "Crop Insurance under Catastrophic Risk." *American Journal of Agricultural Economics* 82(4): 842–855.
- Dunn J.W., and J.R. Williams. 2000. "Farm Characteristics that Influence Net Farm Income Variability and Losses" Paper presented at the Western Agricultural Economics Association Annual Meetings, Vancouver, British Columbia, June 29–July 1.

- Estes, E.A., Blakeslee, L.L., and R.C. Mittelhammer. 1981. "On Variances of Conditional Linear Least-Squares Search Parameter Estimates." *American Journal of Agricultural Economics* (February): 141–145.
- Gardner, B.L., and R.A. Kramer. 1986. "Experience with Crop Insurance Programs in the United States." In *Crop Insurance for Agricultural Development: Issues and Experience*, P. Hazell, C. Pomareda and A. Valdes, eds. Baltimore: John Hopkins Press, pp. 195–222.
- Glauber, J. W. 1999. "Declaration in the U.S. District Court for the District of North Dakota, Southeastern Division." Testimony given in Paul Wiley et al. Daniel Glickman, Divil No. A3-99-32 (May 18).
- Glauber J.W., and K.J. Collins. 2002. "Risk Management and the Role of the Federal Government." In *A Comprehensive Assessment of the Role of Risk in U.S. Agriculture*, R.E. Just and R.D. Pope, eds. Boston: Kluwer Academic Publisher, pp. 469–488.
- Goodwin, B.K. 1993. "An Empirical Analysis of the Demand for Crop Insurance." *American Journal of Agricultural Economics* 75(2): 425–434.
- . 1994. "Premium Rate Determination in the Federal Crop Insurance Program: What Do Averages Have to Say About Risk?" *Journal of Agricultural and Resource Economics* 19(2): 382–395.
- Goodwin, B.K., and M. Vandever. 2000. "An Empirical Analysis of Acreage Distortions and Participation in the Federal Crop Insurance Program." Paper presented at the Economic Research Service workshop, "Crop Insurance, Land Use, and the Environment," held in Washington, DC, September 12–20.
- Griffiths W.E., and J.R. Anderson. 1982. "Using Time-Series and Cross-Section Data to Estimate a Production Function with Positive and Negative Marginal Risks." *Journal of the American Statistical Association* 77(September): 529–536.
- Hall, D.C., and L.J. Moffitt. 1985. "Application of the Economic Threshold for Interseasonal Pest Control." *Western Journal of Agricultural Economics* 10(December): 223–229.
- Heady, E.O. 1952. "Diversification in Resource Allocation and Minimization of Income Variability." *Journal of Farm Economics* 34: 482–496.
- Henneberry, S.R., K. Piewthongngam, and H. Qiang. 1999. "Consumer Food Safety Concerns and Fresh Produce Consumption." *Journal of Agricultural and Resource Economics* 24: 98–113.
- Holt, M.T. 1994. "Price-Band Stabilization Programs and Risk: An Application to the U.S. Corn Market." *Journal of Agricultural and Resource Economics* 19(2): 239–254.

- Holt, M.T., and S.V. Aradhyula. 1990. "Price Risk in Supply Equations: An Application of GARCH Time-Series Models to the U.S. Broiler Market." *Southern Economic Journal* 57(1): 230–242.
- . 1998. "Endogenous Risk in Rational-Expectations Commodity Models: A Multivariate Generalized ARCH-M Approach." *Journal of Empirical Finance* 5: 99–129.
- Holt, M.T., and G. Moschini. 1992. "Alternative Measures of Risk in Commodity Supply Models: An Analysis of Sow Farrowing Decisions in the United States." *Journal of Agricultural and Resource Economics* 17(1): 1–12.
- Hooker, N.H., R.M. Nayga, Jr., and J. Siebert. 1999. "Preserving and Communicating Food Safety Gains." *American Journal of Agricultural Economics* 81(5): 1102–1106.
- Horowitz, J.K., and E. Lichtenberg. 1993. "Insurance, Moral Hazard, and Chemical Use in Agriculture." *American Journal of Agricultural Economics* 75(5): 926–935.
- . 1994. "Risk-Reducing and Risk-Increasing Effects of Pesticides." *Journal of Agricultural Economics* 45(1): 82–89.
- Hurd, B.H. 1994. "Yield Response and Production Risk: An Analysis of Integrated Pest Management in Cotton." *Journal of Agricultural and Resource Economics* 19(2): 313–326.
- Hurt, C., and P. Carcia. 1982. "The Impact of Price Risk on Sow Farrowing, 1967–78." *American Journal of Agriculture Economics* 64(3): 565–568.
- Jensen, C.W. 1961. "Spatial Diversification of the Dryland Farm Unit." *Management Strategies in Great Plains Farming*, Nebraska Agricultural Experiment Station, MP7:91–95.
- Johnson, S.R. 1967. "Reexamination of the Farm Diversification Problem." *Journal of Farm Economics* 49: 610–621.
- Just, R.E. 1974. "An Investigation of the Importance of Risk in Farmers' Decisions." *American Journal of Agricultural Economics* 56: 14–25.
- Just, R.E., L. Calvin, and J. Quiggin. 1999. "Adverse Selection in U.S. Crop Insurance: Actuarial and Asymmetric Information Incentives." *American Journal of Agricultural Economics* 80(4): 834–849.
- Just, R.E., and R.D. Pope. 1979. "Production Function Estimation and Related Risk Considerations." *American Journal of Agricultural Economics* 61: 276–283.
- . 2001. "The Agricultural Producer: Theory and Statistical Measurement." In *Handbook of Agricultural Economics*, B.L. Gardner and G.C. Rausser, eds. Amsterdam: Elsevier, pp. 629–741.
- Just, R.E., and R.D. Pope, eds. 2002. *A Comprehensive Assessment of the Role of Risk in U. S. Agriculture*. Boston: Kluwer Academic Publishers.

- Keaton, K., J. Skees, and J. Long. 1999. "The Potential Influence of Risk Management Programs on Cropping Decisions." Paper presented at the annual meeting of The American Agricultural Economics Association, held in Nashville, TN, August 8–11.
- Ker, A.P., and P. McGowan. 2000. "Weather-Based Adverse Selection and the U.S. Crop Insurance Program: The Private Insurance Company Perspective." *Journal of Agricultural and Resource Economics* 25(2): 386–410.
- Kramer, C.S. 1990. "Food Safety: The Consumer Side of the Environmental Issue." *Southern Journal of Agricultural Economics* 22(1): 33–40.
- Kramer, R., and R.D. Pope. 1982. "Crop Insurance for Managing Risks." *The Journal of the American Society of Farm Managers and Rural Appraisers* 46(1): 34–40.
- Krause, M.A., and W.W. Koo. 1996. "Acreage Responses to Expected Revenues and Price Risk for Minor Oilseeds and Program Crops in the Northern Plains." *Journal of Agricultural and Resource Economics* 21(2): 309–324.
- Krause, M.A., Lee, J-H, and W.W. Koo. 1995. "Program and Nonprogram Wheat Acreage Responses to Prices and Risk." *Journal of Agricultural and Resource Economics* 20(1): 96–107.
- Lin, W. 1977. "Measuring Aggregate Supply Response Under Instability." *American Journal of Agricultural Economics* (December): 903–907.
- Lin, W., G.W. Dean, and C.V. Moore. 1974. "An Empirical Test of Utility vs. Profit Maximum in Agricultural Production." *American Journal of Agricultural Economics* 56: 497–508.
- Love, A., and S. Buccola. 1991. "Joint Risk Preference-Technology Estimation in a Primal System." *American Journal of Agricultural Economics* 73: 765–774.
- Luo, H., J.R. Skees, and M.A. Marchant. 1994. "Weather Information and the Potential for Inter-temporal Adverse Selection." *Review of Agricultural Economics* 16: 441–451.
- Mapp, H.P., and K.L. Jeter. 1988. "Potential Impact of Participation in Commodity Programs and Multiple Peril Crop Insurance on a Southwest Oklahoma Farm." In *Multiple Peril Crop Insurance: AS Collection of Empirical Studies*. Southern Cooperative Series Bulletin No. 34, Washington, DC.
- Marshall, A. [1890] 1920. *Principles of Economics*. 8th ed. London: Macmillan and Co., Ltd.
- McCloskey, D. 1976. "The Open Fields as Behavior Towards Risk." *Research in Economic History: An Annual Compilation of Research*. Vol. 1. Paul Uselding, ed. Greenwich: JAI Press.
- McKenzie, A.M., and M.R. Thomsen. 2001. "The Effect of E. Coli O157:H7 on Beef Prices." *Journal of Agricultural and Resource Economics* 26(2): 431–444.

- Meyer, J. 1987. "Two-Moment Decision Models and Expected Utility Maximization." *American Economic Review* 77(3): 421–430.
- Mishra, A.K., and B.K. Goodwin. 1997. "Farm Income Variability and the Supply of Off-Farm Labor." *American Journal of Agricultural Economics* 79(3): 880–887.
- Mishra, A.K., and M.J. Morehart. 2001. "Off-Farm Investment of Farm Households: A Logit Analysis." *Agricultural Finance Review* 61: 87–101.
- Moschini G., and D.A. Hennessy. 2001. "Uncertainty, Risk Aversion, and Risk Management for Agricultural Producers." In *Handbook of Agricultural Economics, Vol. 1A*, B.L. Gardner and G.C. Rausser, eds. Amsterdam: North-Holland, pp. 87–153.
- Myers, R.J. 1989. "Econometric Testing for Risk Averse Behaviour in Agriculture." *Applied Economics* 21(4): 541–552.
- Myers, R.J. and S.D. Hanson. 1996. "Optimal Dynamic Hedging in Unbiased Futures Markets." *American Journal of Agricultural Economics* 78(1): 13–20.
- Nelson, R.G., and D.A. Bessler. 1989. "Subjective Probabilities Elicited Under Proper and Improper Scoring Rules: A Laboratory Test of Predicted Responses." *American Journal of Agricultural Economics* 71(2): 363–369.
- Officer, R.R., and A.N. Halter. 1968. "Utility Analysis in a Practical Setting." *American Journal of Agricultural Economics* 50: 257–277.
- Orden, D. 2001. "Should There Be a Federal Income Safety Net?" Paper presented at the Agricultural Outlook Forum 2001, held in Washington, DC, February 22.
- Patrick, G.F., W.N. Musser, and D.T. Eckman. 1998. "Forward Marketing Practices and attitudes of Large-Scale Midwestern Grain Producers." *Review of Agricultural Economics* 20: 38–53.
- Pope, R.D. 1976. "An Analysis of Factors Affecting Farm Diversification: With Special Reference to San Joaquin Valley Crop Farms." Unpublished Ph.D. Dissertation. Berkeley: Department of Agricultural Economics, University of California.
- Pope, R., and R. Prescott. 1981. "Supply Response and the Dispersion of Expectations." *American Journal of Agricultural Economics* 63(February): 161–163.
- . 1980. "Diversification, in Relation to Farm Size and Other Socioeconomic Characteristics." *American Journal of Agricultural Economics* 62(August): 554–559.
- Pope, R., and R. Just. 1991. "On Testing the Structure of Risk Preferences in Agricultural Supply Analysis." *American Journal of Agricultural Economics* 73(3): 743–748.

- Quiggin, J., G. Karagiannis and J. Stanton. 1993. "Crop Insurance and Crop Production: An Empirical Study of Moral Hazard and Adverse Selection." *Australian Journal of Agricultural Economics* 37(2): 95–113.
- Regev, U., N. Gotsch, and P. Rieder. 1997. "Are Fungicides, Nitrogen and Plant Growth Regulators Risk-Reducing? Empirical Evidence From Swiss Wheat Production." *Journal of Agricultural Economics* 48(2): 167–178.
- Richards, T.J. 2000. "A Two-Stage Model for the Demand for Specialty Crop Insurance." *Journal of Agricultural and Resource Economics* 25(1): 177–194.
- Robison, L.J., and P.J. Barry. 1987. *The Competitive Firm's Response to Risk*. New York: Macmillan.
- Roumasset, J.A. 1976. *Rice and Risk*. Amsterdam: North-Holland Publishing Company.
- Saha, A., C.R. Shumway, and H. Talpaz. 1994. "Joint Estimation of Risk Preference Structure and Technology Using the Expo-Power Utility." *American Journal of Agricultural Economics* 76(2): 173–184.
- Samuelson, P.A. 1967. "A General Proof that Diversification Pays." *Journal of Financial and Quantitative Analysis* 2(1): 1–13.
- Schultz, T.W. 1980. "Nobel Lecture: The Economics of Being Poor." *Journal of Political Economy* 88(4): 639–651.
- Shogren, J.F., J.A. Fox, D.J. Hayes, and J. Roosen. 1999. "Observed Choices for Food Safety in Retail, Survey, and Auction Markets." *American Journal of Agricultural Economics* 81(5): 1192–1199.
- Smith, V.H., and B.K. Goodwin. 1996. "Crop Insurance, Moral Hazard, and Agricultural Chemical Use." *American Journal of Agricultural Economics* 78(2): 428–438.
- Thompson, G.D., and P.N. Wilson. 1994. "Common Property as an Institutional Response to Environmental Variability." *Contemporary Economic Policy* 12(3): 10–21.
- Tronstad, R., and T.J. McNeill. 1989. "Asymmetric Price Risk: An Econometric Analysis of Aggregate Sow Farrowings." *American Journal of Agricultural Economics* 71(3): 630–637.
- U.S. General Accounting Office (USGAO). 1999. *Agriculture in Transition—Farmers' Use of Risk Management Strategies*. GAO/RCED-99-90. Washington, DC: U.S. General Accounting Office.
- van Ravenswaay, E.O., and J.P. Hoehn. 1991. "The Impact of Health Risk on Food Demand: A Case Study of Alar and Apples." In *Economics of Food Safety*, J.A. Caswell, ed. New York: Elsevier Science Publishing Co., Inc., pp. 155–174.

- Vandever, M.L., and E.T. Loehman. 1994. "Farmer Response to Modified Crop Insurance: A Case of Corn in Indiana." *American Journal of Agricultural Economics* 76(1): 128–140.
- von Massow, M., and A. Weersink. 1993. "Acreage Response to Government Stabilization Programs in Ontario." *Canadian Journal of Agriculture Economics* 41: 13–26.
- Wu, J. 1999. "Crop Insurance, Acreage Decisions, and Nonpoint-Source Pollution." *American Journal of Agricultural Economics* 81(2): 305–320.
- Young D., W. Lin, R.D. Pope, L. Robison, and R. Selley. 1979. "Risk Preferences of Agricultural Producers: Their Measurement and Use." Paper presented at seminar of Western Regional Research Project, held in San Francisco, January 25–26.
- Zenger, S., and B.W. Schurle. 1981. "The Impact of Diversification on Risk at the Farm Level." Abstract. *American Journal of Agricultural Economics* 63: 1043.

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