Chapter 4.

An Assessment of Risk Exposure in Agriculture Based on a Review of the Literature

What is risk?

General perceptions of risk

Agriculture is often noted as a textbook case of economic activity fraught with risk. Agricultural producers regularly demonstrate concern for the economic uncertainty of the industry and major risk management tools such as futures markets have their origins in the agriculture sector. Similarly many farm support programs are justified primarily as risk safety net for agricultural producers. While risk has clear academic definitions as discussed in the next section, lay perceptions of risk are often associated with potential negative outcomes but often not articulated in probabilistic terms. This is in spite of the fact farmer behaviour is often clearly reflective of perceived subjective risk and demonstrated risk aversion.

Economic interpretation of risk

Various authors have addressed the implications and definition of risk in agriculture. For example, Robison and Barry (1987) define uncertainty and risky events in the following manner, "Events are uncertain when their outcome is not known with certainty. Uncertain events are important when their outcomes alter a decision maker's material or social well-being. We define as risky those uncertain events whose outcomes alter the decision maker's well-being" (p. 13). Robison and Barry also go on to note that other definitions of risk consider variances, likelihoods of loss, and safe levels of income or specific requirements on probability distributions. These, however, are argued to be tools with which to classify or order risky choices.

Newbery and Stiglitz (1981) argue that producers are concerned with income variability and how it affects consumption rather than risk factors such as price or yield. In their book, which primarily addresses price stabilization, they argue that price variability itself is not the appropriate metric to judge risk. Newbery and Stiglitz also discuss the distinction between risk and uncertainty, but take a subjective probability approach as suggested by Savage (1954) to indicate that the distinction is largely irrelevant. They state that individuals form subjective probability judgments and on the basis of those judgments are willing to make explicit or implicit bets on the outcome. Newbery and Stiglitz do make a strong assertion that it is relevant to distinguish between systematic and non-systematic risk. They argue systematic risk follows a predictable pattern with known relationships where non-systematic variability arises from shocks and other variability in markets supply or demand due to unforeseeable forces that come to bear on market prices.

Hardaker, Huirne, and Anderson (1997) define uncertainty as imperfect knowledge and risk as uncertain consequences, particularly exposure to unfavourable consequences. Hardaker, Huirne, and Anderson also go on to define several primary causes of risk in agriculture. In particular, they identify production risk stemming from the unpredictable weather and uncertainty about the performance of crops or livestock due to pests and diseases. Secondly, they denote price or market risk due to farmers having to make decisions about input uses without knowing the price of inputs, or more importantly outputs. They also point out that governments are a source of institutional risk for farms in that they may change the policy environment in which farms function. Hardaker, Huirne, and Anderson also characterize human or personal risk as issues associated with individuals that may affect the farm business. For example, they note death of owner, divorce, prolonged illness, or carelessness of a hired employee as a risk to the farm business. Interestingly Hardaker, Huirne, and Anderson argue that the aggregate effect of production, market, institutional, and personal risk is called business risk. Then they distinguish financial risk, which is related to the source and the methods of financing the farm operation.

Harwood *et al.* (1999) describe agricultural risk in the following terms, "Risk is uncertainty that "matters," and may involve the probability of losing money, possible harm to human health, repercussions that affect resources (irrigation, credit), and other types of events that affect a person's welfare. Uncertainty (a situation in which a person does not know for sure what will happen) is necessary for risk to occur, but uncertainty need not lead to a risky situation.

Chavas (2004) defines risk as representing any situation where some events are not known with certainty. He goes on to discuss the distinction between risk and uncertainty and states that there is no clear consensus on this issue. Rather, Chavas suggests that there are two schools of thought, one arguing that risk and uncertainty are not equivalent and that the distinction between the two is the ability to make a probability assessment. Chavas goes on to argue that the debate about the distinction between risk and uncertainty ultimately boils down to an argument about the existence and interpretation of probability. He concludes that this discussion is insightful, but has not led to much empirical analysis and thus he does not draw a sharp distinction between risk and uncertainty and uses the terms interchangeably.

Quantifying risk

Given the general acceptance of a probabilistic definition of risk, there are a number of different metrics that have been used to describe agricultural risk. Often in the simplest risky scenario where there are two possible outcomes, probability can be diagrammed in a decision tree, which can then be expressed in terms of the probability that one will observe one possible outcome versus another. When risks are more complicated but discrete, alternatives can also be described in a decision tree context by identifying each of the discrete possible outcomes. Often such a design is used when it can approximate a more continuous set of outcomes.

In agriculture we observe many risks where the set of outcomes are continuous rather than discrete. For example, prices or yields might be viewed as being continuous across a wide range with a probability distribution that can best be described graphically by a probability density function (PDF) or a cumulative distribution function (CDF). While a PDF or a CDF provides a mathematical representation of risk that can be viewed visually, it does not provide a simple metric that quantifies risk. In applied risk analysis a number of numerical measures have been proposed and used over time. These measures are generally consistent with the definition of Rothschild and Stiglitz (1970) who define risk in terms of a mean-preserving spread as moving probability away from the centre of a PDF to the tails while leaving the mean unchanged Currently in applied risk analysis, the variance or the standard deviation are often used as a measure of riskiness. In the case of a normal probability distribution, the mean and the variance fully describe the PDF. However, when risks are non-normally distributed the variance doesn't fully reflect the dispersion of the probability distribution.

Often, risk analysis focuses on negative or bad outcomes. Because of this, we often see various metrics that in some fashion measure the probabilities of bad events. In some literature, such as Lien, and Hardaker (2001) the probability of bankruptcy has been used as a single quantifiable measure of bad events. Likewise an increasing amount of literature uses value at risk (VaR) to identify some criterion level of risk based on a percentile, such the 5th to the 10th percentile, of the CDF (Vedenov and Barnett, 2004; Giot, 2003; Manfredo and Leuthold, 1999, 2001). This, again, gives a simple numerical metric by which one can judge the probability of bad outcomes.

There are a number of more complex issues involved in describing agricultural risk probabilities. The most obvious is the potential for correlation between random variables underlying the farm's income distribution. In a simple case, assume that both price and yield are random and that they are not independent of each other. In that case to fully reflect the risk that the farm observes in its income, one would need to take into account the correlation between those two random variables. Ultimately, correlation between the random variables on the farm becomes an empirical question, but adds a significant degree of complexity to characterizing the riskiness of the farm. For example, it is quite plausible that the income of a farm is conditioned upon a number of commodities where both price and yield are random. Empirical data tends to suggest that yields of crops on a farm are likely to be highly positively correlated with each other. In some instances yield and prices for a commodity would be negatively correlated with each other. And it is quite likely that agricultural output prices would be positively correlated with each other due to common shocks. In the context of a normal distribution, the multivariate correlations are quite straightforward to model. However, when one moves beyond the multivariate normal, modelling is much more complex as described in Anderson, Coble, and Harri (2008).

What is not risk

The fact that the mean or expected value of an economic variable has a trend or a cyclical behaviour (it is non-stationary) does not necessarily imply risk. An economic variable may follow well-defined linear or cyclical patterns. For example trends may occur in prices and are pervasive in crop yields (Just and Weninger, 1999; Ramirez, Misra, and Field, 2003; Sherrick *et al.*, 2004). Predictable cycles in livestock prices are common due to seasonal production (Crespi, Xia, and Jones, 2008; Rosen, Murphy, and Scheinkman, 1994). Seasonality in the mean level of price and price variability has been repeatedly found in crop agriculture (Anderson and Danthine, 1983; Anderson, 1995; Streeter and Tomek, 1992). This work suggests that prices of seasonally produced goods tend to rise post harvest to cover the cost of storage and prices tend to be more volatile during the growing season. The result is that if the variable consistently follows the pattern there is no risk, even though the realized value may vary over time. Risk implies some degree of randomness, so that any specific realization of the variable may differ from the expected value. The expected value may be stationary or non-stationary. Regardless, the defining characteristic of a risky variable is that realizations may differ from the expected value. Thus, the works cited general estimated trends and cycles and then compute variability after removing the trend or cycle.

A conceptual framework

Businesses manage portfolios of activities from which they seek to generate net returns. Consider a farmer who manages a portfolio consisting of *n* crop and/or livestock production activities. Each activity A_i ($i = 1, 2, \ldots n$) generates a periodic net return $r_i = \mathrm{Re}\, v_i - C_i$ where $\mathrm{Re}\, v_i$ is gross return and C_i is the cost of production. $\mathrm{Re}\, v_i = \pi_i P_i$ where π_i is the quantity of output produced and P_i is the price at which the output is sold, so $r_i = \pi_i P_i - C_i$. For crops, $\pi_i = A_i Y_i$ where A_i is the area measured in hectares used to produce crop *i* and Y_i is the yield per hectare. For both crop and livestock activities the periodic net return r_i is stochastic because each of the right-hand side variables (output, price, and cost) are stochastic. For crops, output π_i is stochastic because yield Y_i is stochastic. For livestock, π_i is stochastic due to death loss or variability in rates of gain due to uncertain factors such as disease or extreme weather events.

Consider a single activity *i* for which there are *k* possible discrete levels of net return. The variance of net returns for activity *i* is calculated as $\sigma_i^2 = \sum_{j=1}^{k} \alpha_{ij} \left[r_{ij} - E(r_i) \right]^2$ where α_{ij} is the probability of net return level *j* for activity *i* and $E(\bullet)$ is the expectations operator. Since $r_{ij} = \pi_{ij} P_{ij} - C_{ij}$ the variance in net returns can be rewritten as $\sigma_i^2 = \sum_{j=1}^{k} \alpha_{ij} \left[(\pi_{ij} P_{ij} - C_{ij}) - E(\pi_i P_i - C_i) \right]^2$. Without expanding the mathematics further, note that the variance of net returns for activity *i* is a function of production variance, price variance, cost of production variance, and the pairwise covariances between production, price, and cost of production. If the covariance between production and price is zero, we say that production and price are unrelated or independent of each other. If the covariance between production and price is negative (positive) then the variance of gross returns is lower (higher) than if production and price were independent.

The net return on the entire portfolio of farm crop and/or livestock production activities is $R = \sum_{i=1}^{n} w_i r_i$ where w_i is the proportion of the total value of the portfolio that is invested in activity *i* and $\sum_{i=1}^{n} w_i = 1$. The variance of net returns for the portfolio is calculated as $\sigma_R^2 = \sum_{j=1}^{n} \sum_{k=1}^{n} w_j w_k \sigma_{jk}$ where σ_{jk} is the variance in net returns on the single production activity when $j = k$ and the pairwise covariance in returns when $j \neq k$ with $\sum_{j=1}^{n} w_j = 1$ and $\sum_{k=1}^{n} w_k = 1$. Thus, the overall variability in net returns for a portfolio of farm production activities is a function of the variance in net returns for each of the various production activities, the proportion of the overall portfolio that is invested in each activity, and the covariances between the gross returns for each of the activities. Recall that the variance of net returns for each activity is itself a function of production variance, price variance, cost of production variance and the pairwise covariances between production, price, and cost of production.

Notice that by including off-farm sources of income among the *n* activities, one can calculate the variability in net income for the farm household’s entire portfolio of farm and non-farm sources of income. The impact of off-farm income on overall household net income variability will depend on the variability of off-farm income relative to net farm income and the covariance between off-farm and farm income sources.

Economists typically assume that individual decision-makers maximize a generalized expected utility function defined over the distribution of R and subject to relevant constraints, with $\frac{\partial E(U)}{\partial E(R)} > 0$ and $\frac{\partial E(U)}{\partial \sigma_R^2} < 0$. That is, expected utility is increasing in expected returns and decreasing in the variability of returns. The latter implies that decision-makers are risk-averse.

Results from empirical studies that have estimated various factors affecting farm household net income variability are then reported. Specifically, these factors are the variability in output prices, input costs, production, and off-farm income as well as pairwise covariances between prices of different commodities, production of different commodities, and price and production of the same commodity. The causes of output price, input cost, and production variability are considered, followed by an analysis decision-makers risk perceptions and risk preferences. The final section contains concluding comments.

Estimation of variability in price, yield and off-farm income

Determinates of farm income variability

As will be evidenced in the following summary, the existing literature on farm income variability has focused primarily on output price risk and production or yield risk. Both of these risks are generally perceived as risks that profoundly affect the financial well-being of the farm family. Other risks, such as input price risk, have received much less attention. This is likely due to the fact that these other risks tend to exhibit less variability over time, although periodic shocks stimulate brief periods of intense research activity.

Data sources and the effect of aggregation on risk measures

Most applied agricultural risk analyses are based on historical series of yield or price data. These historical data typically must be analyzed using quite sophisticated techniques to account for predictable trends (as in technology induced changes in expected yield over time) and cycles (such as seasonal patterns in crop prices reflecting storage cost). For example, as shown in Harri *et al.* (2008), analysts have removed a time trend from historical yield series when assessing the variability of yields. The time trend stands as a proxy for a number of factors that influence agricultural crop yields, but typically it is assumed that the time trend is primarily capturing adjustments in biological yield potential through time. Likewise, price risk is often measured by using historical series of price data. The most prevalent adjustment in price data is to account for the strong potential for auto-correlation.

An alternative data source is subjective probabilities obtained directly from decision makers. This approach, that focuses on methods for eliciting from decision makers the probabilities that they perceive are associated with various potential outcomes, has been used in far fewer studies (Fackler, 1991; Anderson, Dillon, and Hardaker, 1977). Several techniques have been used to encode the probability assessment of a risky decision.

Regardless of the data source, it is important to account for the impact of spatial aggregation bias on risk measures. In agricultural contexts, this is particularly important for yield risk measures.[1] At higher levels of aggregation, poor yields in some areas are offset by good yields in others thereby reducing the overall variability. Various studies have demonstrated an aggregation bias in yield variability (Carter and Dean, 1960; Eisgruber and

Schuhman, 1963; Debrah and Hall, 1989; Marra and Schurle, 1994; Rudstrom *et al.*, 2002; Popp, Rudstrom, and Manning, 2005; Knight *et al.* 2008). Coble, Dismukes, and Thomas (2007) estimated acreage-weighted yield coefficients of variation (CVs) for U.S. maize, soybeans, and cotton at different levels of aggregation. Their findings, shown in Table 4.1, clearly show the impact of aggregation bias on CVs. Average yield CVs measured at the farm-level are more than double those measured at the state-level and more than three times those measured at the national-level.

Table 4.1. The effect of aggregation on yield risk

Level of aggregation	Yield coefficients of variation		
	Maize	Soybeans	Cotton
Farm	0.25	0.25	0.39
County	0.15	0.13	0.26
State	0.12	0.11	0.16
National	0.08	0.07	0.11

Source: Coble, Dismukes, and Thomas (2007), Based on 1975-2004 data.

Aggregation bias makes it extremely difficult to make meaningful spatial comparisons of yield risk magnitudes. Obviously, any spatial comparison of yield risk must take into consideration the level of aggregation (*e.g.* farm, provincial, or national) at which yield is being measured. But even this is often not sufficient. The size of nations, provinces, and farms varies tremendously. In many lower income countries, farms may be no larger than 1-2 hectares while in some OECD countries farms of 500-1 000 hectares are not uncommon. However, even within OECD countries, there is tremendous variability in farm sizes. All of this implies that caution should be used when attempting to make spatial comparisons of yield risk magnitudes. A clear conclusion resulting from this literature is that when assessing the risks faced by producers, farm-level data is the appropriate level of yield aggregation to use when assessing producer risk. Much more readily available aggregate data will severely underestimate the risks producers face.

Output prices

Output price risk can be conceptualized as arising in large part due to the biological lags inherent in most agricultural production and price behaviour. A commitment of inputs may occur months before the farmer has a product to sell. During that period, output price changes may be dramatic. This impact is magnified for tree crops or other commodities that have multiple year time lags between investment and the onset of production. Prices may respond to shocks in demand or supply and differ from yield risk in several fundamental ways.

First, for most major agricultural commodities there are well functioning integrated world markets that result from trade. Thus, though located around the world, producers of a crop like wheat will experience positively correlated price shocks. This is in contrast to yield risk which tends to be much more localized. However, this statement is less true for isolated economies or non-commodity crops that have a unique niche market.

Secondly, a related characteristic of price risk is that the magnitude of price risk for a commodity will tend to be similar for producers worldwide. That is, in an integrated world commodity market the magnitude of price risk is likely to be more homogeneous than the degree of yield risk which tends to vary due to local factors such as weather, soils, and production systems. If information were perfect the difference in commodity prices would simply reflect transportation cost. In practice, many factors cause deviations from the perfect information case; for example, quality variation, vertical integration, and in some cases market power exerted by purchasers. However, there is empirical evidence that many commodity price movements are strongly spatially correlated. An important by-product of the positive correlation is that aggregate price data are much more informative about producer price risk than aggregate yield data are about producer yield risk.

A third distinction is that probability distributions of agricultural prices tend to be much more consistent than those for crop yields (see Goodwin, Roberts and Coble, 2000 in comparison to Harri *et al.*, 2008). That is, as one moves from one crop or region to another little can be said *a priori* regarding the shape of yield distributions. Conversely, commodity prices tend to be right skewed to the point that the right skewed log-normal distribution is well accepted as an appropriate assumption when modelling price distributions.

Measured levels

While various studies have attempted to measure output price risk, it is difficult to make meaningful comparisons across these studies due to differences across countries and over time in government market intervention policies. Many OECD countries have significantly reduced their interventions in markets for agricultural commodities over the past 10-20 years. Thus, when comparing studies of market price risk it is important to note which price (world price or domestic price) is being considered and any market interventions that may have been in place during the time period over which price variability is being measured.

It has long been argued that when countries adopt trade distortions that insulate domestic prices from world market supply or demand shocks this will tend to increase price variability for the rest of the world (*e.g.* OECD, 2004; Bale and Lutz, 1979). However, the impact of domestic price stabilization interventions on world price variability depends on the nature of the intervention. Border protections will almost certainly externalize price variability on to world markets while accumulation and de-accumulation of stocks could reduce world price variability (Johnson, 1975).[2]

In recent years several studies have attempted to measure the impact of market and trade liberalization on agricultural commodity prices (*e.g.* Beghin and Aksoy, 2003; Blake, McKay and Morrissey, 2002; Hertel *et al.*, 2000). However, most of these studies have focused on how liberalization affects the level of commodity prices rather than the variability of prices.

OECD (2004) studied the impact on world price variability of removing domestic market interventions and border protections in Switzerland, Japan, Canada, Mexico, the United States, and the countries of the European Union. These changes would allow supply or demand shocks to be completely transmitted into the domestic markets of these countries. The study found that such complete price transmission reduced world price variability for wheat, coarse grains, oilseeds, and rice by 45%, 32%, 23%, and 21%, respectively. Sarris (2000b) notes that during the 1990s world trade in cereals became more liberalized and many governments also reduced their interventions in domestic cereal markets. Sarris' empirical analysis indicates that these changes had no effect on world cereal price variability.

Barrett (1997) notes that, within a particular country, liberalization typically includes several different reforms making the predicted impact on both levels and variability of domestic commodity prices ambiguous. Using data from Madagascar, Barrett finds that over the long run liberalization increased both the mean and the variance of food prices as the government had a policy regime that held retail and farm prices at artificially low and stable levels. Ray *et al.*

(1998) and Yang, Haigh, and Leatham (2001) find that the reduced market interventions contained in the 1996 U.S. farm bill increased domestic price variability for maize, soybeans, and wheat but not for cotton.

Vrolijk and Poppe (2008) use European Farm Accountancy Data Network (FADN) data for the period 1996-2004 to analyze net farm income variability in Europe. While the time period is relatively short, farms participate in the FADN panel for several years allowing for time-series analysis of individual farms. They find that horticulture and intensive livestock farms have the largest variability in net farm incomes. Since these sectors are not regulated by the CAP, the variability in net incomes is driven primarily by price variability. Interestingly, they also found that while output variability was highest in southern Europe and some of the Nordic countries, the highest net farm income variability was in north-western Europe. This is because farms in north-western Europe tend to be more highly leveraged and have smaller margins. Thus, they are more vulnerable to price and yield shocks.

Differences across commodities

Table 4.2 presents a summary of findings from studies that have reported price coefficients of variation for various crops. Deaton and Laroque (1992) report price CVs over the period 1900-1987. Price CVs for cotton, maize, rice, and wheat were all similar. The price CV for sugar was much higher. Hazell, Shields, and Shields (2005) note a downward trend in the real price of wheat, maize, and rice over the period 1971-2003. They also find that price variance, though still fairly high, is declining. Empirically, they estimate the price CVs of wheat, maize and rice to be 29%, 23% and 33%, respectively, over the period 1971 to 2003. Ray *et al.* (1998) report CVs of U.S. marketing season average prices for various commodities over the period 1986-1996. These findings are generally consistent with those of Deaton and Laroque in that maize and wheat have similar price CVs while the price CV for cotton is lower. Hubbard, Lingard, and Webster (2000) report CVs of monthly prices for Romania over the period 1991-1995. The results for maize and wheat are similar to those from other studies. The reported price CV for potatoes is very high relative to other commodities.

We found no publications that compare long-run price variability across livestock commodities. There are probably several reasons for this. First, in many countries governments establish support prices for highly perishable livestock commodities such as milk. These supports distort estimates of price variability. Second, in most OECD countries, poultry and hogs are produced and sold in vertically coordinated markets that are controlled through production and marketing contracts. While it is still possible to find spot market data for these commodities, economists increasingly question whether these data are representative of the broader vertically coordinated markets. This is especially true with regard to price variability. Thus, in recent years most of the literature on these markets has shifted away from analyzing spot market prices to analyzing the principal-agent relationships that exist in contractual relationships. While increasingly vertically coordinated, the cattle sector currently has more spot market transactions than the poultry or hog sectors. However, even for cattle markets the recent literature has focused on identifying price cycles or variability in basis (the difference between the local cash prices and futures prices) rather than on variability in price *per se*. Finally, relative to crop commodities, price variability in livestock commodities tends to be characterized by short-run price shocks caused by food safety scares or temporary restrictions on trade. As is discussed later, a literature exists that examines the impact of such shocks on livestock sectors but given the short-run nature of the shocks this literature does not report long-run estimates of price variability.

Table 4.2. Summary of studies comparing price risk across crop commodities

Author(s)	Commodity	Location	Years	Price measure	Data manipulation	CV
Deaton and Laroque (1992)	Cotton	World	1900-1987	Annual average over calendar year	Deflated	0.35
Deaton and Laroque (1992)	Maize	World	1900-1987	Annual average over calendar year	Deflated	0.38
Deaton and Laroque (1992)	Rice	World	1900-1987	Annual average over calendar year	Deflated	0.36
Deaton and Laroque (1992)	Sugar	World	1900-1987	Annual average over calendar year	Deflated	0.60
Deaton and Laroque (1992)	Wheat	World	1900-1987	Annual average over calendar year	Deflated	0.38
Hazell, Shields, and Shields (2005)	Maize	U.S. Gulf ports	1971-2003	Annual average from August-September	Deflated and linearly detrended	0.23
Hazell, Shields, and Shields (2005)	Rice	Bangkok	1971-2003	Annual average from July-August	Deflated and linearly detrended	0.33
Hazell, Shields, and Shields (2005)	Wheat	U.S. Gulf ports	1971-2003	Annual average from June-May	Deflated and linearly detrended	0.29
Ray *et al.* (1998)	Cotton	United States	1986-1996	Annual average over marketing season	Detrended	0.101
Ray *et al.* (1998)	Maize	United States	1986-1996	Annual average over marketing season	Detrended	0.133
Ray *et al.* (1998)	Soybeans	United States	1986-1996	Annual average over marketing season	Detrended	0.124
Ray *et al.* (1998)	Wheat	United States	1986-1996	Annual average over marketing season	Detrended	0.146
Hubbard, Lingard, and Webster (2000)	Maize	Romania	1991-1995	Monthly average	Deflated	0.31
Hubbard, Lingard, and Webster (2000)	Potatoes	Romania	1991-1995	Monthly average	Deflated	0.53
Hubbard, Lingard, and Webster (2000)	Wheat	Romania	1991-1995	Monthly average	Deflated	0.26

Table 4.3 reports price CVs for selected countries and commodities calculated by the authors from Food and Agriculture Organization (FAO) non-detrended annual average price data for the period 1991-2005. Comparing price CVs across commodities is complicated by differences that exist across countries. For example, livestock and meat price CVs are generally lower than crop price CVs for the European countries shown in Table 4.3, but this is not necessarily true in other regions. Apples tend to have higher price CVs than field crops in Europe and Japan but not in Australia, Canada, Mexico or the United States. Maize price CVs are generally higher than wheat and oats price CVs, although not in the United States.

Table 4.3. Annual average price coefficient of variation 1991-2005

	Apples	Cattle meat	Maize	Oats	Pigs	Potatoes	Rice	Sheep meat	Turkey meat	Wheat
Australia	0.18	0.23	0.20	0.25	0.11	0.13	0.25	0.24	0.20	0.19
Canada	0.08	0.09	0.31	0.09	.016	0.06		0.14	0.09	0.21
Denmark	0.23	0.22		0.26	0.19	0.28		0.25	0.15	0.24
France	0.30	0.14	0.25	0.24	0.21	0.38	0.20	0.14	0.15	0.26
Germany	0.32	0.21		0.26	0.21			0.12	0.12	0.23
Italy	0.29	0.13	0.37	0.20	0.20	0.20	0.21	0.10	0.16	0.25
Japan	0.17	0.09	0.10	0.11	0.09		0.24	0.09	0.23	0.13
Mexico	0.16	0.14	0.36	0.12	0.13	0.18		0.13	0.21	0.19
Spain	0.29	0.30	0.26	0.23	0.14	0.26	0.25	0.36	0.17	0.25
Sweden	0.32	0.32		0.27	0.37	0.27		0.20	0.28	0.24
United States	0.17	0.13	0.14	0.18	0.17	0.12	0.25	0.23	0.13	0.19

Source: Authors' calculations from non-detrended FAO data.

Differences across time

Hubbard, Lingard, and Webster (2000) report that the coefficient of variation of world wheat prices has changed over time. From 1960-1971 it was only 0.17. From 1972-1975 it was 0.25 and from 1976-1996 it was 0.32.

In contrast, Hazell, Shields, and Shields (2005) using world price data for 1971-2003 found no evidence that price variability had increased in recent years for wheat, maize, and rice.

Schnepf (1999) examined U.S. monthly average price data to measure real price CVs for soft and hard red winter wheat as well as maize and soybeans. The results were reported by decade from 1913 to 1997. Notably, the price CVs tended to move together. The lowest risk periods were the 1950s and 1960s when all four crops were found to have a CV of 5% or less. The riskiest periods were the 1930s and the 1970s, when the CV rose to around 15%, three times greater than the lowest risk periods.

Sarris (2000a, 2000b) also concludes that while there are factors that would tend to increase the world instability of cereal markets, there are other counteracting factors that would tend to diminish it. Further, the empirical evidence suggests that there does not seem to be a general trend toward increasing world cereal market instability.

Jordaan *et al.* (2007) examined futures price data from the South African Futures Exchange for yellow maize, white maize, wheat, sunflower seed, and soybeans. Using GARCH models, they found that the volatility in the prices of white maize, yellow maize and sunflower seed have varied over time. The volatilities of wheat and soybean prices were found to be constant over time. The price of white maize was found to be the most volatile, followed by yellow maize, sunflower seed, soybeans, and wheat respectively.

Subervie (2007) reports the percentage price deviations for cocoa, coffee, rice, cotton, tea, and groundnuts over the 1961-2002 period. Notably, the 1975-81 period was the most variable sub-period for all six crops. Of the six crops, coffee was most volatile and rice the least so.

Differences across locations

Table 4.3 allows for comparisons of price CVs across selected countries. In general, Japan seems to have the lowest price CVs with the North American countries generally having lower price CVs than the European countries.[3] Looking at specific commodities, Japan, Australia, and the North American countries generally have lower price CVs for apples and wheat than the European countries. For oats Australia has a higher price CV, similar to many of the European countries. Japan, the United States, and Australia have maize price CVs that are lower than those in Canada, Mexico, and the European countries. Australia and the North American countries have lower potato price CVs than the European countries. Rice price CVs are similar across all of the countries that report rice data. In the livestock sectors, pigs have lower price CVs in Australia, Japan and the North American countries compared to the European countries. The same is true for cattle meat except that Australia's price CV is more in line with the European countries. The results for sheep meat and turkey meat are more mixed with some European countries having some of the lowest price CVs and other European countries having some of the highest price CVs.

Summary of output price risk

Output price risk has unique characteristics relative to yield risk. Unless countries impose severe border controls, price variability will tend to be positively correlated across countries for most major agricultural commodities. Examples of this include rice in Japan and EU prices in the 1980's. In contrast, yield risk tends to exhibit less spatial correlation. Similarly, the magnitude of price risk tends to be similar across countries for major agricultural commodities whereas the magnitude of yield risk may vary greatly within and across countries. This implies that aggregate price data are much more informative about producer price risk than aggregate yield data are about producer yield risk. Finally, economists tend to agree that commodity price distributions are right skewed (*e.g.* log-normal distribution). This generally does not change across locations. However, the shape of yield distributions can vary greatly across locations (Goodwin, Roberts, and Coble, 2000).

The available evidence suggests that livestock and meat products tend to exhibit less price risk than crops. Fresh fruits, vegetables, and other specialty crops tend to exhibit higher price risk than commodity crops such as cotton, maize, wheat, and soybeans. An important determinant of output price risk is the extent to which the product can be stored for long periods of time without significant reductions in quality. Fresh fruits and vegetables have high price risk because they cannot be stored for long periods of time. For storable commodities merchants can arbitrage price differences over different time periods. This is not possible for fresh produce.

Data from FAO suggest that European countries generally experienced higher price variability from 1991-2005 than did Japan and North American countries. However, such cross-sectional comparisons are always problematic due to differences in market interventions across countries.

As one attempts to measure the relevant measure of price risk confronted by agricultural producers, we again appeal to the conceptual framework described above. Often price variability is reported on a daily, monthly, or annual level. We would argue that the appropriate level of price variability is the one consistent with the time horizon for the decision being made.

In agriculture that can vary. However, in many agricultural contexts the planning horizon is approximately a year. For example, in crop agriculture the time lag from the point of allocating land to various crops until the crop is finally harvested and marketed is often approximately a year. In livestock, production cycles vary from less than a year for poultry and hogs to more than a year for beef and dairy. Thus, we conclude that price variability estimated using annualized prices is generally preferable to price variability estimated over shorter intervals.

A related question is what price data are relevant to the producer's decision making. Readily available price data are generally international, national, border or futures prices. Conceptually, one would prefer local cash prices to measure the risk exposure of producers. However, the more general problem is that of basis risk — variability in the spread between local cash price and the more aggregate price series. Note that basis is often driven by factors such as transportation cost and the ability to arbitrage across geographical markets. A constant level of basis does not pose risk for producers; however producers are subject to risk from fluctuations in various factors such as transportation costs, availability of storage capacity, or interruption of transportation service such as rail or barge traffic.

Input prices

Our search of the literature reveals that much less attention has been given to input price risk than to either output price risk or yield risk. This is consistent with the study by Coble *et al.* (1999) that asked producers to rank risks in terms of potential effect on farm income. They found that producers' rank input price risk third behind output price risk and yield risk.

In terms of risk magnitude, Dhuyvetter, Albright and Parcell (2003) estimated models that forecast diesel fuel, natural gas, and anhydrous ammonia prices. Summary statistics from their data show a CV of 0.187 for Kansas diesel, 0.489 for natural gas, and 0.270 for anhydrous ammonia. Oehmke, Sparling and Martin (2008) recently examined Canadian fertilizer price risk and documented price shocks of greater than 70% between the 2007 and 2008 crop years. They also found the monthly CV of natural gas prices over 1994-2006 to range from 30 to 99% with the greatest volatility in February.

Data from the USDA allows an analysis of selected fertilizer prices from 1960 to 2007 in Table 4.4 To assess changes in the riskiness of fertilizer prices over time, the mean, standard deviation, and coefficient of variation was computed for the 1960 to 1996 period and then for 1997-2007. Several insights arise from this comparison. First, fertilizer price coefficients of variation are typically as high as or higher than many commodity price coefficients of variation. The second conclusion drawn from this table is that the coefficient of variation has not increased dramatically in the last decade (in some cases it has declined). However, the mean prices of various fertilizers have increased for all of the fertilizers examined here.

Table 4.4. Select fertilizer prices 1960-2007

Period	Statistic	Anhydrous ammonia	Ammonium nitrate	Super-phosphate (44-46%)	Diammonium phosphate (18-46-0)
60-96	Mean	228.91	178.32	207.14	238.23
60-96	Standard Deviation	68.21	55.04	66.58	66.19
60-96	Coefficient of Variation	0.30	0.31	0.32	0.28
97-07	Mean	350.45	254.18	273.18	283.55
97-07	Standard Deviation	111.07	68.90	56.48	60.89
97-07	Coefficient of Variation	0.32	0.27	0.21	0.21

Source: USDA Economic Research Service.

A related summary of data is conducted for diesel fuel prices in Table 4.5. Since diesel is a primary fuel used in farm implements such as tractors, these price are reflected in the cost of tillage and various farm operations. The data here allows cross-country comparisons, but for a shorter time period than the previous table. First it appears that diesel prices are similar in both the mean and CV across Europe and the U.S. However, it is also notable that the measured CV for diesel is among the highest observed in this report.

Table 4.5. Diesel fuel prices for various countries 1996-2008

Date	Belgium	France	Germany	Italy	Netherlands	UK	US
Mean	1.62	1.46	1.53	1.69	1.68	1.50	1.35
Standard Deviation	0.86	0.85	0.84	0.92	0.89	0.82	0.81
Coefficient of Variation	0.53	0.59	0.55	0.55	0.53	0.55	0.60

Source: Energy Administration U.S. Government. http://www.eia.doe.gov/emeu/international/oilprice.html;

It is also important to recognize that the output price variability of crops often can be considered an input price risk for the livestock sector. Feed grains and soybeans often serves as the primary energy and protein source in the poultry, dairy, pork, and grain-fed cattle industries. It is typical for feed cost to be the largest single variable input cost in livestock production systems. Therefore, the analysis of output price risk for crops in the previous section applies directly to the input price risk for the livestock industry.

Production risk

Crops

Distributional form

When attempting to model crop yields an important issue is the assumed shape of the yield distribution. It is easier to work with normal distributions because they can be fully described using only two parameters (mean and variance). Also, with multiple normally distributed random variables calculation of the pairwise covariances is straight-forward.

However, a significant body of literature has argued that crop yields are not normally distributed. A standard argument is that yield distributions will tend to be left-skewed because yields can be as low as zero but there is some biological limit to how high yields can go. This argument further suggests that the magnitude of skewness likely depends on the level of aggregation at which yields are measured. It is not difficult to imagine yields near zero for a specific plot but it seems quite unlikely that yields near zero would occur when measured at provincial or national levels. Thus, while skewness may still exist in aggregate yields, one would generally expect yield distributions to be more symmetric at higher levels of aggregation.

Using experimental plot data Day (1965) found evidence of right-skewness in Mississippi cotton yields. However, the far more common finding has been that yields are left-skewed. Gallagher (1987) demonstrated that national U.S. soybean yields are left-skewed. Nelson and Preckel (1989) and Nelson (1990) found evidence of negative skewness in farm-level maize yields from five Iowa counties. Taylor (1990) found negative skewness in maize and soybean yields for Macoupin County, Illinois but positive skewness for wheat yields in the same county. Moss and Shonkwiler (1993) found evidence of negative skewness in national

U.S. maize yields. Ramirez (1997) found evidence of left-skewness in Midwest maize and soybean yields. Wheat yields, however appeared to be symmetric. Wang *et al.* (1998) found evidence of negative skewness in maize yields for Adair County, Iowa. Goodwin and Ker (1998) used non-parametric methods to estimate state- and county-level yield distributions for several commodities. Negative skewness was common though there were cases of slight positive skewness (especially at the state-level of aggregation).

Just and Weninger (1999) argued that methodological problems existed with all previous studies of yield distributions. They contended that when these methodological problems are adequately addressed, insufficient evidence exists to disprove normality of crop yields. Several subsequent studies attempted to address the methodological concerns raised by Just and Weninger (1999). Ramirez, Misra, and Field (2003) reconfirmed the earlier finding by Ramirez (1997) that Midwest maize and soybean yields are left-skewed. Ramirez, Misra, and Field (2003) also found that Texas plains dryland cotton yields were right-skewed, a result that they ascribe to right-skewness in rainfall distributions for the region. Using farm-level yield data from Kansas, Atwood, Shaik, and Watts (2003) found evidence of left-skewness for irrigated maize, irrigated sorghum, dryland sorghum, irrigated wheat, and dryland wheat yields. Using farm level data from Illinois, Sherrick *et al.* (2004) found evidence of left-skewness in both maize and soybean yields. More recently, Harri *et al.* (forthcoming) examined maize, soybean, cotton and wheat yield and find decidedly mixed results with a tendency for low risk crops to be left skewed and high risk crops to be right skewed.

Magnitude of crop yield risk across commodities and locations

As indicated above, most studies have found that yields are not normally distributed. This finding raises questions about how to meaningfully compare magnitudes of yield risk. If yields are not normally distributed then the variance, standard deviation, or CV may not be sufficient indicators of risk. Higher moments of the distribution also affect risk exposure. Despite this, most studies report yield risk using CV because it is difficult to compare higher moments across different distributions.

The magnitude of yield risk depends on a number of agronomic, climatic, and management factors. For example the uses of irrigation, timeliness of planting, and quality of in-season crop inspection are all factors that may affect risk. As mentioned earlier, it also depends critically on the level of aggregation at which yield is measured. This latter point suggests that one should be cautious about drawing conclusions based on cross-sectional comparisons of crop yield risk. It also points to the influence of farm size and spatial dispersion of the farm plots as factors affecting farm risk.

Allen and Lueck (2002) report state (province)-level yield CVs for several crops produced in Louisiana, Nebraska, South Dakota, and British Columbia. A summary of these data is reported in Table 4.6.

Other studies that have estimated yield CVs include Nelson and Preckel (1989) who fit farm-level maize yield data for five Iowa counties to a beta distribution. The resulting CVs ranged between 0.11 and 0.27. Using farm-level yield data from Illinois, Sherrick *et al.* (2004) estimated maize CVs that averaged 0.17 and soybean CVs that averaged 0.14. Hart, Hayes, and Babcock (2006) modelled yield distributions for a representative farm in Webster County, Iowa. They assumed that yields were distributed as a beta and then solved for the distributional parameters that would generate actual federal crop insurance premium rates for 65% coverage. The estimated maize yield CV was 0.27 and the estimated soybean yield CV was 0.25.

As indicated earlier, yield risk measures are affected by aggregation bias so one should be cautious about making spatial comparisons. However, this sample of studies from North America does illustrate some important points. First, some crops have more yield risk than others. In North America, rice, cotton, and wheat are generally considered riskier than sorghum and soybeans. Second, some production practices reduce yield risk. Table 4.6 demonstrates that for a given crop irrigated production typically has lower yield risk than dryland production. Third, some regions have more yield risk than others. For example, Table 4.6 shows that wheat production in Nebraska is less risky than wheat production in British Columbia, Louisiana, or South Dakota.

Table 4.6. Comparison of yield risk across regions

Author(s)	Commodity	Location	Years	Level of aggregation	Data manipulation	CV
Allen and Lueck (2002)	Sorghum (all)	Louisiana	1975-1991	State	None reported	0.06
Allen and Lueck (2002)	Sugarcane	Louisiana	1975-1991	State	None reported	0.10
Allen and Lueck (2002)	Soybeans (all)	Louisiana	1975-1991	State	None reported	0.12
Allen and Lueck (2002)	Hay	Louisiana	1975-1991	State	None reported	0.12
Allen and Lueck (2002)	Cotton	Louisiana	1975-1991	State	None reported.	0.20
Allen and Lueck (2002)	Wheat	Louisiana	1975-1991	State	None reported.	0.21
Allen and Lueck (2002)	Rice	Louisiana	1975-1991	State	None reported	0.28
Allen and Lueck (2002)	Maize (all)	Louisiana	1975-1991	State	None reported	0.29
Allen and Lueck (2002)	Sorghum (irrigated)	Nebraska	1975-1991	State	None reported	0.08
Allen and Lueck (2002)	Sorghum (dryland)	Nebraska	1975-1991	State	None reported	0.15
Allen and Lueck (2002)	Soybeans (irrigated)	Nebraska	1975-1991	State	None reported	0.09
Allen and Lueck (2002)	Soybeans (dryland)	Nebraska	1975-1991	State	None reported	0.17
Allen and Lueck (2002)	Wheat	Nebraska	1975-1991	State	None reported	0.11
Allen and Lueck (2002)	Maize (irrigated)	Nebraska	1975-1991	State	None reported	0.11
Allen and Lueck (2002)	Maize (dryland)	Nebraska	1975-1991	State	None reported	0.24
Allen and Lueck (2002)	Oats	Nebraska	1975-1991	State	None reported	0.16
Allen and Lueck (2002)	Sorghum (all)	South Dakota	1975-1991	State	None reported	0.20
Allen and Lueck (2002)	Soybeans (all)	South Dakota	1975-1991	State	None reported	0.14

Table 4.6. Comparison of yield risk across regions (*cont.*)

Author(s)	Commodity	Location	Years	Level of aggregation	Data manipulation	CV
Allen and Lueck (2002)	Wheat	South Dakota	1975-1991	State	None reported	0.25
Allen and Lueck (2002)	Maize (irrigated)	South Dakota	1975-1991	State	None reported.	0.02
Allen and Lueck (2002)	Maize (dryland)	South Dakota	1975-1991	State	None reported.	0.14
Allen and Lueck (2002)	Oats	South Dakota	1975-1991	State	None reported	0.19
Allen and Lueck (2002)	Hay	British Columbia	1980-1991	Province	None reported	0.15
Allen and Lueck (2002)	Barley	British Columbia	1980-1991	Province	None reported	0.22
Allen and Lueck (2002)	Wheat	British Columbia	1980-1991	Province	None reported	0.18
Allen and Lueck (2002)	Maize (all)	British Columbia	1980-1991	Province	None reported	0.27
Allen and Lueck (2002)	Oats	British Columbia	1980-1991	Province	None reported	0.21
Allen and Lueck (2002)	Apples	British Columbia	1980-1991	Province	None reported	0.18
Allen and Lueck (2002)	Canola	British Columbia	1980-1991	Province	None reported	0.25
Nelson and Preckel (1989)	Maize	Iowa	1961-1970	Farm	CV based on historical data fit to a beta distribution	0.11-0.27
Sherrick *et al.* (2004)	Maize	Illinois	1972-1999	Farm	Detrended, reported CV is average of farm-level CVs	0.17
Sherrick *et al.* (2004)	Soybeans	Illinois	1972-1999	Farm	Detrended, reported CV is average of farm-level CVs	0.14
Hart, Hayes, and Babcock (2006)	Maize	Iowa	NA	Farm	CV based on a beta distribution with parameters that would generate the U.S. crop insurance premium rate for the farm	0.27
Hart, Hayes, and Babcock (2006)	Soybeans	Iowa	NA	Farm	CV based on a beta distribution with parameters that would generate the U.S. crop insurance premium rate for the farm	0.25

Summary of crop production risk

Due to heterogeneity across species and locations, it is extremely difficult to draw general conclusions about crop yield risks. There is increasing evidence that crop yield distributions are generally left-skewed though there are almost certainly some species and locations that would be exceptions (Harri *et al.*). Meaningful comparisons of yield risk magnitudes must account for aggregation bias. However, even if one can control for aggregation bias it is difficult to make general conclusions about which crops and locations are more or less risky. One crop may be more risky than another crop in one location while the opposite may be true in a different location. One location may be more risky than another location for a specific crop but the opposite may be true for a different crop. Common causes of yield risk include drought, excess moisture, disease, pests, hail, freeze, and flooding (USDA, RMA). Production inputs (irrigation, pesticides, improved seeds, etc.) and associated management strategies can reduce the magnitude of yield risk caused by some (but not all) perils.

Livestock production risk

Throughout much of the world, livestock production losses are far less common than crop production losses. In many OECD countries, swine, chickens (both broilers and layers), turkeys, and dairy cattle are kept in either total or partial confinement facilities. This greatly reduces their exposure to weather-related perils, predators, and at least some diseases. Beef cattle are still largely kept in either fenced fields where they graze on improved pastures or (in the western U.S.) open range lands. Thus, beef cattle are more susceptible to death loss caused by extreme weather events. They are also more susceptible to reduced weight gain due to the effects of extreme weather events on the quantity and quality of grass and forage production. For livestock, disease risk often poses the threat of infrequent but severe losses (Gramig *et al.* 2006; Shaik *et al.* 2006). Further, farmers are often required to destroy diseased and healthy animals to avoid spread of infectious disease. Often government compensation is offered, but for a variety of reasons this indemnification is often imperfect (Ott, 2006). The effect of confinement appears to have a mixed effect on risk exposure. Animals are in close proximity to each other which can intensive the spread of disease. However, confinement can also allow greater bio-security which reduces the spread across farms. Confinement also results in more intensive management which is likely to improve disease management. The relative effect of confinement on risk ultimately is somewhat conditioned on the means by which the disease is spread. For example, some diseases can be spread by unsanitary equipment. Others require animal contact. This may take the form of within-species or cross-species transmission

Off-farm income and investments

Off-farm labour income and investment (savings or borrowing) are quite common among farm families in OECD countries. This is in contrast to many developing countries where liquid financial markets are often lacking. Note however, that much of the literature that is available on the issue of off-farm labour and correlation with farm revenue is focused on subsistence agriculture not located in OECD countries. Conceptually, a risk neutral farm family might hold off-farm investments or provide off-farm labour due to an allocation of resources to the highest rate of return. For example, some family member may earn a greater return in off-farm labour than from on-farm activities. Likewise, savings and borrowing may be maintained for purposes of liquidity and convenience, but clearly they also have the effect of smoothing consumption across time thus helping farm families to manage their risk exposure. While this report is primarily directed at quantifying the risk environment of farm firms, we note that inter-temporal consumption smoothing is possible and therefore studies focused solely on static risk measures will tend to overestimate risk and the benefit of risk management strategies.

Off-farm labour

The incentives and opportunities for farm households to engage in off-farm labour are diverse. Several authors have addressed the risk mitigating effect of off-farm income and investments. Fundamentally, off-farm labour represents a diversification of the financial portfolio into a revenue stream with low variability and that has a low correlation with farm income. Conceptually, the labour devoted to off-farm work could have been devoted to the farm production activities.

In a study of Dutch farms, Woldehanna, Lansink, and Peerlings (2000) found that expected short-run farm profit and on-farm labour supplied by a household head have a strong negative impact on the off-farm work decision of a household. Whereas, non-labour income, on-farm labour supplied by other family members and agricultural education do not show any significant impact on the off-farm work decision. However, family size and general education show a positive effect on the desire of households to participate in off-farm work. They go on to conclude that government subsidies aimed at increasing household's income through price policies may have a negative impact on the off-farm employment of farm households. Whereas, direct income support such as the Agenda 2000 CAP reforms are most likely to increase off-farm employment of farm households in the Netherlands. Mishra and Goodwin (1997) studied Kansas farmers and reached a similar conclusion that if farmers are risk averse, then greater farm income variability should increase their willingness to work off-farm.

Using panel data from Israel, Ahituv (2006) was able to examine the evolution of farms over time. This analysis suggests that some family farms tend to expand over time and specialize in farming, whereas other farm households downsize their farming operation and increase their engagement in the off-farm labour market. Therefore, the size distribution of farms was converging towards a bimodal distribution.

El-Osta, Mishra, and Morehart (2008) examined data from the U.S. 2004 Agricultural Resource Management Survey. They found expected government payments decreased the likelihood of off-farm work strategies involving work by the husband only or by both husband and wife relative to a strategy of no work by either husband or wife.

Key, Roberts, and O’Donahue (2006) use data resulting from a large increase in U.S. Federal crop insurance subsidies as a natural experiment to identify the importance of risk for farm operator labour supply. Subsidy increases induced greater crop insurance coverage, which in turn reduced farmers’ financial risks. It was found that greater insurance coverage reduced the off-farm labour supply of operators who produced at least USD 100 000 of output and increased the labour supply of small-farm operators who produced less than USD 25 000 of output.

Lien *et al.* (2006) also noted the distinction of full and part-time farmers in a study of Norwegian famers. He concludes that “full-time and part-time farmers’ goals, risk perceptions, and risk management strategies differ significantly. Further, compared to full-time farmers, part-time farmers plan more frequently to downsize their farm operations, which may be a necessity to cope with multiple job situations.”

Serra, Goodwin and Featherstone (2005) studied Kansas farm records and show a clear result that higher household wealth reduces the likelihood that the household seeks a job off the farm. They suggest that wealthier farms are less risk averse than poorer ones, which may reduce their incentive to seek a more stable source of income than farming. Alternatively, wealth may be a source of household non-work income reducing the motivation for working off the farm. They go on to examine the net effect of the 1996 FAIR Act on off-farm labour and conclude that it was minimal.

Mishra and Godwin (1997) use U.S. farm-level data from Kansas to evaluate the willingness of farm families to work off-farm. A major conclusion is that there is a positive relationship between off-farm labour supply and farm income variability. *Ceterus paribus*, this suggests riskier farms choose to work more in off-farm employment. Their results also suggest farms with higher debt to asset ratios work off-farm more hours.

Mishra and Sandettro (2002) evaluated national-level U.S. farm and non-farm income for a long time-period (1933-1999). They show several periods of sharp year-to-year changes and then periods of greater stability. Their analysis of the relationship between farm and non-farm income suggests that non-farm income has become a greater proportion of family income over time. In a breakdown by farm type, dairy farms, poultry and vegetable producer tend to use off-farm income less than row crop producer. Again using aggregate data, the covariance between farm and off-farm income is estimated and found to take a negative sign if estimate across the 1960-1999 period or the more recent periods. This is suggestive of the risk reduction created by off-farm income.

In a study of Dutch farms, Woldehanna, Lansink, and Peerlings (2000) found that expected short-run farm profit and on-farm labour supplied by a household head have a strong negative impact on the off-farm work decision of a household.

Off-farm investment

Barry and Baker (1984) provided a lucid description of the ways a farm can use debt and savings as a means to manage risk. Farms using credit and other fixed-obligation financing can concentrate the firm’s equity in agricultural production assets and thereby increase agricultural risk exposure. Varangis, Larson, and Anderson (2002) note that increasing financial leverage magnifies the impact for the owner of variability in firm returns. It follows that if the return on total assets is above the borrowing rate, wealth will increase. If rate of return is less than the borrowing rate this can ultimately lead to bankruptcy.

Savings for the farm firm are typical described as financial assets held in a financial investment that earns a rate of return and is typically fairly liquid. As such it can potentially be risk reducing by diversifying the firm’s portfolio into assets outside of agriculture. Further many financial investments such as savings, treasury bonds have low levels of return variability which augments the risk-reduction effect.

Nartea and Webster (2008) note that investment in other industries is also possible and can likewise have a risk reducing effect for the farm family. They find low correlations between rates of return on farm and financial assets available in New Zealand which suggests that significant reduction of income variability might follow their inclusion in farmers’ portfolios. They conclude farmers showing high degrees of risk aversion would gain utility by including financial assets in their portfolios. Specifically they examine financial investments such as ordinary industrial shares, government bonds and bank bills. They find a low correlation between rates of return on farm assets and these financial assets. This suggests that significant reduction of income variability might follow their inclusion in farmers’ portfolios. Bonds rather than ordinary shares are the main contributors to portfolios which maximize utility for individuals classified as ‘somewhat’ risk averse.

Painter (2000) concluded that investments in farmland are negatively correlated with returns with other equity markets. Thus, when added to an equity portfolio, the risk is reduced while maintaining the same rate of return on investment. However, Painter also notes that farmland investment have potential problems including illiquidity, poor marketability and asset lumpiness.

Langemeier and Patrick (1990) used panel data for Illinois grain farms to investigate the marginal propensity to consume which measures the inter-temporal consumption smoothing of the farm. Their results indicate farm family consumption responded little to changes in income. In a related study Carriker *et al.* (1993) use Kansas data to estimate the marginal propensity to consume from different sources of income and found the propensity to consume from off-farm income and government payments were significantly greater than the propensity to consume from farm income.

In a more recent study, Sand (2002) investigated the traditionally low marginal propensity to consume (MPC) observed in farms. In a panel of Norwegian farm households, Sand found a similar result to Carriker *et al.* (1993), that the marginal propensity to consume from farm income is lower than for off-farm income and that average MPC is low but increasing over time in these households.

Summary of off-farm labour and investment

A review of the existing literature on off-farm labour and investment by agricultural producers suggests that either off-farm labour or investment can provide an effective risk mitigation strategy. Incentives to work off the farm appear related to the opportunity cost of the individual's time and the availability of off-farm opportunities. Interestingly, the literature suggests that off-farm labour and government support for producers tend to be substitute risk mitigation alternatives. The literature does not reveal significant differences in behaviour or risk effects across regions or over time. Among the factors affecting the correlation between farm and off-farm income is whether the off-farm source of income is itself related to agricultural production. For example, working at the local grain elevator may not diversify the family income and consumption as much as working as a school teacher because earnings at the grain elevator are more positively correlated with farm income. Estimates of the correlation between farm and off-farm income are generally not available in the literature. This is likely due to the many potential sources of off-farm income and the long time-series of data that would be required to make meaningful estimates. Freshwater and Jetté-Nantel (2008) attempt to address this fundamental weakness in the literature. However, it appears that their analysis also lacks a sufficiently long time series of farm-level data from which to estimate these correlations.

Off-farm investment is financial assets also provides an effective diversification strategy for farm families in much the same way off-farm labour does. However, the investment in financial investments is often readily available even when off-farm labour opportunities are limited. As with off-farm income, an important aspect of off-farm investments is the degree of correlation between the off-farm investment and on-farm investments. For example, investment in a local agri-business firm that is tied to the commodity produced on the farm will likely diversify the family income much less than an investment in a non-agriculturally related investment. Again there is a dearth of appropriate data available.

Correlation of uncertain variables

The co-movements of random variable potentially has a profound effect on the variability of an aggregate summation or product of random variables. At the farm-level, this may be seen when prices and yield for a crop are correlated with each other and revenue is the product of price times yield. Similarly as one sums the revenue from multiple enterprises; the correlation of these revenue streams impacts the whole farm revenue. For example, a mixed crop and livestock farm may gain a substantial risk benefit if net revenue from the crops and livestock are independent of each other or even negatively correlated.

Price-price correlations

Crops

The correlation of crop prices is conceptually driven by market forces and the end use of the crop. For example, grains that are close substitutes tend to have prices the move together, while the prices of a fibre crop like cotton tend to be weekly correlated with feed and food use crops. Trade also profoundly affects the co-movement of commodity prices. A highly localized market will, *ceteris paribus*, have prices that are less correlated with prices in other geographical regions. This may arise naturally due to factors such as perishable nature of the commodity or transportation cost. It may also arise due to protectionist government policy which insulates producers from world market price signals. Table 4.7 shows some results for U.S. price correlations from the model described in Coble and Dismukes (2008). Based on price and yield shocks from 1975 through 2005 the prices simulated in a large sample are all positively correlated. However, the correlation of cotton to the other crops is typically much lower. Conversely, maize prices are highly correlated with soybeans and wheat.

Table 4.7. U.S. price — price correlations

Maize	Maize	Maize	Cotton	Soybean	Wheat
Soybean	Wheat	Cotton	Soybean	Wheat	Cotton
0.719	0.701	0.232	0.514	0.581	0.048

Source: Authors calculations from Coble-Dismukes (2008) model.

Livestock

The relationship of livestock prices can be largely conceptualized through the demand relationships of substitute goods. Thus, beef, pork, and poultry price co-movements are driven by this relationship. Substitutes ultimately tend to have prices that move together as the prices of one meat group “pulls” the price of others. Likewise animal agricultural tends to depend on common feedstuffs — grains and crop protein such as soybeans. Thus production costs for these commodities are also tied together as feed prices do not vary dramatically across species. As with crops, the relationship between livestock prices can also be influenced by international trade policy.

Yield-yield correlations

Crops

Crop yield correlations at the farm level tend to be driven by the degree to which the crops are susceptible to common perils due to similarity in planting season or degree of drought tolerance. Table 4.8 illustrates this point by averaging farm-level correlations produced by the Coble-Dismukes (2008) model for select U.S. states. This model uses empirical correlations between price and county yield which is then adjusted to the farm level by following the procedure of Miranda (1991). The results show that, in many states, maize and soybean yields demonstrate a strongly positive correlation. These crops are often grown on the same farm and are subject to many of the same production risks. In contrast, wheat is never observed to have a correlation greater than 0.351 with another crop. This is likely caused by the predominance of winter wheat in U.S. production which results in differing growing seasons and causes of loss.

Table 4.8. Average farm level yield correlation for selected U.S. states

State	Maize soybean	Maize wheat	Maize cotton	Cotton soybean	Soybean wheat	Wheat cotton
Georgia	0.711	N.A.	0.374	N.A.	N.A.	0.245
Illinois	0.684	0.142	N.A.	N.A.	0.003	N.A.
Iowa	0.642	N.A.	N.A.	N.A.	N.A.	N.A.
Kansas	0.581	0.044	N.A.	N.A.	-0.102	N.A.
Mississippi	0.507	N.A.	-0.050	0.511	N.A.	N.A.
North Carolina	0.475	-0.082	0.445	0.613	0.236	0.180
North Dakota	0.857	0.351	N.A.	N.A.	0.279	N.A.
Ohio	0.758	0.328	N.A.	N.A.	0.279	N.A.
Texas	0.559	0.043	0.353	0.727	N.A.	0.244

Source: Authors calculations from Coble-Dismukes (2008) model.

Livestock

Our search of the literature revealed no studies reporting yield-yield correlations among livestock enterprises. Clearly a lack of scientific attention has been directed in this area. We presume this is due to several factors. First livestock production is increasing in confinement operations which rarely mix species. Secondly, livestock production is often complimentary with crop agriculture and found integrated with crops rather than other livestock on most commercial farms. Finally, crop agriculture is much more likely to measure yield variability than livestock. Livestock disease risk is likely a severe but infrequent loss which may not be well described with a standard deviation nor is a correlation likely to reveal much when losses are infrequent unless one has a time-series longer than typically observed.

Price-yield correlations

Crops

Price-yield correlations at the farm level appear to best be conceptualized as an indirect relationship rather than a causal relationship. Theory clearly suggests a negative correlation between aggregate supply and price. However, agricultural is typically characterized by many small producers whose output decisions will have no effect on aggregate price. This would seem to suggest statistical independence of producer yields and price received. This is, however, contradicted by empirical evidence of negative correlation (Coble, Heifner, and Zuniga, 2000). This can be reconciled if one examines the correlation of a farm's yield with aggregate yield. Geographically or politically isolated markets are likely to exhibit higher correlations between individual farm yields and aggregate supply. However, even in open markets, some crop producing regions tend to dominate. Since some weather events such as droughts or excessive moisture are spatially correlated, producers outside of major production regions are less likely to observe negative price-yield correlation. Conversely, producers in the heart of a major production region are more likely to experience weather or other production shocks that are spatially correlated across a significant number of producers and in aggregate cause a price response. For example, a study by Blank, Carter and MacDonald evaluates several specialty crops grown in California. While most were observed with negative covariances almonds and oranges are found to have the most negative price-yield covariance of the crops studied.

Hazell (p.100) summarized the implication of price yield correlation on agricultural producers as follows:

> *If prices and yields are negatively correlated, the unit revenue forecast will be less than the average price. In this case, rational farmers will produce less of the commodity than calculations based on average prices would suggest, a point often overlooked by many economists and policymakers. The opposite will happen when the correlation is positive. Farmers should produce more of the commodity than calculations based on average prices would suggest. Note that these supply effects will arise even if farmers are risk-neutral. The correlation effect will be amplified if farmers are also risk-averse. Using time series data from a wide range of countries, Scandizzo, Hazell, and Anderson (1984) provide some evidence that farmers in industrialized Western economies do take account of price and yield correlations but that farmers in developing countries and in the centrally planned economies do not.*

Xing and Pietola (2005) investigated optimal forward hedging by Finnish spring wheat farmers and observed a price-yield correlation of -0.36. Bielza and Sumpsi (2007) report a range of price-yield correlations between -0.023 and -0.548 in Spanish olive oil production. Fleege, Richards, Manfredo, and Sanders (2004) examined the use of weather derivatives in western U.S. specialty crops. They reported Pearson correlation coefficient estimates between price and yield of -0.70 for nectarines, -0.032 for raisin grapes, and -0.39 for almonds. Weisensel and Schoney (1989) found no correlation between wheat yields and prices in Saskatchewan, Canada, but lentil yields and prices are inversely correlated with a correlation coefficient of -0.30. Hart, Hayes, and Babcock report a price-yield correlation for maize of -0.51 and -0.12 for soybeans for an Iowa farm.

A summary of price-yield correlation for various studies is reported in Table 4.9. The strongest negative correlations tend to occur in major production regions such as the central U.S. and for more localized markets such as for some specialty crops. Many major commodities with widely dispersed production tend to have correlations near zero.

Table 4.9. Summary of price-yield correlations estimate from various studies

Study	Level	Years	Location	Maize	Soybeans	Cotton	Wheat	Other
Bielza and Sumpsi (2007)	Farm level	1991-1998	Spain olive oil					-0.023 to -0.548
Coble and Dismukes (2008)	Simulated farm	1975-2004	U.S.					
			GA	-0.018	0.111	0.013	0.067	
			IL	-0.500	-0.461	.	-0.043	
			IA	-0.407	-0.394	.	.	
			KS	-0.280	-0.358	.	-0.279	
			MN	-0.296	-0.271	.	-0.367	
			MS	-0.036	-0.110	-0.155	.	
			NC	-0.091	-0.338	-0.302	0.207	
			ND	-0.223	-0.337	.	-0.428	
			OH	-0.400	-0.397	.	-0.147	
			PA	-0.435	.	.	0.314	
			TX	0.048	0.161	-0.096	-0.336	

Table 4.9. Summary of price-yield correlations estimate from various studies (*cont.*)

Study	Level	Years	Location	Maize	Soybeans	Cotton	Wheat	Other
Hart, Hayes, and Babcock (2006)	Simulated farm	1980-2001	U.S. Iowa	-0.51	-0.12			
Fleege, Richards, Manfredo, and Sanders (2004)	Farm level	1980-2001	U.S. Specialty Crops					-0.70
			Nectarines					-0.032
			Raisin Grapes					-0.39
			Almonds					
Weisensel and Schoney (1989)	Farm-level	1970-1980	Canada					
			Wheat				0.0	
			Lentils					-0.30
	Farm-level	1995-2001	Finland					
Xing and Pietola (2005)			Spring Wheat				-0.36	

Livestock

As suggested earlier, modern confinement production systems for poultry, hogs, and dairy have greatly reduced production risk. Production systems that are forage-based remain more exposed to weather uncertainty. Price variation is then less subject to production shocks, but remains subject to aggregate demand shifts such as consumer food safety scares and to trade shocks. Thus, price-yield correlations in such an environment have not received much attention in the literature.

Farm-nonfarm income

We found several studies regarding the incentives for off-farm labour by farm households. However, these studies tend to not report a correlation with on-farm sources of income. Intuitively, off-farm income is presumed to be relatively stable and largely uncorrelated with on-farm income.

Ability of the farm to adjust to risk

That farmers do not adjust their quasi-fixed input as market conditions change is a long-standing issue in agricultural economics literature. Johnson (1956) is often credited with conceptualizing this issue. Given that agriculture tends to increasingly involve major capital investments (land and machinery) this issue remains. While numerous studies (Vasavada and Chambers, 1986; Howard and Shumway, 1988; Nelson, Braden and Roh, 1989) find evidence of asset fixity, the relationship to risk management is somewhat more tenuous. For example, Boetel, Hoffmann and Liu (2007) find evidence of asset fixity in the U.S. pork industry. Foster and Rausser (1991) point out the implication of farm failure to the fixity problem and Robison and Brake (1979) consider the problem in a portfolio theory framework. Chavas (1994) connects this literature to the real option valuation literature. Finally, the most recent work in this area by Musshoff and Hirschauer (2008) concludes that asset fixity has slowed the adoption of organic production in Germany and Austria.

Comparison of agricultural risk to other industries

Our investigation found little literature addressing the riskiness of farm versus non-farm firms. Goodwin examined bankruptcy rates and concluded that farm firms are less likely to fall into bankruptcy than non-farm firms. Presumably government subsidies are one reason for this. An earlier study by Shepherd and Collins (1982) suggested some correlation between farm and non-farm bankruptcy. They estimated that a 1% increase in the nonfarm bankruptcy rate was associated with a 0.44% increase in the farm bankruptcy rate over the1946-78 period. Stam and Dixon (2004) support this by showing farm bankruptcies have often occurred during periods of general economic downturns affecting many sectors of the economy.

Overall assessment of major factors affecting farm income risk

Importance of quantity and price risk in agriculture

Our evaluation of the literature leads to the conclusion that in crop agriculture, output price and yield risk are the major factors driving the farm firm's risk exposure. The attention devoted to price and yield risk in the literature suggests this as well as surveys asking producers to rate or rank the risks they face. We also take the efforts to develop crop insurance and futures markets as *prima facie* evidence that price and yield risk are major concerns for crop producers (although we will admit crop insurance has been highly subsidized and yet has low participation in many countries). Much less attention has been devoted to input price risk. Our assessment of fertilizer and fuel prices suggests the magnitude of fertilizer price risk is similar to the coefficient of variation for most prices and yields. However, diesel fuel price CVs appears relatively high. Interestingly, this seems contrary to perceptions and the amount of research attention devoted to input prices. We suspect that this can be interpreted as resulting from a couple of factors. First, fuel and fertilizer are among many inputs and the volatility of production cost is dampened relative to output and output price risk for crop producers. In many cases fuel or fertilizer prices may only be fractionally transmitted to net returns variability depending on the cost share of those inputs. Second, in many cases the window of input price risk is relatively short as compared to price and yield risk. Often, the majority of fertilizer and fuel costs are incurred within a few months of the onset of production. Conversely, yield and price risk is often not resolved for 6-7 months in crops and sometimes longer in livestock production. Thus, there is more time for prices to evolve away from expectations.

Implications of correlations

Recent literature has focused increasing attention on price-yield correlation and in many studies negative correlation is found in major production regions or in more localized markets. This tends to dampen revenue risk, but it also complicates risk management as price and yield risk tend to be more amenable to differing risk management tools. However, in many locations and agricultural commodities price and yield independence appears in the historical data.

To a great extent yield and price risk have been mitigated by differing risk tools (Coble, Heifner and Zuniga, 2000). For example, government programs have typically provided multiple–peril yield insurance and private firms offer some single peril (*e.g.* hail and frost) yield protection. In yields there is a least some degree of independence of losses which is essential for functioning insurance markets. Many separate government programs have provided output price support either directly or indirectly. Further futures markets are well suited to provide price risk protection due to the high degree of spatially correlation. To producers confronted with correlated prices and yields, revenue protection often appears efficient due to the cases where separate price and yield protection fail to protect against some low revenue scenarios. However, we are unaware of any significant private efforts to provide revenue risk management tools.

Positive correlations between the prices of similar crops and between yields on the same farm tend to profoundly affect the revenue variability of a farm. Combining enterprises with less positively correlated prices and or yields will provide greater risk reduction through diversification. For example, combining crops and livestock has been a longstanding risk mitigation strategy (Hart, Babcock, and Hayes, 2006). However, it appears that movement to larger and vertically integrated livestock production systems for the sake of cost efficiency has reduced the opportunity for many farms to diversify in that manner. However, agricultural producer still have the opportunity to diversify into non-agricultural investments and off-farm labour markets. These strategies continue to appear feasible and widely used.

Recent developments in agricultural risk

Looming issues that appear to have the potential to alter the risk context for farmers are varied. However, the current concern about climate change has already sparked a surprising number of studies which are, however, somewhat inconclusive with regard to the impact on production risk. Biotechnology appears to increase mean yields and several studies suggest this technology is risk decreasing. However, this is difficult to assess as adoption and technological advances are occurring so rapidly we do not have long time series of data to assess the issue in locations such as the U.S. where adoption has occurred rapidly over the past decade. This is confounded by the rapid development of second and third-generations biotech crops. Most public yield trials are for only a few years and do not provide sufficient yield series for yield risk comparisons or examination of susceptibility or resistance to disease. A significant literature has arisen examining the consumer acceptance of these crops, suggesting consumers in many countries view biotechnology enhanced crops less favourably than U.S. consumers (Lusk *et al.2004*), but information on environmental risk appears limited.

Livestock production risk tends to differ from crop production risk. Increased using of confinement production systems appears to have reduced production risk in livestock agriculture dramatically. We do note that many producers are still using less intensive production system such as in grazed beef production which remains subject to significant weather risk. It appears that output price risk remains the major concern of livestock producers. With low probability, but catastrophic implications, disease epidemics are also a major risk factor. Increasingly these events may not only affect output, but also cause catastrophic demand shifts. Finally in many livestock systems, the output price risk of crop agriculture translates into an input price risk for the livestock sector.

Cause of variability in agriculture

Major underlying cause of risk

Crop production

Crop yield risk is caused by many natural factors. While major causes of yield loss vary by species, some are common across many crop species. Among these are drought, excess moisture, disease, pests, hail, freeze, and flooding. In general, weather risk also varies by geographical region as weather patterns differ. For many crops there are areas with near ideal weather and then other production regions where economic incentives (including government programs) induce production at the extensive margin for the crop.

Weather

Weather is generally perceived as the source of much of the crop yield risk in crop agriculture. The literature investigating the most relevant sources of weather risk has increased dramatically in recent years as many have investigated various forms of weather derivatives. Because a weather derivative needs to be highly correlated with yield loss to be an effective risk management tool these studies have tended to sift through the various weather risk to identify the most important. For example, Salk *et al.* (2007) report that 20 to 30% of French GDP is affected by weather risk. They also report that French wine growers identify frost and hail as the most serious weather concerns.

Cafiero *et al.* (2007a) find that temperatures (minimum, mean and maximum, humidity and rainfall explain more than 86% of the variation of grape and wheat yield in the Tuscany region of Italy. Richards, Manfredo, and Sanders (2004), Turvey (2001), and van Asseldonk and Oude Lansink (2003) all focus on temperature risk. Other papers, such as Martin, Barnett, and Coble (2001) focused on rainfall as a source of weather risk in U.S. cotton. Musshoff, Odening, and Xu (2006) focus on precipitation risk in German agriculture as did Stoppa and Hess (2003) when investigating weather derivatives for Morocco and Breustedt, Bokusheva, and Heidelbach (2007) in Kazakhstan.

Other models such as that of Vedenov and Barnett (2004) for Southern and Midwestern regions of the United States, Xu, Odening, and Musshoff (2006) for Germany, and Tannura *et al.* (2008) for Illinois create indexes using both temperature and rainfall because tests of statistical significance show that those factors drive yield risk.

The U.S. federal crop insurance program reports the cause of loss for each indemnified insurance policy. Analyzing these data over a long period of time (1980-2001) reveals the primary causes of yield risk for major U.S. crops. Drought, excess moisture, and hail are the primary causes of yield risk for the major field crops: maize, cotton, soybeans, and wheat. Excessive moisture and freeze are the primary sources of yield risk for sugar beets. Excessive moisture, excessive heat, drought, and freeze are the primary sources of yield risk for potatoes. Drought, excess moisture, freeze, hurricanes, and excessive heat are important causes of yield risk for tomatoes and other vegetables. Freeze is the primary source of yield risk for citrus fruit. For other tree and vine fruit such as apples, grapes, pears, peaches, nectarines, and cherries, the primary sources of yield risk are frost, freeze, hail, and excessive moisture.

Production inputs and associated management strategies can be utilized to mitigate many of these sources of yield risk. Irrigation can reduce the impact of drought. For some crops, tiling fields can reduce the impact of excess moisture. Disease and pests can often be controlled somewhat by fungicide and pesticide applications. Genetically modified crops reduce the yield risk associated with certain insect pests. Some genetically modified crops target pests that feed on the roots of the plant. The result is a stronger and more developed root system that makes the plant more drought-tolerant. Effective mitigation strategies are less common for other perils (*e.g.* hail).

Other disasters and disease

Oerke and Dehne (2004) report estimates of crop losses for wheat, rice, maize, barley, potatoes, soybeans, sugar beet and cotton for the period 1996–1998 on a regional basis for 17 regions. Actual crop losses are estimated at 26–30% for sugar beet, barley, soybean, wheat and cotton, and 35%, 39% and 40% for maize, potatoes and rice, respectively. They also report weeds had the highest loss potential (32%) but also have a relatively high mitigation efficacy. Animal pests and pathogens are less important (18% and 15%, respectively). Finally, they report that although viruses cause serious problems in potatoes and sugar beets in some areas, worldwide losses due to viruses averaged 6-7% on these crops and less than 1-3% in other crops.

Crop prices

Supply shocks in crop input markets

The relatively small amount of research examining price shocks in input markets has focused almost exclusively on fuel and fertilizer prices. Evidence is provided above on the magnitude of the price variability of these inputs. That these two inputs are deemed significant risks is in part due to the fact that both tend to be relatively large components of input cost and that both fuel and many major fertilizer components are commodities themselves and subject to similar market forces as are crop output prices. Furthermore, there is a strong link between nitrogen fertilizer prices and fuel prices indirectly due to ammonia-based nitrogen often being produced from natural gas which also moves with crude oil prices. Groover (2005) reports a correlation of 0.79 between natural gas and nitrogen fertilizer prices.

Fuel costs have received significant attention of late due to increases in gas and diesel prices. Intuitively, these input prices are not commodity specific and may easily impact all enterprises on the farm simultaneously. Further, because OECD countries often import significant portions of their fuel needs, shocks in exchange rates and world agricultural and more importantly non-agricultural demand for fuel may cause fluctuations in the cost of agricultural fuels.

Demand shocks in crop output markets

Price risk for a particular commodity and region is caused by various factors. Deaton and Laroque (1992) provide a seminal discussion of the functioning of storable commodity markets with rational expectations. Earlier models had typically assumed a backward looking cobweb or distributed lag forms. In such markets, storage is an endogenous choice which is fundamental to the price variability of many agricultural commodities.

Goodwin and Sheffrin (1982) provide an early test of the rational expectations hypothesis in an agricultural market, concluding that a model of producer behaviour incorporating rational expectations outperforms models based on adaptive expectations. Shonkwiler and Maddala (1985) develop a detailed model for incorporating rational expectations into the estimation of supply and demand systems in the presence of specific commodity price supports for the U.S. maize market. Holt and Johnson (1989) also provide support for the rational expectation models. These findings are relevant to risk analysis as they imply subjective probability distributions of price and yield determine market equilibriums.

In these models, supply is typically composed of known inventories and expected production while demand is often decomposed into various demand sources. For example, grain market demand can be decomposed into feed, food, ethanol, and export use. Conceptually, these markets may have differing elasticities and bring separate price shocks to the market. For many crop markets models have identified the following major demand components:

- Export demand may be affected by yield shortfalls in other supplying countries or by demand shifts resulting from foreign market demand or policy shock.
- Feed and food use has been shown to depend on the market for livestock while food use may be shocked by sudden changes in consumer preferences. In many cases food safety scares create negative demand shocks in these markets.

- In some markets such as maize, bio-fuel production has created a new and dramatic component to demand.

Less storable crops, such as fruits and vegetables tend to function somewhat differently than major storable commodities. First, in many cases storability is less likely except in a processed form. This tends to accentuate price risk as temporal arbitrage is not possible [Henneberry *et al.* (1999) and You, Epperson, and Huang (1996)]. Fresh market crops tend to be higher valued then crops used in processing, but often both supply and demand may be quite seasonal. Fruits and vegetables also tend to be market segmented by variance in quality. A final distinction of non-commodity crops relative to commodity crops is that for non-commodity crops, markets are often geographically distinct which leads to less opportunity for geographical arbitrage which also would dampen price variability.

Livestock production

Hall *et al.* (2003) surveyed beef cattle producers in Texas and Nebraska regarding their perceptions of risk sources. Respondents were asked to rate sources of risk "in terms of their potential to affect your ranch/farm income" on a scale from one to five (with five being the highest). Severe drought (average score of 4.4) and cattle price variability (average score of 4.3) were reported to be the most significant sources of risk. The next cluster of scores (between 3.0 and 2.5) included in descending order of importance: variation in non-feed input prices; changes in government environmental programs; extremely cold weather; changes in government farm programs; hay price variability; and disease.

Hog producers in Indiana and Nebraska were surveyed about sources of risk by Patrick *et al.* (2007). In that study producers rated price risk highest on a five point scale. Following price risk were environmental and disease risk. However, independent producers (those whose production was not forward contracted to an integrator) were significantly more likely to rate disease risk higher than environmental risks. This study also highlights the differing risk environment of contract producers versus independent producers. The independent producers were significantly more concerned about input costs and market access than contracted producers.

Disease

It is interesting that survey respondents did not list disease as one of the most important sources of risk. However one must be careful in interpreting this finding. Animal diseases generally do not cause large-scale production losses in OECD countries, though governments sometimes order depopulation efforts to control highly contagious livestock diseases. Instead, the impact of livestock diseases is most often reflected in lower market prices (Shaik *et al.*, 2006). Following an outbreak of a highly contagious livestock disease, export demand often plummets as trading partners implement import restrictions to protect domestic herds. Depending on whether the disease can be transmitted to humans, domestic consumption may decrease significantly as well. As a result, all domestic producers are impacted by contagious disease outbreaks, not just those with infected animals. As an example, consider the December 2003 case of Bovine Spongiform Encephalopathy (BSE) in the United States. The disease was found in only one herd of cattle so production losses due to depopulation were miniscule. However the resulting fall in cattle prices cost U.S. cattle producers an estimated one-half billion dollars in lost market value in just the first quarter of 2004 (Gramig *et al.*, 2006). When such an event occurs, market losses will continue until producers are able to regain the confidence of trade partners and domestic consumers.

Unlike major crop perils such as drought, excessive moisture, or hail, diligent management can have a significant impact on animal disease risk. Particularly with confinement animal production, using best management sanitary practices can reduce the frequency and severity of many contagious livestock diseases. For this reason, Gramig *et al.* (2006) describe a country's disease-free status as a non-exclusive common property resource. All producers benefit from the disease-free status but maintaining the common property resource is highly dependent on the sanitary practices of individual livestock producers.

Weather risk

Confined animal operations appear to be subject to weather risk in a much different fashion that grazing agriculture. Confined dairy hog and poultry operations tend not to be subject to many risks such as drought in the same manner as grazing agriculture. However, extreme temperature and rainfall can create risks in these operations. For example, Deng *et al.* (2007) examined the effect of derivatives to mitigate the risk of milk production declines to due to high temperatures. For meat animals, growth rates decline in extreme cold or hot situations. Confinement facilities typically reduce these extremes, but at times will do so at significant cost such as required to cool poultry facilities.

In less intensive grazing agricultural, weather risk can result in significant reductions in available forage. In particular, drought can cause reduced rate of gain or in extreme cases require liquidation of herds (Stockton and Wilson, 2007). An analysis of Palmer Drought Severity Index (PDSI) values for the period from 1895 to 1995 indicates that most of the U.S. West experiences severe to extreme drought more than 10% of the time and a significant portion of the region more than 15% of the time. (Wilhite, 1997)

Livestock prices

Supply shocks in input markets

In the livestock sector, especially confinement feeding operations, feed ingredients represent a major portion of input cost. Thus, the output price risk observed in the grain crops is the primary input risk for the livestock producers. As discussed earlier a number of factors may influence the price of feed grains. These include fluctuation in export demand, yield shortfalls, and acreage shifts. Also, recent policy decision in several counties to produce bio-fuels has added to the demand for grain crops and thus driven up the price of feed used in the livestock sector. Similarly, shocks in fuel and fertilizer also affect livestock grazing profitability as was the case for crops.

Demand shocks in output markets

The output price risks of livestock markets reflect several characteristics similar to crop price risk. Foremost is the general lack of product distinction that leads beef, pork, sheep meat, and poultry products to behave as a commodity. However, a salient feature of many livestock production processes is that there are significant biological lags; and Rucker *et al.*, 1984). Further, Aradhyula and Holt (1990) as well as Chavas, Kliebenstein, and Crenshaw (1985) address modern confinement production which has not eliminated biological lags, but has created a dynamic flow of output. As with crops, trade shocks may arise through export markets and trade intervention.

Some of the most researched demand shocks are associated with health scares. We examine the results from several different events and countries. Lloyd *et al.* (2001) found that beef consumption temporarily fell forty percent in the U.K and some other European countries.

However, beef prices at the retail, wholesale and producer levels in the United Kingdom fell by 1.7, 2.25, and 3.0 pence respectively per kilogram in the long-run after the British government in 1996 announced a possible link between BSE and Creutzfeldt–Jacob disease. Burton and Young (1996), using a dynamic almost ideal demand system, found that BSE had significant negative impacts on British domestic beef demand. Leeming and Turner (2004) found a negative effect of the BSE crisis on beef price but a positive effect on lamb price in the United Kingdom.

As mentioned earlier, Gramig *et al.* (2006) found that the 2003 BSE discovery in the United States cost U.S. cattle producers nearly one-half billion dollars in lost value during the first quarter of 2004. Pritchet, Thilmany, and Johnson (2005) argue that the 2003 U.S. BSE discovery led to a 14% decrease in the choice boxed beef price and a 20% decrease in the fed cattle price between 22 December 2003 and 8 January 2004. Saghaian (2007) found that the same event caused a 6% reduction in retail prices, a 16% reduction in wholesale prices and a 21% reduction in feedlot prices. Schlenker and Villas-Boas (2006) found that futures prices on cattle and grocery store beef prices had comparable price decreases in response to the 2003 U.S. BSE event. Conversely, Piggot and Marsh (2004) find a minimal impact of food safety information on U.S. meat demand when one considers how quickly the effects dissipate. In another study examining hog and live cattle futures, Lusk and Schroeder (2002) find that beef and pork recalls tend to play out quickly.

Peterson and Chen (2005) find that following the BSE discovery in Japan in September 2001 there was a structural change in the Japanese meat market in September followed by a two-month transition. McCluskey *et al.* (2005) find that the consumption of domestic and imported beef in Japan drastically dropped by 70% in November 2001 two months after the Japanese BSE discovery.

In a recent study of Korean data, Park, Jin, and Bessler (2008) conclude that the 2000 domestic foot and mouth disease outbreak induced a structural change in the Korean meat price system. In contrast they find the domestic avian influenza and the U.S. BSE events in 2003 did not lead to any significant meat market structure. They go on to conclude that animal disease outbreaks caused temporary price shocks but the adverse impacts of the 2000 FMD outbreak dissipated and partly recovered over 6 months, and over the next 13 months for the AI/BSE incidents. However, a longer effect was seen in farm pork prices resulting from the 2000 FMD outbreak.

Niemie and Lehtonen (2008) is one of the most recent papers to examine the price risk associated with the outbreak of an epidemic disease. This study considered the case of Finnish pig producers. Results suggested that losses to pig producers can increase considerably when the risk of a prolonged export ban increases. Consumers can gain from a trade ban, because options to adjust supply in the short run are limited.

New concerns

Biotechnology

Agricultural crop yields for many crops have been increasing at a rapid rate. However the driving factors have varied. The causal factors have included hybrid seed for crops like maize, improved equipment, and new chemical herbicides to name a few. In recent years, significant attention has been directed toward how biotechnological change impacts the distribution of crop yields. While much of the research has focused on average yields, some literature has also addressed the implications for yield variability.

Kim and Chavas (2003) investigated the linkages between technological change and production risk, using data from Wisconsin maize experiment station plots. The empirical results indicate that technological progress contributes to reducing downside risk in maize production, although this effect varies across sites.

Carew and Smith (2006) examined Canadian canola yields using a Just-Pope production function. They observed yield heteroscedasticity in the data (*i.e.* increasing variability over time). They also found that hybrid and herbicide tolerant varieties experienced an increase in mean yield over time but did not have higher yield variability. In a similar study, Hurley, Mitchell and Rice (2004) examined Bt maize in the U.S. and found Bt maize can be marginally risk increasing or decreasing and can either increase or decrease maize acreage. Also, depending on the price, Bt maize can provide a risk benefit to farmers, even when Bt maize is risk increasing.

Crost and Shankar (2008) examine the adoption of Bt cotton in India and South Africa. Interestingly they note adoption bias in the data suggesting better farmers are earlier adopters of this technology. Controlling for this effect, they find Bt technology risk reducing in India but not in South Africa.

Snow *et al.* note the potential positive production effects of GMOs in developed and developing countries However, they also identify five primary environmental risks: (1) creating new or more vigorous pests and pathogens; (2) exacerbating the effects of existing pests through hybridization with related transgenic organisms; (3) harm to nontarget species, such as soil organisms, non-pest insects, birds, and other animals; (4) disruption of biotic communities, including agro-ecosystems; and (5) irreparable loss or changes in species diversity or genetic diversity within species.

Aslaksen, Natvig, and Nordal argue that GMOs demand new approaches to risk assessment, risk management and risk communication. In particular they advocate applying the precautionary principle to GMO risk. Moreover, they discuss Bayesian analysis in the context of improving the informational basis for decision-making under uncertainty. They argue that more myopic risk analysis may seriously mischaracterize the economic consequences of environmental uncertainties.

Clapp (2008) addresses the direct legal liability for producers that has arisen in a number of cases of “accidental” or “unintentional” releases of genetically modified organisms (GMOs) that were not approved for human consumption or for commercial planting. Clapp noted that the agricultural input industry has instituted Corporate Social Responsibility reporting and some are participants in the UN's Global Compact. However she goes on to argue that these measures have proven weak and that external, state-based regulation which places liability on firms is more likely to prevent illegal releases.

Climate change

The topic of climate change has attracted significant attention in a relatively short period of time. We found several studies addressing climate change but the lack of historical and experimental data has lead to an emphasis on the use of simulation and other modelling techniques.

The potential impact of climate change on crop production in the Netherlands using a whole farm portfolio analysis approach was examined by van Asseledonk and Langeveld (2007). Projected joint crop yield distributions were derived from crop growth models so that projected impacts of weather conditions could be compared with historic data. The results for a representative Dutch farm with potatoes, sugar beets and winter wheat show projected crop yields and ultimately farm income increased due to more favourable climate conditions, even when the risk of poor performance of a particular crop due to extreme weather conditions increases. Increased risk of crop failure and income loss due to climate change was not confirmed. The authors suggest this is, in part, due to the fact that poor yields often have positive effects on farm income due to increased crop prices in times of relative commodity shortages.

Quiggin and Horowitz (2003) argue that the costs of climate change are primarily adjustment costs. They conclude that climate change will reduce welfare whenever it occurs more rapidly than the rate at which capital stocks (interpreted broadly to include natural resource stocks) would naturally adjust through market processes. They do note that costs of climate change can be large even when lands are close to their climatic optimum, or evenly distributed both above and below that optimum.

Fuhrer *et al.* (2006) report a study on climate risk impacts on agriculture and forests in Switzerland. Their models project more frequent heavy precipitation during winter which increases the risk of large-scale flooding and loss of topsoil due to erosion. In contrast, they find that constraints in agricultural practice due to waterlogged soils may become less in a warmer climate. Fuhrer *et al.* also find a decrease in the frequency of wet summer days, and shorter return times of heat waves and droughts.

Torriani *et al.* (2007) also examine the effect of climate change on crops in Switzerland. They conclude that climate change is expected to affect both the average level and the variability of crop yields. Climate change effects on the mean yield of maize and canola were consistently negative, but they found a positive impact on the mean yield of winter wheat for elevated CO2 concentrations. The yield CV increased for maize and canola, but decreased for wheat.

Xiong *et al.* (2007) assessed China's potential maize production given alternative climate change scenarios using the PRECIS Regional Climate Model. Without the CO2 fertilization effect, China's maize production was predicted to suffer a negative effect under most scenarios with the largest production decreases occurring in today's major maize planting areas. When the CO2 fertilization effect is taken into account, production was predicted to increase for rain-fed maize but decrease for irrigated maize.

Howden *et al.* (2007) examined the adaptations of agriculture to climate change. They note that there are many potential adaptation options available for marginal changes to existing agricultural systems, often variations of existing risk management techniques. However, they go on to conclude that there are limits to the effectiveness of these strategies under more severe climate changes.

John, Pannell, and Kingwell (2005) investigated how changes in climate would affect agricultural profitability and management systems in Australia. Using a whole-farm linear programming model, with discrete stochastic programming to represent climate risk, they find that climate change may reduce farm profitability in the study region by 50% or more compared to historical climate conditions. In their model this leads to a decline in crop acreage due to greater probability of poor seasons and lower probability of very good seasons.

Chang (2002) modelled the potential impact of climate change on Taiwan's agricultural sector. Yield response regression models were used to investigate the impact of climate change on 60 crops. Results suggest that both warming and climate variations have a significant but non-monotonic impact on crop yields. Society as a whole would not suffer from warming, but the study does conclude a precipitation increase may be devastating to farmers.

A synthesis of the climate change literature which provides clear measures of climate change implication for crop yield variability is reported in Table 4.10. Most models rely on some form of crop growth simulation models. The time periods examined are generally for at least thirty years in the future. Results are quite varied across studies. There appears to be a more cases where mean yields increase than decline, especially if CO^2 fertilization is considered. The effect of climate change on yield risk is much less clear from the relatively few studies that provide quantified results (many studies focus solely on the first moment effects of climate change. Further, these studies seldom address the speed of climate change onset; however it appears that the time spans evaluated suggest gradual increases in climate change relative to the time-span of most risk management tools in use.

Table 4.10. Comparison of climate change studies addressing crop variability

Author and date	Study area	Analytical method	Time period	Mean effect	Variability effect
Chang (2002)	Taiwan	Regression and math programming	Not reported	Mostly positive	Mostly negative
	60 crops				
Fingers and Schmidt	Switzerland				
	Maize			+	-
	Wheat			+	-
Fuhrer *et al.* (2006)	Switzerland	Simulation	2058-2108	-	-
	Mixed crops				
Harle *et al.* (2007)	Australia	Simulation	2030		
	Wool			-	-
Isik and Devadoss (2006)	U.S. Idaho	Just-Pope Production function	2025-2034		
	Wheat			+	-
	Barley			-	-
	Potatoes			+	+
	Sugar beets			-	+
Lobell *et al.* (2006)	U.S. California	Simulation	2050	-	+
	perennial crops				
Richter and Semenov (2005)	England	Simulation	2020-2050	+	-
	Wheat				
Toriani *et al.* (2007)	Switzerland	Simulation	2071-2100		
	Maize			-	+
	Canola			-	+
	Wheat			+	-
Van Asseldonk *et al.*	Netherlands	2050			
	Potato			+	+
	Sugar beet			+	+
	Winter wheat			+	+
Xiong *et al.* (2007)	China Maize	Plant growth simulation		Mixed (conditional on CO^2 Assumptions	None

Policy reform

WTO compliance and risk management

Historically, governments in OECD countries have used various combinations of four general mechanisms to provide direct benefits to producers of agricultural commodities. The first of these are price or income supports that are tied directly to agricultural production and prices.[4] These supports provide opportunities for farmers to receive effective prices for their agricultural commodities that are higher than prevailing market prices. In exchange for receiving higher effective prices, farmers may be required to "set-aside" (not plant) some of their land. A second general mechanism includes various types of border protection such as import quotas and tariffs. Border protections tend to maintain domestic prices that are higher than world market prices. When price or income support programs are in place, border protections are often necessary to support domestic market prices and thus reduce the cost to the government of the price or income support program. The third general mechanism is "decoupled" transfer payments to farmers that are not tied to production of any particular commodity or to market prices. The fourth mechanism is various types of disaster payment or subsidized agricultural insurance programs that compensate farmers for production or revenue shortfalls.

In recent years, many OECD countries have shifted much of their agricultural support from price or income supports to decoupled payments. There has also been a general tendency toward reducing border protections for agricultural commodities through various bilateral trade agreements. Widespread multilateral reduction of border protections is likely contingent on a successful resolution to current World Trade Organization (WTO) negotiations. Disaster payment and subsidized agricultural insurance programs are utilized extensively in some OECD countries.

As the European Union and the United States have moved more of their agricultural supports to fixed decoupled payments questions have been raised about the risk effect of these transitions. Simple non-dynamic analysis of risk suggests that a shift from a price responsive program to a non-stochastic program would decrease risk protection afforded producers. However, this ignores the potential for producers to save and borrow across time. Thus, fixed payments could be used to smoothing income if the producer chose to use the funds in that manner.

It also merits attention that many government risk management programs are redundant with private risk management tools. A clear example, is price support programs such as U.S. marketing loan programs and revenue insurance program that strongly compete with private risk management instruments such as futures contracts and forward pricing contracts (Coble, Miller, Zuniga, and Heifner, 2004).

Macro-economic shocks

In OECD countries, exchange rate variability affects farmers primarily through its impact of export and import markets and thus, domestic prices (Cho, Sheldon, and McCorriston, 2002; Pick and Vollrath, 1994; Pick, 1990). Changes in real interest rates (nominal interest rates minus the rate of inflation) affect both production costs (through the cost of credit) and asset values. Barnett (2000) describes how the U.S. farm financial crisis of the early 1980s was caused by significant monetary policy changes implemented in 1979.

Sawada (2007) provides a detailed overview of the impacts that manmade or natural catastrophe have on household welfare. Catastrophes considered included natural disasters and wide-scale economic down turns. Importantly they assess ex ante and *ex post* risk management strategies. Sawada also makes an important distinction between diversifiable risk and non-diversifiable risk. Sawada shows that ex ante insurance and insurance-like mechanisms are likely to perform poorly for rare unforeseen events. Ultimately, Sawada argues that credit availability is likely an essential risk-coping strategy which is particularly relevant during the recent credit crisis of 2008.

Blancard *et al.* (2006) find empirical evidence of credit and investment constraints among French farmers. They conclude that financially unconstrained farmers are larger, are financial more sound and make more productive choices. Bessant (2007) argue that financial crisis and similar terms are usually not meaningful as used by political leaders. Bessant goes on to identify four main criteria for an "agricultural crisis": 1) farm financial difficulties (low or unstable incomes, indebtedness, and increasing reliance on nonfarm revenue), 2) structural changes in agriculture (increasing scale, concentration, and consolidation), 3) dwindling communities, institutions, and services, and 4) international factors such as market fluctuations, trade regulations, and disputes.

Shane and Liefert (2000) argue that exchange rates, consumer income and interest rates are the key macro-economic variables likely to affect agricultural producers. All these factors influence agricultural trade. Consumer income declines reduce the demand for agricultural goods and interest rates affect both consumers and the producer's cost of borrowing.

Breustedt and Glauben (2007) use regional data for 110 regions in Western Europe to indicate that exits from farming are strongly influenced by farm characteristics and policy conditions. They conclude that "exit rates are higher in regions with smaller farms and are closely related to production structures. Exit rates are lower in regions with more part-time farming, high subsidy payments and high relative price increases for agricultural outputs." They conclude that off-farm income and government intervention have slowed down structural change in European agriculture.

Subservie (2008) analyses the effect of world price instability on agricultural supply from developing countries and addresses the extent that the price instability effect is dependent on macroeconomics. She concludes that producers from agricultural exporting countries are particularly vulnerable to the fluctuations of world prices. Importantly the ability to cope with price instability is found to be conditional upon macroeconomic factors such as infrastructure and inflation. Using panel data for 25 countries between 1961 and 2002, Subservie finds the expected negative effect of world price instability on supply. In addition, the macroeconomic factors of high inflation, weak infrastructure and a poorly developed financial system exacerbate the problem.

The literature on changes in government macroeconomic policy suggest that these can also be a major source of risk for agricultural producers. Macroeconomic policies affect exchange rates, interest rates, and the rate of inflation, all of which directly affect many agricultural producers. Our assessment is that the literature on these topics has been fairly sporadic in response to the economic context of the time.

Policy and trade shocks

While various government policies can be used to reduce farmers' exposure to risk, the potential for changes in government policies is itself a major source of risk. As indicated above, government agricultural support programs change over time. The European Union's CAP was changed in 1999 and 2003. U.S. agricultural policy changes approximately every five years when a new "farm bill" is adopted. Modest changes occur even more frequently in response to changing market conditions, government budget constraints, or trade negotiations. Increased variability in farm wealth is likely the most important impact of changes in government agricultural policies. Gardner (2001) provides a comprehensive discussion of the risk implications of changing government agricultural policies.

Obviously, farm policy changes cause variability in farm revenues. However, since farm revenues (including government program benefits) are capitalized into the value of farmland and other specialized agricultural assets, these changes also cause variability in the value of farm assets and hence, wealth (Duffy *et al.*, 1994; Barnard *et al.*, 1997; Beach, Boyd, and Uri, 1997; Weersink *et al.*, 1999; Oltmer and Florax, 2001; Roberts, Kirwan, and Hopkins, 2003; Shaik, Helmers, and Atwood, 2005; Lagerkvist, 2005; OECD, 2008).

As this is being written, the World Trade Organization (WTO) is engaged in a round of trade negotiations focused on reducing agricultural subsidies. Should this round of negotiations result in an agreement that significantly reduces agricultural subsidies, this will certainly have an impact on cotton, sugar, cereals and oilseeds farmers (the commodities that receive the largest share of agricultural subsidies). Reduced subsidies would not only affect farm revenues but also the value of farm assets that were purchased with an expectation of continued government support. However, if a WTO agreement also reduces global border protections for agricultural commodities, farmers in many OECD countries would benefit from increased export opportunities. Regardless, the uncertainty associated with multilateral trade agreements is another important source of risk for agricultural producers.

Recent efforts to move from non-renewable to renewable fuels has created new and significant demand for maize in the United States, sugarcane in Brazil, and soybeans in Europe. Government subsidies for biofuel production have contributed to significantly higher prices for some agricultural commodities. Farmers are currently faced with tremendous uncertainty regarding the longevity of these high commodity prices as policy-makers in both the U.S. and Europe reconsider government subsidies for biofuels.

Animal diseases

While difficult to analyze, livestock producers appear to have a concern regarding the possibility of new and unknown diseases that have never occurred at least in their region. Recent attention to the potential for high pathogen avian influenza illustrates this point. The perceived risk magnitude and the economic consequences of such a risk are quite difficult for even professionals to assess. Much of the literature in this area tends to be conditioned upon an outbreak. For example, Ekboir (1999) estimated that potential losses due to a hypothetical FMD outbreak in California would amount to USD 13.5 billion. Similarly, Schoenbaum and Disney (2003) estimated that net changes in consumers' and producers' surplus due to a hypothetical FMD outbreak in the United States would amount to USD 789.9 million annually.

Much of the recent research in this area has focused on sub-optimal behaviour of producers given that many diseases spread from herd to herd and that bio-security and disease mitigation efforts represent an unvalued positive externality to adjoining farms. Gramig, Horan, and Wolf (2005) address the potential moral hazard problem of validating incentives to encourage risk mitigation. Bicknell, Wilen, and Howitt (1999); Ott (2006); Shaik *et al.* (2006); and Hennessy, Roosen and Jensen (2005) all have addressed the policy incentives to induce greater risk mitigation of these low probability events. In a related paper, von Asseldonk *et al.* (2005) examine the potential for a public/private partnership to protect against livestock diseases.

Huirne *et al.* (2005) provide an overview of a variety of animal disease control issues in the European Union and point out the economic consequences of various diseases often vary dramatically from one farm to another. Nielen *et al.* (1999) conducted a financial analysis of Classical Swine Fever outbreaks in the Netherlands. There results include an assessment of the financial consequences for governments, farms, and related industries. They conclude the costs of the 1997/1998 outbreak are USD 2.3 billion. Losses for farmers and related industries are USD 423 million and USD 596 million respectively. In a related study Meuwissen *et al.* (1999) address the significant cost increase incurred by the Dutch poultry industry to manage the financial risk of poultry epidemics. The potential for High-Pathogenicity Avian Influenza (HPAI) epidemics has contributed to insurance costs incurred by the industry (Meuwissen *et al.*, 2006).

An assessment of primary risk factors and changes occurring over time

A synthesis of the literature on crop risk clearly identifies crop yield, output price and to a lesser extent input prices as the major risks confronting crop producers. Clearly, weather dominates the body of literature addressing cause of crop yield risk (Deng, Barnett, and Vedenov, 2007). While, irrigation and other modern production practices may mitigate some weather risk, these practices are not cost effective in many production systems. Further as competition arises for water resources in many locations, widespread increases in irrigation are unlikely.

It is useful to note the specific aspects of weather that induce losses. Once one reaches this degree of detail, rainfall and temperature tend to dominate the research findings. With both rainfall and temperatures, extreme high and low values are usually detrimental to crop growth. The recent explosion of weather derivative research has led to significantly broader knowledge of the specific relations between weather factors and yields. It appears that functional forms and parameterizations of the yield-weather relationship are not robust in the sense that effective models need to be re-estimated as one moves across crops and regions.

Price risks affect crop producers in both the input and output markets. Clearly the literature examining output prices dominates input price risk literature by a wide margin. Further, producer surveys asking for a ranking of risks suggests output price is generally of greater concern to producers (Coble *et al.* 1999). Of the input risks that have been studied two stand out: fuel and fertilizer prices. The data we observe suggest that fertilizer and fuel tend to be commodities and subject to price fluctuations much like all other commodities. An interesting side note is that futures markets exist for fertilizer and fuel but are seldom used by producers in part because contract sizes are too large to be practical for all except the largest of farms. Further it appears that fertilizer and fuel price risk is equal to or greater than output price risk for most major commodities. The causes of fertilizer and fuel risk appear to be linked somewhat as nitrogen fertilizer is often produced from energy sources and in some instances due to significant fertilizer transportation cost (Dhuyvetter, Dean, and Parcell, 2003). However, price fluctuations in fuel prices are clearly driven by non-agricultural demand and supply issues. Perhaps the recent price shocks in both fertilizer and fuel markets will encourage researchers to augment the very limited amount of research available on input price risk.

Output price risk in crop commodities has been addressed widely for different crops and for many locations (Shonkwiler and Maddala, 1985). The literature describing the causes of price risk clearly identifies production shocks from major production regions as a source of variability. Thus, weather events such as droughts and flood in major production regions tend to matter. It is also important to distinguish storable commodities from non-storable commodities as stock-holding can reduce intertemporal price volatility. Various shocks may also arise from the demand side of the market. For crops traded in international markets, policy changes and exchange rate changes are both potential market shocks. Several crop commodities have multiple uses creating a composite demand that may be shocked by various factors. Many major crops such as maize and wheat have both feed and food uses which may diversify demand somewhat. We would also note that recent efforts to produce bio-fuels have added a new dimension to some crop markets. In effect, this ties the demand for maize and sugarcane-based ethanol and soybean-based bio-diesel to the price of oil, various government policies related to energy markets, and trade policies affecting these emerging markets.

Our review of the literature also suggests that markets for non-storable products such as some fruits and vegetables function somewhat differently than markets for storable commodities (Henneberry, Piewthongngam, and Qiang, 1999). Often there is variation in quality and grades which add to the complexity of the market and perishability tightens the supply and demand window. In many cases these markets are more geographically limited which reduces spatial arbitrage opportunities. This suggests greater price risk in these markets.

A synthesis of livestock production risk depends critically on whether modern confinement production systems are used (Aradhyula and Holt, 1990). If so, many production risks may be reduced although disease risk may be concentrated. Some livestock production systems continue to rely heavily on grazing which does leave the livestock producer subject to much of the same temperature and rainfall risk faced by crop producers. Livestock price risk also occurs in the input and output markets. Clearly, grain-based feeds are a major input cost which makes output price risk for crops like maize a major input price risk for many livestock enterprises. The aforementioned fertilizer and fuel price risk can also apply to grazing operations.

Output price risk in livestock generally reflects limited storability of slaughter-ready livestock and cyclical behaviour due to relatively long biological lags. Another dimension of these industries is the advent of strong vertical integration in livestock agriculture. For example, many U.S. poultry producers do not own the animals and thus do not confront price risk in the typical fashion. Recent disease events such as BSE have created significant shocks in livestock markets across several countries. These events have been widely studied. Some studies suggest that many disease-related price shocks have sharp, but relatively short-term, price impacts. Other studies find long-term effects.

Finally, we address some of the looming trends likely to alter the agricultural risk environment in coming years. First, the advent of bio-technology based traits appears to alter not only mean yields but the variability of yields as well. Recent claims of reduced yield risk for bio-tech crops have been validated in some studies. The genetic improvement, however, appears to be proceeding much faster than risk research can validate with long time-series data. It is interesting to note that the U.S. federal crop insurance program recently approved a rate reduction for a particular bio-technology enhanced seed variety based on evidence of reduced yield risk. As biotechnology moves forward, the risk profile of crop agriculture may evolve rapidly.

Recent attention to climate change issues has resulted in a rapidly expanding body of literature on the effect of climate change on production agriculture. It appears several important agricultural risk issues are obvious. First, alteration of rainfall and temperature patterns would cause shifts in the feasible production area and weather risks confronting producers. These changes may cause shifts in the value of agricultural assets at a specific location. It does appear that the rapidity of climate change is also a crucial issue. If climate change occurs gradually, producers may have sufficient time to adapt to the changes without significant losses. Thus, the real risk implications of global climate are related to changes in the second and higher moments of the yield distribution and how accurately that can be assessed.

Policy risk remains relevant as unanticipated government action may alter expectations of agricultural enterprises with fairly fixed assets. Among the shock affecting agriculture are exchange rates and fiscal policies. Looming uncertainties include bio-fuel production policy and continued evolution of trade policy.

Producer risk perceptions and preferences

Risk perceptions

In this section we review the empirical literature that addresses producer subjective risk perceptions. First, we address general rankings of major agricultural risks. Then we review literature that compares elicited subjective probabilities to objective estimates of the same risk.

Identification of primary risks

Coble *et al.* (1999) surveyed U.S. crop farmers regarding their risk perceptions. The responses indicated that price risk and yield risk were the farmers' primary concerns. Patrick *et al.* (2007) surveyed U.S. hog producers and asked them to rate, on a scale of 1 (low) to 5 (high), a number of sources of risk in terms of their potential to affect the operation's income from hogs. Hog price variability was rated the highest source of income variability at 4.28 and was followed by changes in environmental regulations (3.92) and disease in hogs (3.90). Similarly, Hall *et al.* (2003) asked beef producers to rate the risks that they faced. Drought and price variability were rated the highest (4.4) and (4.3). The third highest rated risk was non-feed input price variation. Meuwissen *et al.* (2001) also identified the primary risks observed among Dutch livestock farmer. Output price received the highest score with disease a clear second. Flaten *et al.* (2005) conducted a similar study of Norwegian organic and conventional dairy farmers' perceptions of risk and risk management. Organic farmers appeared the least risk averse of the two groups. Further, institutional and production risks were perceived as primary sources of risk, with concerns about reductions in farm support payments at the top of the list. Compared to their conventional producers, organic farmers gave more weight to institutional factors related to their production systems. Conventional farmers were more concerned about costs of purchased inputs and animal welfare policy.

Table 4.11 provides a summary of the ranks various studies have provided. The top five risks as ranked by average Likert scale scores for the surveyed producers are identified by study. One can observe price risk being ranked as either top or second place for all five studies. The concern for other categories is less clear. Production risk is either first or second in three studies that do not include confinement livestock production. Disease and input price risk also are noted in four of six studies. Disease ranked high in specialty crops and confinement livestock operations. Input price risk is not highly rated as a risk in specialty crops and Dutch livestock farms.[5]

Table 4.11. Comparison of studies identifying farmers' primary risk concerns

Authors	**Coble *et al.* (2005)**	**Blank, Carter, McDonald**	**Patrick *et al.* (2005)**	**Hall *et al.* (2005)**	**Flaten *et al.* (2005)**	**Meuwessen *et al.* (1999)**
Producer group	**US row crop producers**	**California specialty crops**	**Independent US hog producers**	**US beef cattle producers**	**Norwegian dairy farmers**	**Dutch livestock farmers**
	Ranking of top five perceived risks					
Production risk	2	2		1		
Disease		4	2		5	2
Freeze (extreme cold)		3		5		
Input price	3		5	3	4	
Output price	1	1	1	2	2	1
Pests		5				
Environmental regulations	5		3	4		
Market access			4	n.a.		
Farm program uncertainty	4				1	
Animal welfare policy					3	
Illness or death of operator					5	3

Perceived risk magnitude

Eales *et al.* (1990) compared producer subjective price distributions to objective futures-based price expectations and volatility of price. Notably they find that producer subjective price expectation is quite accurate. However, producers' subjective variances are found to generally be less than those implied by the options market.

Pease (1992) compared subjective and historical (objective) probability distributions for crop producers from Kentucky. In many cases there were wide discrepancies between the two estimators. This was true in both the estimated mean and the variance of yields.

Egelkraut *et al.* (2006) used survey data from Illinois maize farmers to investigate the relationship between subjective and objective yield measures. They found that farmers viewed themselves as having better than average yields and lower than average variance of yields. They also found that over and under confidence influence farmers' crop insurance purchasing decisions. The effects are not symmetric in that overconfidence is primarily reflected in a farmer's belief that his/her yields are higher than average while under-confidence emerges mainly from a belief that his/her yields exhibit higher variability than average.

Blank, Carter, and MacDonald also elicited producer risk concerns from California crop producers in 1992. This survey included producers of several specialty crops such as grapes, lettuce, and processing tomatoes. Their study asked for a ranking of various risk sources. Output price risk was most often ranked first with drought second. Two more production risks, freeze and disease, were the third and fourth most common risks reported.

Risk preferences

Are producers risk averse?

Decision maker preferences about risk are fundamental to understanding behaviour in the presence of risk. It also follows that understanding farm risk preferences is essential to evaluating agricultural policy intended to assist producers in the management of agricultural risk. By far the most widely accepted model for understanding choices between risky outcomes is expected utility theory as formalized by John von Neumann and Oskar Morgenstern (1947). Their axiomatic representation of risk preferences allow for risk aversion, risk seeking behaviour and risk neutral behaviour. Pratt (1964) built upon their work by defining a risk aversion coefficient defined in terms of the curvature of the utility function. The Arrow-Pratt absolute risk aversion (ARA) measure may be written:

$$ARA = -\frac{U''(W)}{U'(W)}$$

where U is the producer utility function defined over ending wealth. Also, U' and U" denote the first and second derivative of utility respectively. Given the standard assumption that producers prefer more wealth than less, the first derivative is positive. The second derivative determines whether the producer is risk averse, neutral or risk loving. Risk aversion results from $U'' < 0$. As noted in OECD (2004), it is common to consider subclasses of risk aversion including constant absolute risk aversion (CARA) and decreasing absolute risk aversion (DARA).

The related measure relative risk aversion (RRA) scales risk aversion by ending wealth such that

$$RRA = -\frac{U''(W)}{U'(W)}W$$

Again, there are common subclasses of RRA, most notable is constant relative risk aversion (CRRA). CRRA implies that the level of ending wealth does not affect preferences.

Since these seminal studies, expected utility theory has dominated the conceptualization of how decision makers evaluate risk. This holds generally, but in agriculture as well. It merits note that several more restrictive non-expected utility models of risk preferences have been widely used in agriculture. For example mean-variance models (Freund, 1956), but we would argue largely because of tractability rather than conceptual validity. Another vein of agricultural risk literature — stochastic dominance — is conceptually based in expected utility, but avoids having to know the degree of risk aversion for the decision maker. The limit of these studies is that they shed little light on producer preferences.

In this section, we focus on the literature that specifically has attempted to characterize the risk preferences of agricultural producers. Nearly all this literature is based on the expected utility model. However, one needs to recognize that numerous studies finding behavioural anomalies have been observed that conflict with the expected utility assumptions and variant models have been introduced, *e.g.* see Starmer (2000) and Fredrick, Loewenstein, and O'Donoghue (2002) for reviews. We would suggest that alternative models such as prospect theory (Kahneman and Tversky, 1979) have not been widely adopted to evaluate agricultural producer risk due to complexity and other limits on empirical application.

Quantifying risk preferences

Various studies have attempted to estimate the risk preference of producers. Given the importance of risk analysis in agriculture, these studies have important implications. However, that empirical data required in most cases is quite difficult to obtain. OECD (2004) followed Young's (1979) categorization of risk preference estimation into three groups: first, direct elicitation of utility functions which typically has involved posing hypothetical choice games to the producer. The second approach is categorized as experimental methods. This approach has gained increasing favour over the years among economist and involves placing farmers in a controlled context and observing choices among real monetary payoffs. However these payoffs typically are of small value and often have been criticized for potentially being subject to a scale effect. Finally, the third approach and most often used in the literature is observed economic behaviour. This approach uses *ex post* behavioural data in some real-world economic decision such as acreage allocation and then estimates risk preference parameters from these choices. Typically, econometric techniques are used, but some studies such as Brinks and McCarl (1978) calibrated a programming model instead. As noted in OECD (2004) comparison of absolute risk aversion estimates are difficult because the risk aversion estimate is dependent on prices, quantities or income. Relative risk aversion measures, on the other hand, can be compared because they are independent of ending wealth. However comparisons across countries are always tenuous due to different institutional frameworks.

We begin with a quick summary of risk aversion estimates estimated in a fashion that precludes comparison. For the most part these are studies estimated under the assumption of constant absolute risk aversion. A related study by Bard and Barry (2001) used Illinois crop farmer data to examine risk attitudes using a non-parametric “closing-in” procedure and also developed a multi-attribute scale. Interestingly, Bard and Barry conclude, “The responding farmers, on average, self-assessed their risk attitudes as slightly risk-seeking. However, their responses to utilization of risk management tools and the "closing-in" method indicated mild degrees of risk aversion.” More recently, Gardebroek (2006) estimated risk aversion among organic versus non-organic producers in the Netherlands. Using a Bayesian version of Antle's (1987) approach, Gardebroek found that organic farmers were on average significantly less risk averse than non-organic producers. This paper also notes what several papers also found: significant heterogeneity of preferences across individuals is typically found when the procedure allows for heterogeneity to be addressed.

Several other papers have attempted to identify the risk preferences of agricultural producers. To facilitate a summary of the findings Table 4.12 categorizes the results into two categories the first group finds some evidence of risk loving behaviour. The second group finds a preponderance of risk averse preferences. The study by Pennings and Garcia (2001) using data from hog farmers in the Netherlands finds evidence of risk seeking behaviour among producers. However, their more general conclusion is that risk preferences are more complex than can be represented by a single dimension. Ultimately this result appears to be an outlier among papers that generally find that risk aversion is well supported in at least a significant percentage of producers.

Table 4.12. Summary of papers examining agricultural risk preferences

Some risk neutral or risk loving preferences	Risk aversion in most or all cases
Collins, A., W.N. Musser, and R. Mason, (1991) – 30-32 risk loving King, R.P., and G.E. Oamek (1983) – 70% Mixed Lin, W., G. Dean, and C. Moore (1974) – 17% mixed Tauer, L.W. (1986) 26% risk loving Thomas, A.C. (1987) 13% Risk loving Pennings and Garcia (2001) – Mostly risk loving Wilson, P.N., and V.R. Eidman (1983) – 22% Risk loving	Brink, L., and B. McCarl (1978) Chavas, J.-P., and M.T. Holt (1990) Chavas, J.-P., and M.T. Holt (1996) Gardebroek (2006) Gómez-Limón, J.A., L. Riesgo and M. Arriaza (2002) Hennessy, D.A. (1998) Hildreth, C., and G.J. Knowles. (1982) Lansink (1999) Lien (2002) Love, H.A., and S.T. Buccola (1991) Pope R.D. and R.E. Just, (1991) Ramaratnam, S.S., M.E. Rister, D.A. Bessler and J. Novak (1986) Saha, A. (1997) Saha, A., C.R. Shumway, and H. Talpaz (1994) Schurle, B., and W.I. Tierney, Jr. (1990)

Because our purpose in this chapter is to compare risk aversion across farms and regions, the literature couched in terms of CRRA is more useful. Thus, we concentrate on a summary of studies reporting CRRA estimates. These parameter estimates are reported in Table 4.13. This table builds upon the tables reported in OECD (2004) and the paper by Gardebroek (2006)

Table 4.13. CRRA parameter estimates

Authors	Farm Type	Country	Minimum	Mean	Maximum
Antle (1987)	Crop farmers	India	-0.1	0.82	1.4
Bar Shira *et al.* (1997)	Crop farmers	Israel		0.611	
Brink and McCarl (1978)	Crop farmers	United States	0	~0.22	> 1.25
Bontems and Thomas (2000)	Crop farmers	United States		3.7174	
Chavas and Holt (1996)	Maize and soybean farmers	United States	1.41		7.62
Kumbhakar (2002)	Salmon producers	Norway		0.051	
Lence (2000)	All farms	United States	1.136	1.136	1.136
Lien (2002)	Crop farmers	Norway	0.1	2.2	10.8
Love and Buccola (1991)	Crop farmers	United States	2.4	10.6	18.8
Oude Lansink (1999)	Crop farmers	Netherlands	0.2		0.31
Saha, Shumway, and Talpaz (1994)	Wheat farmers	United States	3.8	4.6	5.4

Antle (1987) econometrically estimated producer risk preferences from data derived from south-central Indian rice farmers. He found these farmers to be both Arrow-Pratt and downside risk averse but quite heterogeneous in their risk preferences which ranged from nearly risk neutral to risk averse with a risk premium as high as 25% of expected income. The CRRA coefficients from this study ranged from -0.1 to 1.4. Brinks and McCarl (1978) used a programming approach which precluded risk loving behaviour. Thus, the minimum CRRA was found to be 0 in their study. There results were reported in ranges with an average of approximately 0.22. This is suggestive of near-risk neutrality. Bontems and Thomas (2000) estimated an average CRRA of 3.717 using U.S. data. Saha, Shumway, and Talpaz (1994) followed Antle's (1987) study with another econometric study which suggested a more flexible functional form for the utility function. Using data from Kansas wheat farmers they also found farmers to be risk averse with relative large values ranging from 3.8 to 5.4. Chavas and Holt (1996) used aggregate U.S. data to find CRRA ranging from 1.41 to 7.6 while Lence (2000) also used U.S. data and found a relative risk aversion coefficient of 1.136; and Bar-Shira *et al.* (1997) studying crop farmers from Israel found an average CRRA parameter of 0.611. Kumbhakar's (2002) study of Norwegian salmon producers concluded that the subjects examined fell into the lower end of typical risk aversion ranges with an average CRRA value of 0.051. Lien (2002) used Norwegian crop data to estimate CRRA parameters that varied between 0.1 and 10.8. Love and Buccola (1991) used U.S. crop farm data to estimate CRRA parameters that are well above those of any other study compared in Table 4.13. Love and Buccola found a minimum CRRA of 2.4 and a maximum of 18.8 which is more than double the next highest estimate. Finally, Oude Lansink (1999) estimated CRRA using data collected from crop farmers in the Netherlands. This study found CRRA values that were relatively low compared to other studies. The range was from 0.21 to 0.31

In summary, a synthesis of these studies suggests several conclusions regarding risk aversion across farmers and regions. First, only two of eleven studies suggest either risk neutrality or risk loving behaviour. In several studies the minimum CRRA was well above zero. Thus, it seems clear that a great deal of evidence supports the risk aversion assumption. While, producers in several countries were subjects of these studies, US data dominated. Our review of the literature suggests the variation across studies likely has much more to do with differences in estimation procedures than with the region or agricultural product produced. In the end, it seems that this summary is fairly Consistent with the characterization of Anderson and Dillon (1992) who provide a general guideline shown in Table 4.14.

Table 4.14. Anderson and Dillon risk aversion categories

Relative risk aversion coefficient	Anderson and Dillon characterization
0.5	Hardly risk averse
1.0	Somewhat risk averse (normal)
2.0	Rather risk averse
3.0	Very risk averse
4.0	Extremely risk averse

The primary discrepancy between the empirical estimates and the Anderson and Dillon classification is that there is some empirical evidence of CRRA values beyond 4. OECD (2004) chose a range of zero to five which appears a reasonable generalization of the Anderson and Dillon rule of thumb.

Extension of expected utility

A limited set of papers have empirically investigated relaxing the expected utility assumption. In all these cases it appears there is a clear ramification for risk management. Thus we add a summary of this literature to our assessment.

Two studies have investigated the interaction of risk and time preferences. Typically risk analysis in agriculture that involves significant time lags can be modelled by simply discounting the expected utility with a market-based discount factor. Howitt *et al.* (2005) and Lence (2000) both investigated models of the Kreps-Porteus family that allow for an intertemporal elasticity of substitution that differs from the degree of risk aversion. Howett *et al.* rejected time-additive separability, with or without risk aversion, such as the standard constant relative risk aversion utility model. The improvement in model fit when recursive preferences are used is notable. Lence fit a generalized expected utility model to U.S. farm data to estimate farm operator's time preferences and risk attitudes. He found the forward-looking expected utility model is soundly rejected in favour of the generalized expected utility paradigm. Importantly, the generalized expected utility model was also found to fit the data better than the discounted expected utility model typically used to study agricultural production under risk.

Lessons learned on the magnitude and causal factors of agricultural risks

The purpose of this chapter is to synthesize the evidence provided by existing scientific literature regarding the magnitude and casual factors underlying the risks faced by agricultural producers. Further, we examined the existing scientific evidence regarding the risk preferences of agricultural producers. We first note that the scientific evidence in many respects is thin at best and in many cases appears to be non-existent. The authors have consciously attempted to avoid allowing U.S. research to dominate our discussion, but in many instances it appears the literature is simply deeper there than in other locations. Further, we must acknowledge that the literature is not robust across commodities. Not surprisingly, the research on major crops and livestock enterprise dominate the literature cited in this paper. It is also noted that much of the existing literature fails to examine farm household income or consumption as theory would suggest. In effect, studies that focus on a single risk such as price risk or a single output are inherently myopic and may over-estimate the value of risk management tools. We conclude that greater attention should be devoted to obtaining farm-level time-series data so that more realistic measures of risk reduction can be made. This is particularly true when farms are well diversified across enterprises.

Magnitude of agricultural risk

We easily conclude that in crop agriculture, output price and yield risk are the major risk factors associated with most crop production. Yield risk is largely driven by weather-related factors such as rainfall and temperature, while price risk often arises due to the long production lags in agriculture which allow supply and demand forces affecting commodities prices to drive price away from expected levels. The empirical measurement of objective data would also indicate the output price and yields are relatively variable as compared to several other risks (Deaton and Laroque (1992), Ray *et al.* (1998), Poor and Hegedusne Baranyai (2007), Hubbard, Lingard, and Webster (2000), Hazell, Shields, and Shields (2005), Subervie (2007)). Also, we also take the efforts to develop insurance and futures markets as *prima facie* evidence that price and yield risk are major concerns for crop producers.

What is less clear in our review of the literature is the importance of input price risk in production agriculture. Objective measurements of those data indicate fertilizer and fuel CVs equal to or greater than those for price and yield risk [Oehmke, Sparling and Martin (2008)]. Dhuyvetter, Albright and Parcell (2003) estimated a CV of 0.187 for diesel, 0.489 for natural gas, and 0.270 for anhydrous ammonia. However, producer surveys have tended to not rank input price risk particularly high in comparison to other risks. This is likely due to the fact that the inputs most often considered risky typically reflect only a portion of total cost and contribute relatively less to net revenue risk than do either yield or output price risk. It is quite clear, however, that the literature related to input price risk is quite limited and appears an area in need of further research to better understand these risks.

A consistent theme in the literature is that commodity prices are right skewed (Goodwin, Roberts, Coble). Annualized price coefficients of variation typically range from 0.15 to 0.25 for both commodity crops and livestock. Somewhat higher values appear typical for more perishable crops. Certainly, market volatility spikes beyond these levels at times. Input price variation appears to be of a similar magnitude or slightly higher than that observed for commodity output prices.

Yield risk is much more difficult to assess from the literature than price risk (Just and Weninger. Yields measured in the aggregate simply provide a quite biased estimate of farm-level yield variability. This limits the literature to those few instances where a time-series of farm yields is available. An examination of the literature that does use farm-level data suggests a great deal of heterogeneity in the shape of the probability distribution and the coefficient of variation (Just and Weninger (1999), Allen and Lueck (2002), Hart, Hayes, and Babcock (2006)). In general, it appears that the magnitude of farm-level yield risk tends to exceed that of price risk, but many exceptions will exist. Knight *et al.*(2008) and Marra and Schurle (1994) show that larger farms are less risky. Likewise certain production practises such as irrigation also profoundly affect yield risk. For livestock, production risk appears dramatically lower in modern confinement operations versus more extensive production systems such as pasture-based cattle production in arid regions.

Correlation of random variables

When one considers that risk preferences are generally defined in terms of wealth or consumption, then the risk context of a farm often results from the summation or product of random variables. Thus, correlation among these random variables matters. Recent literature has focused increasing attention on price-yield correlation and in many studies negative correlation is found in major production regions or in more localized markets (Coble and Dismukes (2008); Weisensel and Schoney (1989); Bielza and Sumpsi (2007); Hart, Hayes, and Babcock). This tends to dampen revenue risk. However, for many commodity-location combinations, price and yield independence appears in the historical data. Positive correlations between the prices of similar crops and between yields on the same farm tend to profoundly affect the revenue variability of a farm. Ultimately, it also creates the risk mitigating value of enterprise diversification. For example, combining crops and livestock has been a longstanding risk mitigation strategy. However, it appears that movement to larger and vertically integrated livestock production systems for the sake of cost efficiency has reduced the opportunity for many farms to diversify in that manner.

Off-farm income

Off-farm income and investments are well documented in the literature with most research focused on the choice of how much off-farm labour to supply. Studies from the U.S. tend to assume a risk reducing effect and generally do not report a correlation between farm and no-farm income. El-Osta, Mishra, and Morehart (2008) found expected government payments decreased the likelihood of off-farm work strategies. Lien *et al.* (2006) conclude full-time and part-time farmers' goals, risk perceptions, and risk management strategies differ significantly. Mishra and Godwin (1997) find riskier farms choose to work more in off-farm employment. Mishra and Sandettro (2002) find a negative covariance between farm and off-farm income suggestive of the risk reduction created by off-farm income. It appears in other literature that there is a strong presumption that off-farm investments and labour returns are uncorrelated (or weakly correlated) with farm revenue unless the non-farm employment (investment) is in a closely related agricultural industry. Nartea and Webster (2008) note that investment in other industries can have a risk reducing effect for the farm family. Painter (2000) concluded that investments in farmland are negatively correlated with returns with other equity markets.

Causes of agricultural risk

A synthesis of the literature on crop risk identifies crop yield, output price and to a lesser extent input prices as the major risks confronting crop producers. Clearly, weather dominates the body of literature addressing cause of crop yield risk. While, irrigation and other modern production practices may mitigate some weather risks, these practices are not cost effective in many production systems. It is useful to note the specific aspects of weather that induce losses. Once one reaches this degree of detail, rainfall and temperature tend to dominate the research findings. Cafiero *et al.* (2007a) find that temperatures and rainfall explain more than 86 percent of the variation of grape and wheat yield in the Tuscany region of Italy. Richards, Manfredo, and Sanders (2004), Turvey (2001), and van Asseldonk and Oude Lansink (2003) all focus on temperature risk. Martin, Barnett, and Coble (2001) in U.S. cotton and Musshoff, Odening, and Xu (2006) and Stoppa and Hess (2003) all identify precipitation risk. Another set of studies find both temperature and rainfall affect yields (Vedenov and Barnett (2004); Xu, Odening, and Musshoff (2006) and Tannura *et al.* (2008). With both rainfall and temperatures, extreme high and low values are usually detrimental to crop growth. The recent explosion of weather derivative research has led to significantly broader knowledge of the specific relations between weather factors and yields. It appears that functional forms and parameterizations of the yield-weather relationship are not robust in the sense that effective models need to be reestimated as one moves across crops and regions.

Price risks affect crop producers in both the input and output markets. Clearly the literature examining output prices is much larger than the input price risk literature by a wide margin Hazell, Shields, and Shields (2005). Further, producer surveys asking for a ranking of risks suggest that output price risk is generally of greater concern to producers. Of the input price risks that have been studied, two stand out – fuel and fertilizer. The data we observe suggest that fertilizer and fuel tend to be commodities and subject to price fluctuations much like all other commodities (Dhuyvetter, Dean and Parcell, 2003). The causes of fertilizer and fuel price risk appear to be linked somewhat as nitrogen fertilizer is often produced from energy sources and in some instances due to significant fertilizer transportation cost.

Output price risk in crop commodities has been addressed widely for different crops and for many locations (Henneberry *et al.* 1999). The literature describing the causes of price risk clearly identifies production shocks from major production regions as a source of variability (Deaton and Laroque (1992), Coble (1999). Thus, weather events such as droughts and flood in major production regions tend to matter. It is also important to distinguish storable commodities from non-storable commodities as stock-holding can reduce intertemporal price volatility. Various shocks may also arise from the demand side of the market. For crops traded in international markets, policy changes and exchange rate changes are both potential market shocks. Several crop commodities have multiple uses creating a composite demand that may be shocked by various factors. Many major crops such as maize and wheat have both feed and food uses which may diversify demand somewhat. We would also note that recent efforts to produce bio-fuels have added a new dimension to some crop markets. In effect this ties the demand for maize and sugarcane-based ethanol and soybean-based bio-diesel to the price of oil, various government policies related to energy markets, and trade policies affecting these emerging markets.

Our synthesis of livestock production risk depends critically on whether modern confinement production systems are used (Marsh, 1992). If so, many production risks may be reduced although disease risk may be concentrated. Some livestock production systems continue to rely heavily on grazing which does leave the livestock producer subject to much of the same temperature and rainfall risk faced by crop producers. Livestock price risk also occurs in the input and output markets. Clearly, grain-based feeds are a major input cost which makes output price risk for crops like maize a major input price risk for many livestock enterprises. The aforementioned fertilizer and fuel price risk can also apply to grazing operations.

Output price risk in livestock generally reflects limited storability of slaughter-ready livestock and cyclical behaviour due to relatively long biological lags. Another dimension of these industries is the advent of strong vertical integration in livestock agriculture. For example, many U.S. poultry producers do not own the animals and thus do not confront price risk in the typical fashion. Recent disease events such as BSE have created significant shock in livestock markets across several countries. These events have been widely studied Lloyd *et al.* (2001). Some studies suggest that many disease-related price shocks have sharp, but relatively short-term, price impacts. Other studies find long-term effects.

Looming developments in agricultural risk

Looming issues that appear to have the potential to alter the risk context for farmers are varied. We identify four potentially important issues which may alter the risk environment for producers: 1) climate change, 2) genetically modified crops, 3) potential disease epidemics in livestock, and 4) unexpected policy shocks. The current concern about climate change has already sparked a surprising number of studies which are, however, somewhat inconclusive with regard to the impact on production risk and appear region specific (van Asseledonk and Langeveld (2007); Quiggin and Horowitz (2003); Fuhrer *et al.* (2006); Toriani *et al.* (2007); Xiong *et al.* (2007); Howden *et al.* (2007); John, Pannell, and Kingwell (2005)). It does appear that a distinction can be made between changes in mean levels of temperature and rainfall versus the variability of temperature and rainfall. Gradual onset of climate change would have dramatically different implications than if rapid onset occurred. Several models do not address the speed at which climate change is expected to occur, but the literature appears to implicitly assume the onset will be gradual enough to allow some agricultural adjustment. Biotechnology appears to increase mean yields and studies also suggest this technology is risk decreasing. However, this is difficult to assess as adoption and technological advances are occurring so rapidly we do not have long time series of data to assess the issue. Furthermore, the literature suggests concerns related to the environmental risks of biotechnology as well. Disease epidemics are also a looming risk factor (Gramig, Horan, and Wolf (2005); Bicknell, Wilen, and Howitt (1999); Ott (2006); Shaik *et al.* (2006); Hennessy, Roosen and Jensen (2005); von

Asseldonk *et al.* (2005)). Increasingly these events may not only affect output, but also cause catastrophic demand shifts. Meuwissen *et al.* (1999) illustrated the large costs resulting from prevention efforts and losses due to livestock disease epidemics. Policy risk remains relevant as unanticipated government action may alter expectations of agricultural enterprises with fairly fixed assets. Often the most profound shocks to agriculture may arise from macro-oriented policies rather than agricultural policies themselves. For example exchange rates and fiscal policies may provide dramatic shocks to the agricultural sector. Looming agriculturally-oriented issues appear to include bio-fuel production policy and continued evolution of trade policy.

Risk perceptions and risk preferences

The surveys that have asked producers to identify major risk categories are quite confirming of the emphasis placed on yield and output price risk (Coble *et al.* (1999); Patrick *et al.* (2007); Hall *et al.* (2003) Flaten *et al.* (2005)). We do note that a fairly limited literature suggests that subjective risk perceptions of risk magnitude are not always consistent Eales *et al.* (1990); Pease (1992); Egelkraut *et al.* (2006). Input price risk tends to be identified as of lesser importance in recent surveys, but might rate higher in the current environment. The literature on agricultural producer risk preferences lacks the geographical diversity that one would desire.

While the expected utility hypothesis has been criticized in the literature, it remains the dominant assumption in agricultural risk modelling. Many papers simply impose risk aversion in simulation studies which indicate researcher acceptance of risk aversion but do not scientifically confirm it. A much smaller literature estimates risk aversion parameters (Saha, Shumway, and Talpaz (1994); Antle's (1987); Bar-Shira *et al.* (1997); Kumbhakar (2002); Lien (2002); Love and Buccola (1991)). A synthesis of the studies that have been reported clearly support the assumption of risk aversion (OECD, 2004 Gardebroek (2006)). However some common functional forms such as CARA do not allow comparisons across individuals with differing contexts. Where the CRRA model is used comparisons can be made. Only two of eleven studies suggest either risk neutrality or risk loving behaviour. In most of these papers the minimum CRRA parameter is well above zero. It appears that variation across studies has more to do with individual differences rather than the region or agricultural product produced. This makes cross-country-comparisons of risk aversion somewhat tenuous.

Research and data needs

This summary of scientific literature has already noted various omissions in the research and knowledge. There appears to be a fairly strong consensus that researchers have conceptualized the agricultural producer's risk management problem but data constraints have precluded fully empiricizing models and thus more completely understanding producer decisions or the implications of risk management tools provided by either markets or governments. Our assessment of productive research directions would include the following: identify a population of producers to follow across time to create panels; and survey to obtain farm-level risk preferences, income, consumption, saving/borrowing, and off-farm labour choices. Also, we suggest collecting enterprise-level cash prices and yields and risk management decisions.

Notes

1. Prices tend to exhibit high spatial covariance so they are far less susceptible to aggregation bias.
2. A recent study suggests that under certain conditions (highly inelastic demand that generates prices with "chaotic motion" time paths) liberalization may actually increase world price variability (Boussard *et al.,* 2006).
3. Readers are again cautioned about the difficulty in making meaningful comparisons of domestic price coefficients of variation across countries when countries impose different types and magnitudes of market interventions.
4. Price support programs ensure that the commodity will not be sold at prices lower than the price support. Income support programs do not support prices but instead compensate producers for the difference between the target price and the market price whenever the market price is less than the target price.
5. Likert scale questions are survey question that allows the user to choose the response that best represents his or her opinion relative to a scale reflecting varying strength of opinion.

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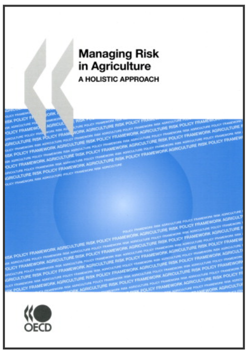

Managing Risk in Agriculture

A Holistic Approach

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