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Risk, Government Programs, and the Environment

Michael J. Roberts
Craig Osteen
Meredith Soule

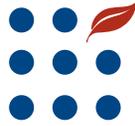




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Michael J. Roberts, Craig Osteen,
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Abstract

Nearly all farm business ventures involve financial risk. In some instances, private and public tools used to manage financial risks in agriculture may influence farmers' production decisions. These decisions, in turn, can influence environmental quality. This bulletin summarizes research and provides some perspective on private and public attempts to cope with financial risks and their unintended environmental consequences. Specifically, it examines the conceptual underpinnings of risk-related research, challenges involved with measuring the consequences of risk for agricultural production decisions, government programs that influence the risk and return of farm businesses, and how production decisions influence both the environment and the risk and average returns to farming.

Keywords: risk, agricultural production, government programs, environment.

About the Authors

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Summary

Prices and yields of most agricultural commodities vary markedly across space and time in unpredictable ways. Farmers must cope with these and other financial risks, sometimes with the assistance of government programs designed, in part, to mitigate these risks. How do these risks and the government programs designed to mitigate them influence what crops farmers choose to produce, amounts they produce, and their production practices? How do farmers' production decisions, in turn, influence environmental quality?

Volumes of basic and applied research address these questions. These volumes encompass many different views of risk and apply many different models. Multiple models are used to address the same empirical phenomena and policy questions, sometimes without the acknowledgement of alternative views. Even fewer articles describe testable hypotheses that might distinguish the empirical relevance of one model as compared to others, which makes it difficult to gain a perspective on all views.

Risk often influences farmers' production incentives, even when the costs of risk-coping are small. In other instances, when risk-coping costs are large, risk affects production incentives in entirely different ways; it may even influence the structure and organization of whole agricultural sectors. This report introduces and reviews the concepts and findings from the disparate literature on risk, government agricultural programs, and their impact on the environment.

The report also provides a roadmap to the different ways risk influences production decisions in agriculture. It describes the market mechanisms that might theoretically exist to provide risk-coping tools for farmers, the reasons why such risk-coping tools may not exist, and the extent to which government programs may alleviate the costs of risk coping. It also describes applied research that examines the links between risk and the production decisions farmers make, how different agricultural production practices influence the risk and returns of farming, and how different production practices influence environmental quality.

After considering many views on the links between risk, government programs, and their impact on the environment, as well as methodological challenges involved with assessing these links, we draw six conclusions. These conclusions are meant to clarify key difficulties involved with research in this area so that future research can work to overcome them. Briefly, we find:

- (1) Many studies emphasize farmers' attitudes toward risk (or "risk aversion") when analyzing farmers production decisions. However, risk can affect farm production decisions through many other channels. For example, greater uncertainty about rainfall may alter a farmer's fertilizer applications, regardless of his or her attitude toward risk.
- (2) In some cases, the effects of risk on production can appear similar regardless of the channel through which they arise. Because policy implications may be different depending on which channel gives rise to the effects observed, it is important to evaluate the relative importance of the different channels.

- (3) Risk is difficult to measure, and the effects of risk are easily confounded by the effects of factors that have nothing to do with risk. Empirical estimates regarding the effects of risk will be more precise if they carefully account for these factors.
- (4) Our understanding of the effects of risk would benefit from an improved understanding of how key environmental factors (such as location, climate, and soil) affect land use. These factors are among those most likely to confound the effects of risk in empirical studies, and are central to understanding the effects of agricultural production on environmental quality.
- (5) Many economic models linking production to risk are static in nature. These models overlook important longrun risks, which are more difficult for farmers to insure against than shortrun risks. Longrun risks are central to key production decisions, including capital investment, technology adoption, crop rotations, and tree plantings.
- (6) Economic models of behavior contain many basic assumptions about the way people make decisions in the face of uncertainty, but experimental research deriving from psychology casts doubt on some of these basic assumptions. The practical relevance of these findings for farmers' production decisions remains poorly understood and is an open area for future research.

Risk, Government Programs, and the Environment

Introduction

Financial Risks in Agriculture

Farming, like many entrepreneurial ventures, has many financial risks. Prices for corn, soybeans, beef, pork, and most other commodities, as well as the inputs used to produce these commodities, can vary widely and in unpredictable ways both during and between seasons. Crop yields on non-irrigated land can be more variable and uncertain than prices.

Uncertain prices and yields are the principal financial risks in agriculture, but there are other risks too. Other important risks pertain to variability and uncertainty in the quality of agricultural commodities, uncertainty about the productivity of new seed varieties and technologies, and, increasingly, uncertainty about future governmental actions, such as the size of future direct payments or new environmental regulations.

How well do farmers cope with these risks? How do these risks influence the crops and livestock that farmers choose to produce, the amount they produce, and the inputs and agricultural production practices they use? How do these input and production practice choices, in turn, affect environmental quality? For over 30 years, economists have studied these questions from many different perspectives, both theoretically and empirically. Yet, despite a plethora of research, few sharp conclusions emanate from it. Indeed, whether or not risk is of any practical importance at all appears to remain a contentious issue (Just and Pope).

Despite the still-ambiguous consequences of risk, concern about risk and farmers' ability to efficiently cope with it has served as an important backdrop for government agricultural support programs. These programs, a mainstay of U.S. agriculture since the Great Depression, have mainly taken the form of price supports and supply control programs. In recent years, government programs that directly tar-

get risk have been expanded to include counter-cyclical payments and newly increased subsidies on yield and revenue insurance. In addition, congressionally approved ad hoc disaster assistance serves to compensate farmers for extreme local weather events that damage or destroy crops. All of these programs transfer wealth to certain farmers from the rest of the economy and reduce specific risks associated with some farm operations.

These policies give rise to questions about how well private markets might function to provide risk-coping tools to farmers in the absence of government policies and to what extent government programs actually alleviate the costs of coping with risk.

New questions have emerged about the magnitude of unintended environmental consequences that may stem both from risk and from government programs. Agricultural production inputs and byproducts, such as pesticides, nutrients, and livestock waste, may cause environmental problems if managed improperly. For example, farmers may overapply pesticides and fertilizer inputs in order to smooth profit flows, which, in turn, may contribute to water quality degradation of streams and lakes. With such a scenario, government programs that insure farm income may have the added benefit of reducing excess applications of environmentally damaging inputs. On the other hand, subsidized crop insurance may encourage farmers to plant crops on fragile lands, which could harm the environment.

Risk also lies at the heart of some theories that characterize the organization and size of farms, which, in turn, may have new environmental consequences. For example, recent trends in the livestock industry indicate growing numbers of farmers are signing contracts with processors rather than producing their product independently and selling via spot markets. This increase in contracting has been associated with an

increase in the size and concentration of livestock farms. As livestock farms become larger and more geographically concentrated, local land areas are unable to absorb all the nutrient waste, creating potential environmental problems. If risk management underlies a driving force behind this structural change, then a better understanding of it will help researchers and policymakers understand the associated environmental problems. Thus, understanding the link between risk and structure as well as the links between structure and the environment can help to inform agricultural and environmental policy.

Objective

This report presents an overview of the interactions between public and private risk management strategies and environmental resources. The report first describes how individual incentives are shaped both by risk and by government programs that possess risk-mitigating properties. Risk can influence production decisions in many ways. Researchers have illustrated these different influences using different modeling approaches. Since different approaches often are used to describe the same phenomena, this report provides a description of all approaches in a single place to help researchers gain perspective on the many ways risk can influence production decisions.

In Chapter 2, we define risk as it is usually understood within economic analysis, explain how markets can trade and thereby share risks, and then review two general ways that risk can influence choices in an idealized world of perfect markets. In Chapter 3, we explain why markets are not perfect and review three additional approaches for modeling risk in imperfect markets. Each approach is presented using the simplest possible example—the goal is not to spell out every implication of every approach, but to illustrate the economic tradeoffs underlying each one, so the reader can see how the diverse views of risk differ. Chapter 3 concludes with a discussion about why risk research appears to lack harmony.

Government programs can influence agricultural risk and returns, and they may directly or indirectly influence the environment. We present a brief overview of the relevant agricultural programs in Chapter 4. Then, in Chapter 5, we characterize the different kinds of production alternatives available to farmers, individually and collectively, and explain how these alternatives may influence risk, returns, and the environment. In Chapter 6, we discuss the complicated interaction of risk, government programs, and the environment, and provide six conclusions that we feel future research should bear in mind.

Chapter 2–Risk in Perfectly Functioning Markets

This chapter defines risk as it is usually modeled and understood within the agricultural economics literature and explains how perfect markets could, in theory, take risk into account. These concepts, which provide the building blocks researchers use to analyze risks, are important for understanding how risk-management policies influence farmers' decisions.

The primary financial risks farmers face involve variations in yields and prices. For example, on a typical corn, wheat, or soybean field in the United States, the **coefficient of variation** (for definition of terms in bold, see glossary at end of each chapter) of year-to-year yields is about 0.3 (Makki and Somwaru). This means that the average field will post a yield of more than 30 percent above or below the historical trend curve, approximately one-third of the time. The coefficient of variation of year-to-year price changes is over 0.2 for most commodities. Because farmers' profits, on average, are only a small share of their total revenues, the large variability of both prices and yields implies that, in any single year, a farmer's profit may vary widely for reasons beyond his or her immediate control. Holding all other factors the same, these numbers imply that revenue for the average "lucky" field and year (those with above-average yields in years with above-average prices) is well over twice that of the average "unlucky" field and year

(those with below-average yields in years with below-average prices).

Risk Versus Uncertainty

Most economists do not draw a sharp distinction between risk and uncertainty. Usually both terms refer to situations in which economic variables vary randomly according to probability distribution functions that are known to decisionmakers. Some draw the distinction that risk refers to instances in which probability distribution functions are known and uncertainty refers to instances in which probability distribution functions are unknown (Knight). This distinction holds particular relevance in empirical analyses, in which researchers almost never know the true probability distributions. In economic modeling of risk, however, economists usually make the assumption that economic agents hold beliefs that are consistent with a known probability distribution function. This view is generally referred to as the *Bayesian* or *Subjectivist* view of probability, and it is the view adopted for most of this report.

The Bayesian view of probability contrasts with the *Frequentist* view of probability, which holds that probabilities equal the relative frequencies from repeated experimental trials as the number of trials tends toward

Assumptions that Imply Perfect Markets

1. **Symmetric information** Economic agents (individuals, firms, community groups, government) have the same set of information about all aspects of production, exchange, and distribution activities, including market opportunities, available technologies, costs of production under alternative production arrangements, the quality of goods produced, and the intentions of other agents.
2. **Large numbers of buyers and sellers** A large number of buyers and sellers of all kinds of goods and services prevents individual buyers or sellers from influencing prices.
3. **Free entry and exit** Economic agents can freely enter and withdraw from markets.
4. **Profit maximization** Economic agents are motivated purely by profit and/or utility maximization and are cognitively capable of making decisions perfectly to achieve these objectives, subject to budget constraints.
5. **No externalities** Actions taken by one economic agent do not directly influence costs or utility of other agents (except via prices).

infinity. Because it is impossible to perform an infinite number of experimental trials, to a *Frequentist*, the true probability distribution function is simply unknowable, which corresponds to the notion of uncertainty as distinct from risk. Except where explicitly stated otherwise, we assume in this report that probabilities are known to the decisionmakers and we use the words risk and uncertainty interchangeably.

Perfect Markets

Theory implies that, when markets function perfectly, there is no particular reason why risks should be a major policy concern in agriculture. Perfect markets do not, however, imply perfect certainty. The assumptions that underlie the perfect-markets condition are still strong and, interpreted literally, unrealistic. Despite their lack of realism, the assumptions that underlie this condition provide a useful starting point from which to construct more realistic models. One may then reconsider (or test empirically) each assumption and hopefully move on toward more realistic models and assumptions, which should lead to a deeper understanding of agricultural production and the implications of agricultural policy.

The perfect-market condition implies that competitive prices and wages exist for all goods and services in all possible contingencies (potential “states of the world”). For example, taken literally, the perfect-markets condition implies that separate and competitive markets exist for a bushel of corn delivered August 30, 2002, contingent on when rainfall in Cowley County, Kansas, is both an inch above normal and an inch below normal in a given month, *holding all other conditions the same*. Accordingly, many refer to a perfect market as one with “complete contingent claims.” To satisfy the perfect-market condition literally, one must imagine an infinite number of separate contingent markets just for corn delivered on August 30, 2002. There would also be an infinite number of markets for corn delivered on August 31, and another infinite number for each and every other good and service (or potential good and service) that might be delivered at every moment into the infinite future.

Although a perfect-markets assumption is implausible, only slightly less implausible is the observation that tradable securities, insurance, and futures markets effectively constitute contingent claims to deal with the largest risks faced by individuals. Furthermore,

contingent claims might be combined in ways to track other risks that are not explicitly traded. For example, a farmer cannot actually sell a bushel of corn in June for delivery in August contingent on a month’s rainfall in Cowley County, Kansas; but he might use a futures market to sell a bushel of corn in June for *unconditional* delivery in August and purchase yield insurance for his crop. Taken together, these claims might well approximate a contingent market for corn deliveries.

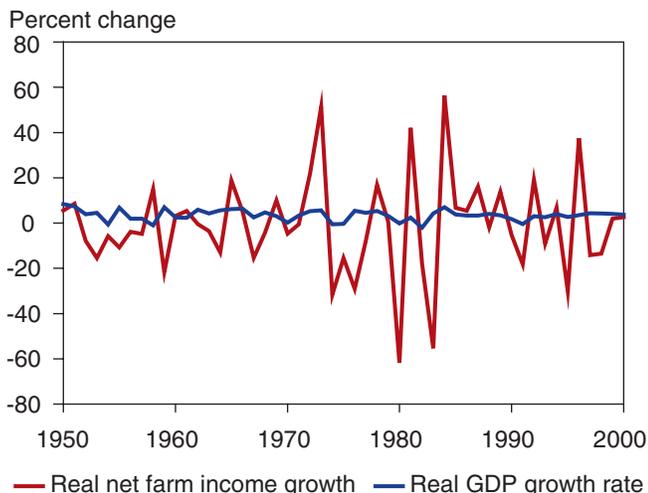
Risk Sharing

Trade in contingent claims effectively allows individuals to share all risks regarding wealth, health, and the weather. If people are averse to risk, then sharing risks reduces the risk that any individual must live with, and thereby increases the welfare of all those pooling their risks. In this way, the gains from risk sharing are much like the economic reasoning that more generally underlies gains from trade. In perfect markets, when all risks are shared, individual risks are averaged across everyone in the population—unlucky outcomes are averaged with lucky outcomes, reducing total risk. Therefore, weather in Cowley County, Kansas, would not be of particular concern. What matters is the aggregate outcome, the cumulative sum of all risks stemming from the weather and otherwise. Farmers would find it beneficial to pool their risks not only with other farmers but also with individuals in other sectors of the economy. Thus, despite the large price and yield risks with which farmers must contend, if these risks are uncorrelated with national income then, in principle, they are completely insurable under perfect markets.

To measure the potential insurability of agricultural risks, one can examine the relationship between farm income and national income. Figure 1 shows the growth rate for real net farm income from 1950 to 2000 overlaid with the growth rate of real gross domestic product (GDP) over the same period. As one might expect, farm income varies far more than national income; however, the two series are positively correlated. It is not readily apparent to the naked eye, but these two series have a positive and (narrowly) statistically significant correlation equal to 0.302—they tend to move up and down together, but just slightly. Because national farm income averages away most of the income risk faced by individual farmers, even nationwide net farm income grossly underestimates the risk faced by a typical farm operation. Under perfect

Figure 1

National income growth and farm income growth



markets, when all income risks are pooled, farmers and all other individuals in the economy would be concerned only with the variability in GDP, which is a small fraction of nationwide farm income and only the tiniest fraction of the income variability experienced by an uninsured (or non-risk-sharing) farm operation. In a nutshell, farm income risk is of no concern to farmers, if markets are perfect.

Decisions under Uncertainty in Perfect Markets

Price and yield uncertainty can influence agricultural production decisions even when markets are perfect. The perfect markets assumption implies that only the best possible decisions will in fact be made and that farmers' individual tolerances for risk are of no relevance to those decisions. However, perfect markets do not imply that decisions in the face of uncertain prices and yields are equivalent to decisions that would be made if prices and yields were certain values fixed at the average level observed in the real world, or if they were variable but known with certainty in advance.

The effects of uncertainty on production decisions result from the physical irreversibility of some decisions and the fact that some decisions must be made before the decisionmaker knows the outcome of a random event. In other words, these kinds of effects have to do with how the flow or level of *information* interacts with the timing of decisions.

A Two-Period Example

Many of the ways in which risk can influence decisions under perfect markets can be illustrated using a simple two-period model of profit maximization. In the first period, farmers make production decisions given their beliefs about the possible outcomes of random events beyond their control (such as the weather). To illustrate, let $\pi(\mathbf{x}, \mathbf{s})$ denote profits as a function of a farmer's production decisions (the vector \mathbf{x}) and exogenous random factors (the vector \mathbf{s}). In perfect markets, farmers are completely insured against uncertain variability in profit itself; so their rational objective is to maximize the expected value of π given their beliefs about \mathbf{s} , which are summarized by a probability distribution function. The value of the farming operation (denoted V) is given by

$$V = \max_{\mathbf{x}} E[\pi(\mathbf{x}, \mathbf{s})].^1$$

The relevance of uncertainty (the randomness of \mathbf{s}) to decisions depends on the shape of the profit function. Consider the neoclassical profit function for a competitive firm where $\mathbf{x} = [L \text{ (labor)}, K \text{ (capital)}]$, $\mathbf{s} = [p \text{ (output price)}, w \text{ (wage)}, r \text{ (rental price of capital)}]$, and the production function $q(L, K)$ transforms labor and capital inputs into a single output q :

$$\pi(\mathbf{x}, \mathbf{u}) = pq(L, K) - wL - rK.$$

Note that, in this example, all prices are uncertain and, because the firm is competitive, prices enter the profit function linearly. One can write the value of the firm as

$$V = \max_{L, K} E[p]q(L, K) - E[w]L - E[r]K.$$

Decisions in this uncertain environment are, therefore, equivalent to an environment wherein prices are fixed at the expected values of the random prices. In general, if one can write the profit function as $\pi(\mathbf{x}, \mathbf{s}) = s_a +$

¹This objective is not correct unless returns to farming are uncorrelated with returns of the aggregate economy. A slightly positive correlation is evidenced between net farm income and GDP, so farm income risk will have a small influence on production choices even in perfect markets. Asset pricing is concerned primarily with the measures of aggregate risk and the covariance of tradable investments such as stocks and bonds (and agricultural production decisions) with the aggregate. This report focuses mainly on the implications of individual farm risks, which are mostly uncorrelated with the aggregate. (See Cochrane for modern review of asset pricing.)

$s_b g(x)$, where s_a and s_b together comprise s and $g(x)$ is an arbitrary production function (profit is a linear function with respect to s), then decisions in certain and uncertain worlds will be equivalent in this way. This result follows from the fact that, in this special case, $E[\pi] = E[s_a] + E[s_b] g(x)$, so that optimal decisions about x depend only on the expectation of s .

This equivalence between choices in certain and uncertain worlds is a special case that crucially depends on three assumptions: (1) perfect markets (or complete risk sharing), (2) all uncertainties enter the objective linearly, and (3) a two-period world wherein all decisions must be made in the first period.² If any one of these three assumptions is altered, this equivalence no longer holds. The rest of this chapter discusses relaxation of assumptions (2) and (3)—the instances where risk matters to decisions even when markets are perfect. The next chapter discusses the implications of imperfect risk sharing.

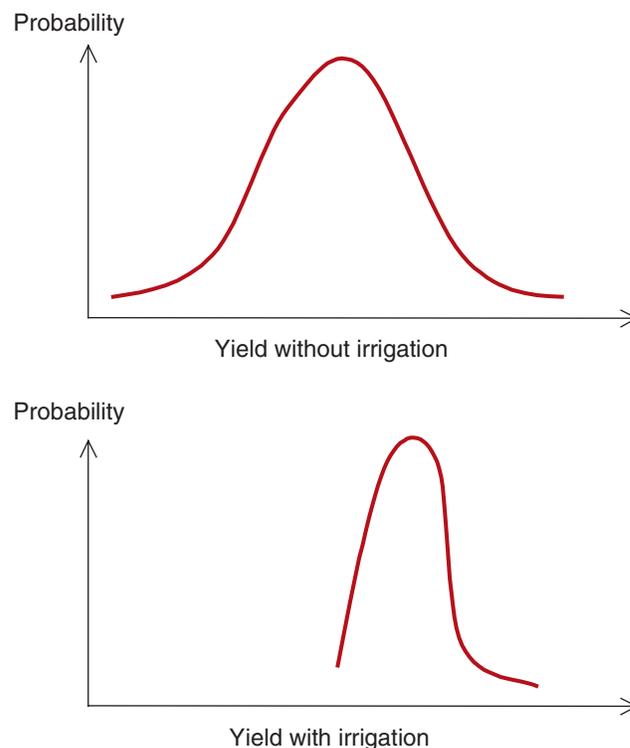
Nonlinear Risks

Statistics suggest that yield uncertainty could be as large as, or even larger than, price uncertainty. Unlike price risks, farmers also might control the degree of uncertainty associated with yields, often in nonlinear ways. For example, irrigation might push up yields at the bottom of the distribution more than those at the top (see figure 2). A linear effect, by contrast, would influence all possible yield levels by the same amount, either additively or proportionately. This nonlinearity negates the above equivalence results for uncertain prices.

The nonlinearity of yield uncertainty in response to certain inputs follows from the nature of plant growth. Justus von Liebig's *Law of the Minimum* states that yield is proportional to the amount of the most limiting plant growth factor, whichever it may be (van der Ploeg). Because the most limiting factor is often supplied by the weather (such as rainwater, sunlight, or an absence of hail or pests), human provision of additional inputs results in higher yields only when those inputs turn out to be the most limiting factor. Thus, irrigation increases yields greatly during years with little rainfall but increases them much less in years with heavy rainfall.

²One may substitute for the third assumption that all decisions are completely and costlessly reversible.

Figure 2
Irrigation affects yield risk in a nonlinear way



The role of risk in perfect markets also hinges on the timing of decisions relative to the resolution of uncertainties. Returning to the irrigation example, if irrigation decisions can be made after observing the rainfall and moisture content of the soil, then the optimal amount can be applied in all states of the world. In this context, more risk really implies more variability in the marginal value of irrigation applications (and in the amount applied). On the other hand, if the investment decision or application amount must be made prior to observing rainfall and moisture content of the soil, then risk affects production in an entirely different way.

Another example is that farmers may sometimes apply surplus nutrients, such as fertilizer and phosphorus, to their crops (Babcock). When plant growth is limited by a factor other than nutrient applications, the excess can build up in the soil and ultimately increase nutrient runoff into streams and lakes, a potentially serious environmental problem.

Why would farmers apply costly surplus nutrient applications if such applications do not result in higher yields? A straightforward explanation involves the way uncertainty about required nutrient applications

enters into the profit function nonlinearly. Pre-existing nutrient levels in the ground are unknown to the farmer and vary spatially across a field. Weather conditions may also preclude mid-season re-entry into the field to adjust nutrient applications as needed. Thus, a farmer must apply nutrients before knowing how much will be needed to maximize plant growth via von Liebig's *Law of the Minimum*.

One can demonstrate the effects of these uncertainties using the two-period model wherein $\mathbf{x} = [n$ (nutrient applications)] and $\mathbf{s} = [\bar{n}$ (the uncertain level of n that maximizes plant growth)], and m is the price of nutrient applications. Profits are characterized by

$$\pi(\mathbf{x}, \mathbf{s}) = \pi(n, \bar{n}) R(n, \bar{n}) - mn,$$

where revenues, $R(n, \bar{n}) = rn$ if $n < \bar{n}$ and equal $r\bar{n}$ if $n > \bar{n}$. The exogenous scalar m (not random) denotes the price of nutrient applications. The associated perfect-markets value function is

$$V = \max E[R] - mn$$

where

$$E[R] = P[n > \bar{n}]rn + P[n < \bar{n}]rE[\bar{n}|n > \bar{n}]$$

$$= (1 - F(n))rn + F(n)rE[\bar{n}|n < \bar{n}].$$

The function $F(\cdot)$ denotes the probability distribution function (or cumulative density function) of \bar{n} . Inspection of this profit function makes clear that uncertainty about \bar{n} is central to the decision about n —it is incorrect to substitute the expected value of \bar{n} for the random variable.

The first-order condition of the optimization problem implies that the economically optimal level of nutrient applications (n^*) solves the equation

$$F(n^*)(1 + nf(n^*)) + n^*f(n^*) - n^* - f(n^*)E[\bar{n}|n^* < \bar{n}] = 1 - m/r.$$

Without further assumptions about the distribution function $F(\cdot)$ one cannot solve explicitly for n^* . It is possible, depending on the distribution function and the ratio m/r , that n^* is either greater than or less than the expected level of \bar{n} . Unless uncertainty about \bar{n} is arbitrarily small, however, an economically optimal

application of nutrients may often induce an agronomically excessive application level. This contrasts with applications in a certain world in which no excess nutrients would be applied. The expected level of excess nutrients is equal to the probability that ($\bar{n} < n^*$) multiplied by the expected value of ($n^* - \bar{n}$) given that ($\bar{n} < n^*$). Mathematically, expected excess nutrients are equal to $F(n^*)E[n^* - \bar{n} | \bar{n} < n^*]$.

Thus, uncertainty about the level of nutrients required for optimal plant growth influences the level of nutrient applications, the level of excess nutrients applied on average, and indirectly, the environmental quality of streams and lakes.³

In general, uncertainty that enters into the objective in a nonlinear fashion will be an important determinant of agricultural production decisions. Except for price uncertainty faced by competitive firms, nonlinear risks are likely to be the rule rather than the exception in agriculture. And when firms are not competitive (that is, they have market power or control over the prices they receive) price uncertainty also may be important.⁴ The existence of market power, however, violates the perfect-markets condition, which is the focus of this chapter.

Dynamic Decisions under Uncertainty

Even when markets are perfect and uncertainty enters the profit function linearly, risks will often influence decisions in dynamic environments. Unlike the two-period model presented above, many decisions in the real world have implications over the long run.

Furthermore, people possess a certain amount of flexibility about the timing of these decisions. For farmers, these longrun decisions include decisions about when to plant a new orchard or replace an old one, whether to alter a previously planned crop rotation in light of changing commodity crop prices, and when to buy a new tractor, combine, or irrigation system.

³Note that if farmers pay nothing for damages associated with excess nutrient applications, then those damages constitute a negative externality, which violates the assumptions that underlie perfect markets.

⁴When a producer holds some market power, it is not precisely correct to refer to "price uncertainty," as if it is exogenous. In such a context, prices are jointly determined by the producer's decisions and by random events beyond his or her control (for example, demand uncertainty).

Three elements, central to relevance of risk to these kinds of decisions, cannot be embodied within the two-period model above. These three key elements are: (1) the irreversibility or partial irreversibility of the decision, such that it entails longrun consequences, (2) the decisionmaker's ability to control both the timing and nature of the decision, and (3) when uncertainty becomes resolved over time, it holds the implications that persist into the future.

We can illustrate all of these features using a slightly more complicated three-period example. In the first period, a farmer may choose to buy a tractor or to wait until period two to make the purchase decision. If he buys the tractor in period one, it will increase his output in periods two and three. If he decides to buy the tractor in period two, it will increase output only in period three. Profits depend on whether or not the farmer buys a tractor and the price of the crop, which is uncertain. The price of the crop in periods two and three will not be learned until period two ($p_2 = p_3$). So the farmer can make a more informed decision if he waits until period two to make it; however, by waiting until period two, he will miss out on the second period's increased output that would have been provided had he purchased the tractor in period one. For this example, suppose that it is worthwhile to buy the tractor if prices turn out to be high but not worthwhile to buy the tractor if prices are low.

Should the farmer wait in the first period? The answer depends on the odds of high versus low prices and how much profit is affected by both the price level and the tractor purchase decision. There are four possible profit levels. Suppose that these are 0 and +1 for low and high prices without a new tractor, and -1 and +2 with a new tractor. In this case it is optimal to wait if the probability of a high price is less than 2/3. If the farmer did not have the option of waiting until period two—that is, the farmer were forced to make his decision in the first period—then he buys the tractor if the probability of a high price is greater than 50 percent.

Note that this example, illustrated in figure 3, possesses each of the above three elements. First, the tractor is assumed to be an irreversible decision. If, after the second period, the farmer could return the tractor for a full refund in the event that prices turned out low, then risk would have no bearing in this model—the decision would be based on the probability of 1/2, not 2/3. Second, the farmer has control over the timing of his

decision. If the farmer were for some reason forced to make his purchase decision in the first period, the same equivalence between the certain and uncertain models described above for the two-period linear model would occur. Third, whether prices turn out high or low in the second period, the random outcome persists into the third period. If the uncertainty were *transitory* rather than persistent (it had no bearing on the price in period three), then whatever the farmer learns about the price in the second period, he learns too late to make any use of it; once again, the choice would be based on the probability of 1/2, not 2/3.

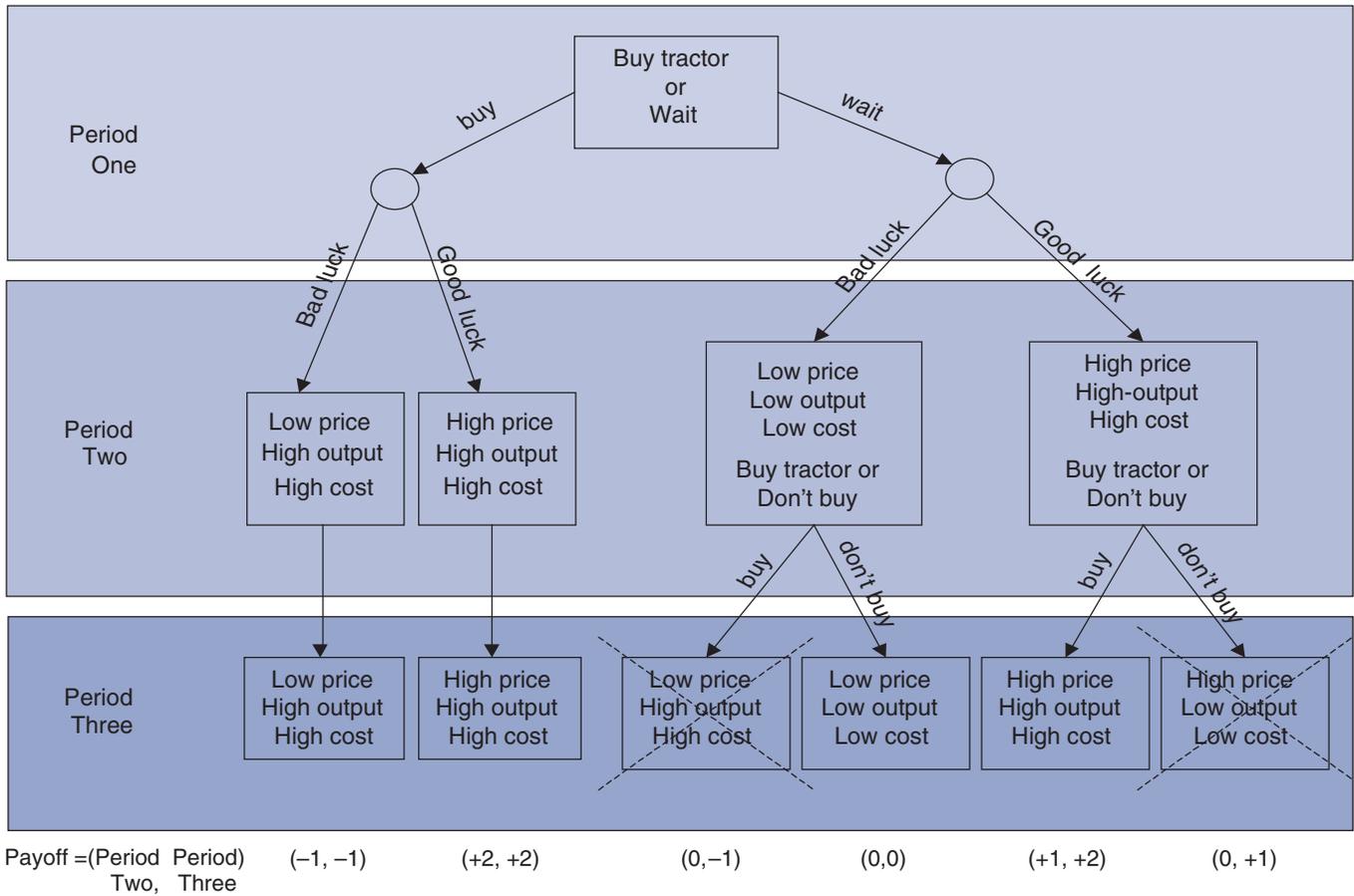
For this three-period example, the lower the probability of high prices, the more likely it is optimal for the farmer to wait until period two to make his decision. In more general problems, the greater the level of uncertainty about the profitability of irreversible decisions, the more likely the farmer is to wait. The intuition is that the greater the level of uncertainty, the greater the amount of *information* the farmer will obtain by waiting to make his decision. Because information is always valuable, a greater flow of it over time is more likely to forestall decisionmaking, all else the same.

Beyond this simple model, how relevant is dynamic uncertainty to agricultural decisionmaking? Some basic features of modern agriculture suggest that it is very important for many decisions. In thinking about the relevance of dynamic uncertainty to a particular decision, one should pose three questions about each of the three crucial elements of the above model: (1) How long-lived or irreversible is the decision? (2) How much latitude does the decisionmaker possess regarding the timing of his or her decision? (3) How much information transpires over time, and for how long does the relevance of information persist into the future?

Many basic decisions in agriculture possess all three elements. Decisions regarding capital investment and technology choices are partially if not totally irreversible. Farmers may be able to sell purchased machinery and equipment but are not likely to procure the full price. There also are transaction costs associated with salvaging machinery. Other kinds of investments, such as drip irrigation systems that entail large installation costs or educational expenses to learn how to implement new technologies, may be totally irreversible (Marra and Carlson).

Figure 3

Sequential decisions under uncertainty



Because both the disposition of the land and the stock of pests to which crops are susceptible depend on what crops were planted in prior rotations, even year-to-year planting decisions entail a certain amount of irreversibility. For example, switching from a corn-soybean rotation to a corn-soybean-soybean rotation involves certain irreversibilities beyond the nominal machinery and human capital investments that may be required for such a change. To the authors' knowledge, there has been no formal supply-response analysis of field-crop rotations in light of dynamic price uncertainty and past irreversible planting decisions. Such an analysis might help to explain why supply elasticities for corn, soybeans, and wheat are seemingly so inelastic. "Waiting" in this context, implies a tendency to forestall altering a crop rotation in light of changing prices. Given large enough uncertainty about future prices, it may take large price swings before farmers are finally induced into switching from previously planned crops.

Irreversibility is clearly important for tree crop plantings and removals. Trees have a long production life, removal is irreversible, and new plantings require several years of growth before they reach full productive capacity. Replacing a current stand with a new stand (and perhaps a new variety) therefore entails large irreversible costs.

Although farmers have full discretion with regard to the timing of most decisions, the third element, the persistence of new information, is more relevant for some kinds of risks than for others. The stochastic properties of commodity prices imply that they are random walks or near random walks. (A pure **random walk** implies that the best guess for next year's price is the current price.) In other words, shocks to commodity prices persist very long into the future. Quite the opposite from prices, yield shocks are highly transitory in nature—yield in one season usually provides little or no information about the level of the next season's yield. Yield variation is due mainly to the

weather, and this year's weather provides little information about next year's weather. Thus, price risks are typically important to dynamic decisions under uncertainty, and yield risks are relatively unimportant, so long as markets function perfectly.⁵

The next chapter examines how risk influences decisions in imperfect markets. In imperfect markets, transitory yield risk can influence decisions in ways different from perfect markets. This difference between yield uncertainty and price uncertainty can be useful in analyses that attempt to sort out the empirical relevance of the different ways risk affects agricultural production. We return to this point in Chapter 3, which includes a brief discussion of empirical strategies.

To analyze dynamic decisions under uncertainty requires the use of dynamic programming. The intuition of dynamic programming, illustrated in the simple three-period example above, utilizes the logic of **backward induction**. As the name suggests, these problems must be solved in reverse chronology, through all possible contingencies in all future periods. For more realistic problems, the dynamic program requires use of a computer to solve. These models also can be econometrically calibrated with economic data (Rust). For certain time-continuous problems one can derive analytical solutions using stochastic calculus (Dixit and Pindyck). Review of these particular methods is beyond the scope of this report.

⁵Note that in the beginning of Chapter 1 we quantified yield risk using deviations from a trend curve and quantified price risk using year-to-year changes. We quantified yield and price risks in these ways because yield shocks are mostly transitory whereas price shocks are mostly permanent.

Conclusion

When markets function perfectly, individuals can share their individual risk so that the only risk individuals intrinsically care about is aggregate risk. However, even when markets are perfect, risk is still important to many kinds of agricultural production decisions. The relevance of risk in this context has to do with the timing of information as compared to the timing of decisions. Within a two-period framework, risks that enter into the objective in a nonlinear fashion influence choices because they must be made without knowledge of certain key variables, such as in the nutrient example. Price uncertainty, however, does not influence decisions in this two-period context because uncertain prices enter into the objective function linearly—choices are equivalent to those that would be made if prices were fixed at their expected level. Risk is also important in dynamic environments when farmers have control over the timing of their decisions. In dynamic environments, farmers must balance the cost of waiting to make a decision against the potential gains that stem from the new information that they might collect.

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Glossary

backward induction	A method for deriving optimal behavior by working sequentially backward in time through all possible contingencies.
coefficient of variation	Measures the proportional variation of some data. It is approximately equal to the <i>average proportional difference from the average</i> . Mathematically, it is equal to the standard deviation divided by the average.
perfect markets	A condition that implies that competitive prices exist for all goods and services in all possible contingencies. The assumptions that underlie the perfect markets condition are summarized in the box on page 3. In the context of risky environments, perfect markets are sometimes referred to as <i>complete market of contingent claims</i> .
probability distribution function	A function usually denoted as $F(x)$ that gives the probability that the realization of a random variable will take on a value less than or equal to x . $F(x)$ is always positive, weakly increasing in x , tends to zero as x tends to negative infinity, and tends to 1 as x tends to positive infinity. It is sometimes referred to as the cumulative density function .
random walk	A time-series stochastic process (y_t) in which the current level of the series includes the sum of all past random shocks—the best guess for next period's level is the current level. Mathematically, $y_t - y_{t-1} = e_t$, where e_t is a random variable independent of all e_i for all i not equal to t .

Chapter 3—Risk in Imperfect Markets

Market Imperfections and Risk

Chapter 2 examined the ways in which risk influences agricultural production decisions when markets are perfect. Among other assumptions, perfect markets imply that a complete (or “as if” complete) set of contingent claims exists to facilitate farmers’ sharing their risks with all others in the economy. In such a world, the good or bad luck of each individual is averaged with the good and bad luck of everyone else, which leaves individual farmers to care only about aggregate risk, not the risk of their particular farm operation. In perfect markets, uncertainty faced by an individual farm operation is relevant to farm-level decisions only to the extent that it embodies a certain lack of information.

This chapter focuses on different consequences stemming from risk. These consequences follow when markets are imperfect, a complete market of contingent claims does not exist, and individuals cannot share all their risks. Amid imperfect risk sharing, farmers may in fact care about the income uncertainty associated with their particular farm operation. For example, in bad years they may be unable to consume as much as they do in good years. The disutility associated with variable consumption, formally defined as **risk aversion**, may cause farmers to alter their production decisions to make farm income less risky and variable. Farmers may also diversify their income-earning opportunities by working off the farm.

Imperfect markets can hinder farmers’ ability to obtain funds to purchase or rent all the inputs required for production. A farmer’s good luck may, therefore, bring unexpected cash flow and, with it, new profitable farming opportunities. On the other hand, bad luck can force a farmer into bankruptcy or a forced sale even when the ongoing farm operation is expected to be profitable. This result differs from perfect markets in which all individuals can exploit all profitable opportunities.

Information-related effects of risk examined in Chapter 2 remain relevant when markets are imperfect; however, there has been little research to examine how information-related effects interact with imperfect risk sharing. Recent theoretical research by Athey is a

notable exception. This chapter focuses on the direct effects of imperfect risk sharing.

Asymmetric Information

In reality, individuals and firms share many risks and often finance production using contingent claims. Individuals and firms often borrow, save, and fund investments using financial markets. But these markets probably do not constitute complete contingent claims—individuals still bear considerable risk that would be insurable in a perfect world. What prevents market participants from trading risks via contingent claims? Why are not *all* risks shared?

The foremost answer to this question put forth by economists is **asymmetric information**. The problem is not that inherent uncertainties exist, but rather that some individuals are better informed than others. Akerlof’s seminal (and Nobel prize-winning) paper, “A Market for Lemons,” put down in formal mathematical language what almost anyone who has bought a used car plainly understands: typically, one who sells a used car knows more about its uncertain quality than a potential buyer. This fact helps to explain why a car is usually worth less than the new purchase price the moment after a buyer drives it off the dealer’s lot.

The logic underlying lemon markets is as follows. Those who buy used cars rationally expect that the car they purchase will be of average quality. Those selling cars of above-average quality are less willing to sell because they can receive only an average-quality price; so some potential sellers choose to keep the car. Buyers rationally understand that those with high-quality used cars are less likely to sell, so the buyers are willing to pay only a lower-than-average quality price. As a result, sellers of even average-quality cars are less willing to sell, because they cannot receive even an average-quality price. And so on.... Thus, used car markets are thinner than they would be if car quality were plainly observable—that is, if one could costlessly spot “a lemon.”

The general observation that some individuals are better informed than others helps us to understand why some markets, including those for certain contingent claims, will not always exist. And when they

do exist, they will differ from those predicted in perfect markets.

Individuals and firms work to overcome inefficiencies caused by asymmetric information by writing contracts, developing reputations for high-quality goods and services, offering “money back guarantees,” and so on. These mechanisms constitute costly signals that markets can use to credibly communicate information from one party to another. However, due to the costs embedded in sending these signals, these mechanisms will not work to share all risks.

The two main conceptual ideas used to better understand asymmetric information environments are **adverse selection** and **moral hazard**.⁶ The tension underlying each of these ideas can be presented as an optimal contract between informed and uninformed parties, labeled respectively as the “agent” and the “principal.”

Adverse Selection

Adverse selection involves situations in which the agents know something about their situations the principals do not know, e.g., the used-car sellers in Akerlof’s market for lemons. From the perspective of the principals, they would like to write different contracts for different types of agents. For example, some agents may own riskier farms than others, and insurance companies (the principals) would like to charge different premiums for different risk classes. They cannot do so because they cannot distinguish the riskier classes from those that are less risky. In some situations, the problem of adverse selection can be partially overcome by offering menus of contracts to agents who reveal their types through the contracts that they select. For example, insurance companies typically will offer a menu of different premium-deductible combinations to differentiate high-risk types from low-risk types (Makki and Somwaru). Indeed, according to the **revelation principle**, an optimal insurance scheme will always induce agents to reveal whether they are low risk or high risk. But, in some situations, these markets simply will not exist—some risks are uninsurable.

⁶A third type, called **hidden information**, is closely related to adverse selection, so we do not review it here. See Chapter 14 in Mas-colell, Whinston, and Green for an explanation of this kind of asymmetric information as well as more formal presentations of adverse selection and moral hazard.

Moral Hazard

The problem of moral hazard involves situations in which both parties know the probability distribution of possible outcomes but in which the agents’ decisions are not explicitly contractible. For example, the physical and mental effort exerted by a laborer may not be measurable in a way that can be explicitly defined in a compensation contract. In moral-hazard environments, the principal and agent must write a second-best incentive scheme based on some observable and verifiable outcome(s), such as yields, prices, and/or profits. The observable outcome depends on the agent’s decision (usually called “effort”) but also on luck. Because the agent’s compensation depends on luck in addition to his decisions or effort, his income is not completely insured. Indeed, Robert Shiller regards moral hazard as the chief reason why not all risks are shared:

“Living standards are not fully insurable because of moral-hazard problems: if people or organizations knew that their income were guaranteed regardless of the amount of effort that they put in, then there would be a markedly reduced incentive to make efforts to maintain income.” (Shiller, p. 1)

Thus, moral hazard embodies a natural tension that arises between insurance (risk sharing) and incentive provision.

Adverse selection and moral hazard give compelling reasons for why risks are not insured. The focus of this report, however, pertains to the *consequences* of imperfect risk sharing for agricultural production choices. Are agricultural production decisions different because farm income (or profit) risks are not fully insured? If so, how are they different?

The answers to these questions depend on the model used to answer them. Below we review three broad departures from perfect markets that are often used to shed light on how imperfect risk sharing might influence agricultural production. First, however, we review economists’ standard definition of risk aversion, because it is often the cornerstone of these departures.

Risk Aversion

Since publication of seminal papers by Arrow and Pratt, the notion of “risk aversion” to economists has been synonymous with “diminishing marginal utility of consumption.” Because consumption is inextrica-

bly tied to an individual's wealth, under certain conditions, it is also synonymous with "diminishing marginal utility of wealth." In other words, the richer one is, the less one values an additional dollar. And the more risk averse one is, the more rapidly one's marginal utility declines with one's level of consumption or wealth.

Mathematically, if utility is defined as $u(c)$, where c represents consumption, risk aversion implies that $u''(c) < 0$ (' and '' denote the first and second derivatives, respectively). If consumption is random with an average value of c^* then risk aversion ($u''(c) < 0$) implies $u(c^*) > E[u(c)]$: the utility of average consumption is greater than the expected utility of consumption. The two measures of risk aversion, pioneered by Arrow and Pratt, are the coefficient of absolute risk aversion ($-u''(c)/u'(c)$) and the coefficient of relative risk aversion ($-c u''(c)/u'(c)$). In accordance with these two measures of risk aversion, there are two commonly used utility functions in which these measures of risk aversion are the same, regardless of the amount consumed. Given a measure of risk aversion r , these two utility functions are

Constant absolute risk aversion (CARA):

$$u(c) = A - e^{-rc}$$

Constant relative risk aversion (CRRA):

$$u(c) = -Ac^{(1-r)}/(1-r)$$

In both utility functions, larger r implies more risk aversion—a larger difference between $u(c^*)$ and $E[u(c)]$ for the same probability distribution function of c .

For dynamic models in which utility is additively separable over time, risk aversion also measures the elasticity of intertemporal substitution. Indeed, the concepts of intertemporal substitution and risk aversion are very similar: the first measures willingness to substitute consumption between one period of time and another; the second measures willingness to substitute between one "state of nature" and another. In the first case, the more inelastic the intertemporal substitution, the more one prefers a smooth consumption profile over one that grows or diminishes rapidly with time; in the second case, the more risk averse one is, the less one prefers more uncertain consumption over less uncertain consumption. The two concepts are identical if an individual's overall utility (after the fact) through

a period of fluctuating consumption is the same, whether or not the fluctuations in consumption were anticipated before the fact.

Although diminishing marginal utility makes good common sense, to some it may seem strangely disconnected from the notion of risk. Indeed, there is growing skepticism in psychology and some areas of economics about the fundamental (behavioral) equivalence of risk aversion and diminishing marginal utility (Kahneman and Tversky; Rabin, 2000). This skepticism stems in part from observed levels of risk aversion, both experimentally and in market data, that are so large as to defy rationalization via diminishing marginal utility (Mehra and Prescott; Rabin, 2000). Furthermore, although the concepts of risk aversion and intertemporal substitution are conceptually quite similar, empirically they differ substantially (Weil).⁷

Aside from pushing economists to reconsider their notion of risk aversion, these empirical findings imply that even a modest amount of unshared agricultural risk could be crucially important to many agricultural production decisions.

No Risk Sharing

The most prevalent way to model the effect of imperfect risk sharing on agricultural production choices follows an influential paper on price uncertainty by Sandmo that assumes no risk sharing at all. This approach assumes that farmers choose inputs to maximize a static, concave (risk-averse) function of profits, like the utility function described in the last section except that current profits are substituted in place of consumption. This objective appears similar to the two-period objective presented in Chapter 2, except it is the expected "utility" of profits that is maximized rather than just expected profits.

Again denoting production decisions by the vector \mathbf{x} and exogenous random factors by the vector \mathbf{s} , the value of the farm operation is given by

$$V = \max_{\mathbf{x}} E[u(\pi(\mathbf{x}, \mathbf{s}))].$$

⁷See the box, "The Equity Premium Puzzle" (p.17).

Because the utility function is itself a nonlinear function of profits, random factors will influence optimal decisions even when they enter into the profit function linearly. Thus, the equivalence of production decisions, whether or not prices are uncertain, no longer holds as it did in Chapter 2. All kinds of uncertainty now matter for production decisions.

This optimization problem, the solution to which characterizes the way risk influences production choices, is somewhat more complicated than the two-period problem of Chapter 2. We can characterize an approximate solution to the general problem by taking a second-order Taylor expansion around the average (or expected) level of profits. Specifically, we can approximate by

$$V \approx \max_{\mathbf{x}} u(E[\pi(\mathbf{x}, \mathbf{s})]) + \frac{1}{2} u''(E[\pi(\mathbf{x}, \mathbf{s})]) \text{VAR}(\pi(\mathbf{x}, \mathbf{s})),$$

where $\text{VAR}(\pi(\mathbf{x}, \mathbf{s}))$ denotes the variance of profits.

Because risk aversion implies negative u'' , production decisions that increase profit variance, all else the same, are underutilized in comparison to those in a perfect-markets world; while those that decrease profit variance, all else the same, are over-utilized in comparison to those in a perfect-markets world.

Production decisions that may influence the variance of profits include the applications of specific inputs, such as nitrogen and pesticides, as well as allocations of acreage between crops. Because crop returns will not be perfectly correlated, an incentive to mitigate risk through crop diversification is built into this objective (Freund).

Although the no-risk-sharing approach may seem as extreme and unrealistic as perfect markets, the no-risk-sharing assumption is relatively simple analytically. It allows one to see how risk may influence farmers' decisions when they can avail themselves of very few risk-coping tools. The problem with using such extreme assumptions is that it attributes all nonlinearity in the current-period objective to risk preferences. In reality, farmers' preferences may matter, but the nature of the constraints that prevent them from sharing (or insuring) all of their risks probably matters more.

One might, however, interpret the risk-aversion coefficients estimated within this paradigm loosely—not as

preferences per se, but as an amalgamation of preferences and constraints on risk sharing. This interpretation, however, could be misleading, in part because constraints may be more binding in some states of the world than in others. For example, a farmer with large cash reserves and little debt may be better able to self-insure against random income shocks than a farmer with small cash reserves and large debts may. The static risk-averse objective cannot encapsulate these time-varying constraints.

More important, however, there is no reason to believe that the nature of the constraints will be such that they can be approximated by a smooth, concave utility function. This modeling approach thus obscures important features of these constraints. Indeed, it is possible that a risk-neutral or risk-averse individual will appear to be risk-loving, given the asymmetric information environment in which the person resides (Ghatak and Pandey). This point is explained in more detail below in the discussion about contracting.

Despite these shortcomings of the no-risk-sharing approach, its simplicity, as compared with other ways of modeling the influence of risk, has inspired a large literature that examines the effects of risk on agricultural production decisions. It has been applied to interesting analyses of production scale, technology, and crop allocation decisions (e.g., Just and Zilberman, Just *et al.*, Freund).

Credit Constraints

In perfect markets, it is inconsequential whether capital investment is financed with retained earnings, equity, or debt, an important result first observed by Modigliani and Miller. One implication of asymmetric information, however, is that it may preclude financing of some profitable farming operations (Stiglitz and Weiss, Jaffee and Russell, Jensen and Meckling). If asymmetric information prevents farmers from obtaining external funds to finance their operations, then they may need to accumulate funds on their own via savings or retained earnings, contrary to Modigliani and Miller.

Farm income risk holds new implications in this environment. Good luck, perhaps in the form of higher-than-expected prices and/or yields, may provide a farmer with resources to finance an operation for which the farmer could not previously obtain funds.

The Equity Premium Puzzle

Through the study of financial markets, researchers have learned that individual behavior toward risk is complex and that it is probably different from that depicted in standard economic models. Perhaps most noteworthy is the observation that over the last 100 years stocks have earned, on average, a premium of 6 to 8 percent greater than the returns of Treasury bills and other low-risk investments, a phenomenon normally explained by risk aversion. The degree of risk aversion implied by this premium is very large, a well-known observation in finance called the “equity premium puzzle” (Mehra and Prescott; Hansen and Jagannathan; Rabin, 2000).

The size of the stock-market premium is puzzling because aggregate consumption growth is relatively smooth. In other words, the fluctuations of the stock market have caused little variation in consumption, so the only way the large risk premium and small consumption variability can be reconciled under the standard notion of risk aversion is if people are extremely risk averse. In fact, researchers have shown that (regardless of assumptions about individual preferences) the stock market premium implies that the marginal value of a dollar varies by an average of 30 to 50 percent per year or more (Hansen and Jagannathan).

If a small but non-negligible portion of the population held a more modest degree of risk aversion (such that they were willing to tolerate somewhat larger consumption variability in exchange for much greater consumption growth), then the premium would be driven down via competition. These individuals would sell low-risk assets and buy stocks, ultimately pushing down the price of safe investments and bidding up the price of stocks, thereby reducing the size of the premium. Therefore, the equity premium puzzle not only implies that some people are very risk averse, but that most people are very risk averse.

The equity premium puzzle becomes even more confounding when the level of risk aversion implied by it is checked against the historical patterns of interest rates and consumption growth. To understand this alternative viewpoint, it is important to recognize that the concepts of risk aversion and intertemporal substitution are conceptually quite similar—the first measures willingness to substitute consumption between one “state of nature” and another, and the second measures willingness to substitute consumption between one period of time and another. In standard economic models of consumption, these concepts amount to the same thing: variation in marginal utility caused by consumption variation. A high degree of risk aversion therefore implies highly inelastic intertemporal substitution—people are very unwilling to substitute consumption over time.

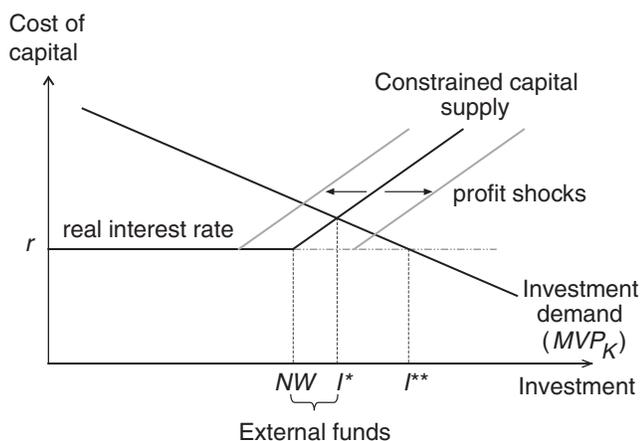
If individuals are unwilling to substitute consumption between one period of time and another, and consumption is growing, then they would have a strong desire to shift future consumption toward the present. The collective desire to shift future consumption to the present should drive interest rates up to levels higher than actually observed. This phenomenon has been termed the “risk free rate puzzle” (Weil). Furthermore, as consumption growth fluctuates over business cycles, interest rates also should fluctuate far more than they actually do.

To resolve these and other puzzles, economic researchers are increasingly turning toward psychological models of behavior. (See the section “An Addendum on Psychology-Based Models, p. 21”.) In the future, researchers may wish to investigate whether these empirical observations from finance are relevant to farmers’ decisions in light of the financial risks they face.

Bad luck, on the other hand, may cause a farmer to scale back previously planned (though still profitable) operations due to a new shortage of funds. In an extreme case, a farmer may be forced to sell or declare bankruptcy, even when the ongoing farm operation is expected to earn acceptable profits over the long run. In short, the existence of credit constraints implies that it sometimes takes wealth to make wealth.

The anatomy of credit-constrained capital investment is depicted in figure 4 (also see Hubbard). In perfect markets, a firm chooses inputs to maximize expected profits, which implies that the marginal value product (MVP) of an input is set equal to the price of the input. Thus, in perfect markets, the marginal value product of capital (MVP_K) should equal the interest rate (assuming no capital depreciation). This unconstrained level of investment is depicted as I^{**} in figure 4. However, if asymmetric information constrains farms from borrowing investment funds or otherwise obtaining them externally, then investment will be lower than in perfect markets. One might imagine that the cost of capital to a farmer equals the real rate of interest so long as the level of investment is less than the current net worth (NW). To borrow funds beyond NW becomes more costly, as depicted by the upward sloping “constrained capital supply” curve. Given a sufficiently high level of investment demand or sufficiently low NW , the constrained level of capital investment (I^*) will be less than the unconstrained level.

Figure 4
The effect of credit constraints



Notes: NW is the internal net worth of the firm or individual; I^* is the optimal (credit-constrained) investment; I^{**} is unconstrained investment; r is the real interest rate; MVP_K is the marginal value product of capital.

Because income or profit shocks influence NW , these shocks also influence the constrained supply of investment funds and the level of investment. The effect from profit risk is quite different from those previously discussed. In some circumstances, the effect may be difficult to sort out empirically from other kinds of effects. For example, a shock to the price of an agricultural commodity is likely to persist into the future (see Chapter 2). The price shock, therefore, shifts out the supply of capital by increasing NW , but also shifts out the demand for capital. Any attempt to measure the effect of the credit constraint requires careful control of investment demand. Due to the effects of dynamic uncertainty discussed in Chapter 2, controlling for investment demand can be difficult.

Sometimes credit constraints can restrain capital investment (or other inputs) even without a shortfall in wealth, if wealth is illiquid or otherwise costly to quickly leverage in order to obtain funds precisely when needed. In this context, credit constraints are sometimes called liquidity constraints.

Most of the research on credit constraints involves empirical tests regarding their mere existence—whether or not capital investment is sometimes fore-stalled due to a shortfall of cash. These findings have been used to assess whether and how much business-cycle fluctuations in the macro economy stem from investment cycles that derive from liquidity constraints (Hubbard). Much of this research finds evidence of liquidity constraints in manufacturing and other sectors of the economy. Additional research reports a certain amount of skepticism regarding these empirical findings, in part because of possible confounding of investment demand and supply shocks noted above (Gomes). A lot of research also examines the role of credit constraints to agricultural production, consumption, and poverty in developing countries (Bardhan and Udry).

Several papers have tested for credit constraints in U.S. agriculture (Bierlen and Featherstone, Hubbard and Kashyap, Barry *et al.*); all of these papers report evidence that these constraints are important. Farmers also tend to save more than people with other kinds of (presumably less risky) occupations and tend to hold a disproportionate share of their assets in farmland and farm capital (Carroll). The Economic Research Service (ERS) reports that U.S. farm households have a higher average income than nonfarm households

(\$61,947 vs. \$56,313 in 2000) and higher average net worth than nonfarm households (\$492,195 vs. \$272,083 in 1998), yet they consume less on average than nonfarm households (\$27,981 vs. \$35,250 in 1998) and, therefore, save more. ERS reports that, in 2001, 63 percent of farm households held half or more of their wealth in farm business assets. Farmers also report that they use cash reserves as their primary method of risk coping (Harwood et al.). These facts suggest that the role of self-finance, and therefore risk in light of credit constraints, appears to be a key feature in agriculture. Unlike the no-risk-sharing model, the importance of risk is not driven by individual tastes, such as risk aversion or diminishing marginal utility of wealth.

The main focus of this report, however, is whether risk (and in this case, whether risk in light of credit constraints) influences the nature of agricultural production decisions in the United States. We are especially interested in decisions that pertain to environmental quality. To our knowledge there has been little research that explicitly examines the role of credit constraints to decisions besides capital investment, nor any empirical research that attempts to identify the environmental consequences of these constraints (at least outside of developing economies).⁸ These effects could be more complicated than our simple presentation above. Credit constraints may lead farmers not only to reduce the quantity demanded of certain inputs such as capital, but also to substitute other, less expensive (and less efficient) inputs, and to manage already-owned resources less efficiently than if they were not credit constrained. For example, credit-constrained farmers might plant more high-value, but land-degrading, crops; or they might delay adoption of conservation practices in the short run in the hope of building up financial resources to afford more efficient longrun decisions in the future. They might also be less inclined or less able to adopt expensive irrigation or precision technologies, which may influence environmental quality.

Contracting Models

Because asymmetric information provides the theoretical underpinnings of both the no-risk-sharing and credit-constrained approaches to modeling imperfect mar-

⁸An exception by Roberts and Key examines the effect of credit constraints on planting decisions.

kets, perhaps the most theoretically pleasing approach is to build the asymmetric-information environment explicitly into the model. This approach is the one taken by the contracting literature (Hueth and Hennessy).

This section illustrates the contracting approach and describes the nature of the theoretically optimal contract in moral hazard environments. Recall that moral hazard environments involve situations in which specific actions taken by an individual (such as a farmer supplying labor and other inputs) cannot be contracted explicitly by an outside interest (such as a landlord, bank, or other financier). Instead, an incentive contract is written whereby the individual is compensated based on some observable and verifiable outcome that depends on both the individual's supplied inputs and random events outside the individual's control—both inputs and luck matter for output. If the individual is risk averse, then such an incentive contract is always second best, because uncertainty in the individual's compensation causes "excessive" risk bearing which must be shouldered in order to provide incentive for the individual.⁹ If the contract paid a fixed wage, and thereby protected the contractee from risk, then the contractee would have no incentive to apply costly inputs. If the inputs themselves were contractible, then the optimal action could be undertaken while providing full insurance to the individual (if the outside party is risk-neutral). The problem involves a tension between providing the right incentives versus providing income insurance.

The standard analytical setup typically is as follows. A business venture earns stochastic profit $\pi(\mathbf{x}, \mathbf{s})$, which depends upon a vector of inputs (\mathbf{x}) applied and the outcome of some random variables \mathbf{s} . For example, \mathbf{x} could index the on-farm costs for inputs and labor and \mathbf{s} the random events related to weather. Suppose that another individual owns the business venture and cannot explicitly contract the laborer's choice for \mathbf{x} , and therefore must choose a compensation scheme for the laborer based on realized profits, $\pi(\mathbf{x}, \mathbf{s})$. The contract is defined by the function $w(\pi)$ —

⁹The word "excessive" is in quotes because some might disagree with its use in this context—because in a world with asymmetric information, the information-constrained optimum is the best that one can do. The term is used here only to highlight the tradeoffs that must be made in the moral hazard environment that are not present in a perfect-markets world with fully contractible inputs.

given realized profits π , the laborer gets $w(\pi)$ and the owner gets $\pi - w(\pi)$.

The value of the contract to the principal (such as a bank or financier) is defined by

$$V = \max_{x,w(\cdot)} E[\pi(\mathbf{x}, \mathbf{s}) - w(\pi(\mathbf{x}, \mathbf{s}))]$$

subject to: $E[u^{lab}(w(\pi(\mathbf{x}, \mathbf{s}))) \geq \underline{u}$ (IR constraint)

and

$$x = \arg \max_x E[u^{lab}(w(\pi(\mathbf{x}, \mathbf{s})))]. \quad (\text{IC constraint})$$

The IR (individual rationality) constraint ensures that the laborer's expected utility under the contract is greater than or equal to the laborer's opportunity cost (\underline{u} , a lower bound for the laborer's utility). The IC (incentive compatibility) constraint ensures that the laborer's effort is at an optimal level given the contract $w(\pi)$.

The solution to this contracting problem can be complicated, even when both the vectors \mathbf{x} and \mathbf{s} contain only one variable. Even in this simple case, one cannot be assured that the contract $w(\pi)$ is monotonically increasing or even continuous—in general it can be highly nonlinear.

The ambiguous shape of the contract curve implies that production decisions in asymmetric environments can be influenced by risk in complicated ways. In the first model presented in Chapter 2, the farmer chose \mathbf{x} simply to maximize expected profits, $E[\pi]$; in the no-risk-sharing model, this was generalized to maximization of $E[u(\pi)]$; under the optimal contract, the objective is generalized further to maximization of $E[w(u(\pi))]$.

This report shows that it is nonlinearity of one form or another that makes risk important to decisions. Within a static (two-period) environment, there are now three layers of nonlinearity that must be assessed in order to trace out the influence of risk. The first layer entails nonlinear influence of uncertainty on profits; the second layer entails individual preferences (curvature of the utility function); and the third layer entails nonlinearity in the incentive scheme ($w(\cdot)$). This third layer is by far the most complicated. The nature of the incentive scheme (its nonlinearity) is

itself determined by the nature of the uncertainty and how decisions made by the farmer influence those risks. That is, the contract and risk are jointly dependent on each other. In the first two layers, at least the objective was exogenous.

Furthermore, the nature of nonlinearity in the contract scheme is more ambiguous than in the other two layers. Nonlinearity of the first layer is governed by features of the production function about which natural science may provide some insight, such as von Liebig's *law of the minimum*. Nonlinearity in the second layer is governed by reasonable assumptions about individual preferences—that is, diminishing marginal utility of consumption. In the third layer, however, small differences in the environment may lead to very different contract shapes, which may be discontinuous as well as nonlinear. This means that risk could have almost any conceivable influence on production choices, depending on subtle features of the profit function and the probability density function for \mathbf{s} .

Finally, this problem differs from reality by its static nature. Compensation schemes will be complicated further when they take into account the sequential flows of information, input decisions, and profits (Antle).

The complexity of even the simplest asymmetric information problems creates large empirical challenges. Although the tensions posed by the moral hazard problem are representative of those in many production, marketing, tenure, and debt contracts observed in agriculture, and though it seems clear that asymmetric information in conjunction with risk will influence agricultural production decisions, developing testable hypotheses with regard to these effects is difficult. Theory alone cannot predict whether imperfect markets increase or decrease input use of any particular kind of input, even in the simplest representations of the problem.

Transaction Costs and Industrial Organization

Ronald Coase's 1937 article, "The Nature of the Firm" raised and answered a fundamental question: Why do firms exist in a market economy? In a world of perfect markets, all factors in the economy, including material inputs, labor, and technologies, are priced and traded in competitive exchange—all production decisions are decentralized. A firm, by contrast, is a cen-

tralized institution of decisionmaking in which many intermediate factors are produced and freely provided within it. What determines the size and nature of firms, these centralized decision-making units?

Coase's answer to these questions is **transaction costs**. Transaction costs between individuals or firms are those associated with finding goods and services and negotiating prices for them. Transaction costs within firms include costs of monitoring workers or otherwise providing incentives that induce them to make choices and exert efforts as instructed by their managers. Coase hypothesized that the size and nature of firms is determined by an optimization problem: the industry structure we observe is the one that minimizes transaction costs. Since Coase, transaction costs have been used to explain the structure and organization of all kinds of social and political institutions (Williamson).

One modern interpretation of transaction costs involves the loss of efficiency embedded in the second-best incentive schemes of asymmetric-information environments. These transaction costs are sometimes called **agency costs**. As a crude model, we might imagine that, within a firm, workers earn fixed wages; but the firm must employ costly tiers of managers to monitor their work. In other words, workers' actions (elements of the vector x in our modeling approaches) are explicitly contracted, but at a cost. Between firms, prices serve as a second-best incentive scheme, as in the moral hazard contract. Firm size, industry size, and organization evolve so as to minimize the sum of these within-firm and between-firm transaction costs, which include agency costs. The moral hazard model of the last section showed that an important kind of agency cost depends on the amount of risk—the optimal contract involves balancing a natural tension between incentive provision and insurance. Thus, the greater the level of risk, the greater the agency costs, all else the same.

The point is that because risk is central to agency costs, an important kind of transaction cost, risk may also be important for understanding the size and organizational structure of farms. And the structure of agriculture may entail important environmental consequences.

Historically, farms have been among the most decentralized production units in our economy. Even today, sole proprietorships and partnerships account for a majority of U.S. farms and total agricultural produc-

tion value.¹⁰ For some commodities, however, this structure is beginning to change. Producers are increasingly signing production and marketing contracts with processors who often provide many of the material inputs to production. The institutional distinction between the farm and the processor is becoming less clear.

Furthermore, in some industries, the prevalence of contracting has been associated with larger farm operations and a greater geographic concentration. The hog and broiler industries are striking examples of these trends. A related environmental challenge involves the management of nutrient waste originating from the increasingly concentrated livestock industry. Local cropland and pastureland cannot physically assimilate the high concentration of this waste (Gollehon et al.).

Theoretically, risk, structure, and environmental quality are related. Empirically, structural change and environmental quality are geographically correlated for certain livestock industries. However, because there are many kinds of transaction costs besides risk-related agency costs, the causal link between risk, structure, and the environment remains ambiguous.

An Addendum on Psychology-Based Models

Most of the research on agricultural risk is based on expected utility theory (EUT). Expected utility theory also provides the basis to substantiate economists' notion that risk aversion is synonymous with diminishing marginal utility of consumption. Formally, it says that preferences are linear in probabilities: the value V an individual places on the probabilities $P(s)$ over possible states of the world (s) that yield utility $u(s)$ is equal to $V(P(s), u(s)) = \sum P(s)u(s)$.

The key assumption underlying EUT—the one with the least obvious implications and the one that has received the greatest amount of skepticism—is the independence axiom. The independence axiom is a

¹⁰In 1997, sole proprietorships made up 86 percent of U.S. farm households and produced 53 percent of U.S. farm product sales. See the USDA-ERS briefing room on farm structure, <http://www.ers.usda.gov/briefing/FarmStructure/Questions/Closeup.htm>

close cousin of the transitivity assumption in standard, certain-world utility theory. It says that a linear transformation of a set of lotteries should not alter an individual's ranking of lotteries. That is, if an individual prefers lottery A to lottery B, then after probabilistically combining these two lotteries with a third lottery (say, C), the individual should prefer the augmented lottery A over the augmented lottery B. For example, the independence axiom implies that if A is preferred to B, then (50 percent chance of A + 50 percent chance of C) must be preferred to (50 percent chance of B + 50 percent chance of C).

To make the above example concrete, suppose lottery A is \$3,000 for sure, lottery B is an 80-percent chance of \$4,000 and a 20-percent chance of \$0, and lottery C is \$0 for certain. If one prefers lottery A to lottery B (as most people do in experimental trials), then the independence axiom implies that (25 percent chance of A + 75 percent chance of C) should be preferred to (25 percent chance of B + 75 percent chance of C). The second two lotteries amount to (a 25-percent chance of \$3,000 plus a 75-percent chance of \$0) and (a 20-percent chance of \$4,000 plus an 80-percent chance at \$0). Contrary to the independence axiom, in experiments most people prefer augmented lottery B over augmented lottery A despite their preference of unaugmented lottery A to unaugmented lottery B (Kahneman and Tversky).

This and other experimental anomalies have cast broader doubt on all economists' standard risk-modeling approaches. Other notable anomalies include a tendency by individuals to overweight small-probability events, to be risk averse with respect to losses and risk loving with respect to gains, regardless of wealth, and to choose differently between substantively identical alternatives depending on how the alternatives are "framed." Although these anomalies have been well known for many years, and many generalizations of EUT have been developed in attempts to accommodate experimental findings, little research applies these generalizations to observed agricultural production decisions. Applications in mainstream economics are just beginning to gain wider acceptance and application.

Application of these experimental phenomena to observed economic behavior remains a new frontier in economic research. Delayed application of non-expected utility theories has been slow to arise due to basic questions that remain about how to interpret the experi-

mental findings for application to real economic behavior. Consider, for example, an essential difference between experimental risk behavior and real-world behavior under uncertainty: in an experimental setting, probabilities are objective values provided by the experimenter; in the real world, probabilities are subjective beliefs or "feelings" an individual holds about possible outcomes. It is not clear that individuals hold the cognitive ability to connect their beliefs (or feelings) to the rational concept of probability. But, it is possible that individuals' behavior is in accordance with expected utility outside of an experimental setting, even if individuals cannot articulate those beliefs in objective terms, such as probabilities. For example, it seems unlikely that a randomly chosen individual can accurately report the probabilistic odds of experiencing a car accident on two alternative driving routes, but that person may still be capable to choose between them, perhaps in accordance with EUT. If an individual can choose without articulating probabilities, then one might want to reconsider the practical relevance of decisions made in an artificial experimental context, wherein objective probabilities exist, but wherein the individual has not experienced the probabilities so as to internalize exactly what they portend.

Another reason that few researchers have applied non-EUT theories (so-called "generalized expected utility theories") is that many of these alternative theories also fail to match all experimental evidence (Camerer).

Experimental evidence aside, some economic data suggest a psychological basis for some decisions under risk. Despite enormous research efforts, the so-called "equity premium puzzle" (see the box on page 17) remains deeply puzzling to financial economists. And leading theories that try to reconcile the large premium that stocks earn over bonds are increasingly looking toward psychological motives with roots in habit formation, herd behavior, and generalized expected utility models (Cambell and Cochrane, Shiller, Epstein and Zin). Psychology-based models have also been used to explain certain features of life-cycle consumption behavior (O'Donoghue and Rabin).

Future research in agriculture may benefit from further application of these psychology-based models to the empirical study of microeconomic production decisions.

Conclusion

On the back cover of their recent book, *A Comprehensive Assessment of the Role of Risk in U.S. Agriculture*, Just and Pope write: “After all the research on agricultural risk to date, the treatment of risk in agricultural research is far from harmonious.” Partly in an attempt to put some perspective on this disharmony, we have systematically reviewed the different ways that risk can be important for agricultural production decisions

To tease out the influences of risk, researchers have been forced to make extreme and often unrealistic assumptions so as to draw sharp conclusions. Chapter 2 describes how risk influences decisions, even when markets are perfect and all risks are insured. In this chapter, we have explained why all risks are not actually insured (because of market incompleteness caused by asymmetric information) and reviewed the general approaches used to approximate the effects of risk in imperfect markets. Although researchers have obtained relatively precise conclusions regarding the effect of risk using the no-risk-sharing and credit-constraints approaches, in general, contract theory suggests that there are no precise conclusions with regard to the effect of risk on production choices. Thus, it is not surprising that research on agricultural risk lacks harmony.

There are several dimensions to the disharmony. The first dimension involves the contrast between risk’s effects in perfect markets versus risk’s effects in imperfect markets. In perfect markets, risk affects outcomes mainly through the interaction of decision timing and the timing of resolving uncertainties—in other words, effects that pertain to information flows. In imperfect markets, the effect of risk affects outcomes mainly through nonlinear objectives caused by imperfect risk-sharing or imperfect insurance. These two kinds of risk effects are fundamentally different.

Research, however, tends to focus on one kind of effect to the exclusion of the other. In some instances, research has explained the same empirical phenomenon using both approaches. One example concerns excess nutrient applications in agriculture. These can be explained using a model in which applications must be made before knowing the nutrient requirements of crops. If crop growth is a nonlinear function of fertilizer applications, then excess nutrients may often be applied. Excess applications have also been explained

as an attempt by farmers to reduce profit variability. Another example, also prevalent outside agriculture (especially macroeconomics), concerns the “lumpiness” of capital expenditure over time. This phenomenon can be explained using the model of dynamic uncertainty in Chapter 2 or via the credit-constraints approach of Chapter 3. There has been relatively little research to date that attempts to reconcile the relative importance of these two effects by considering them simultaneously, or by carefully controlling for one effect, while accurately measuring the other.

A second dimension involves the multitude of ways risk can influence choices in the real world of imperfect markets. The no-risk-sharing and credit-constraints approaches to approximating imperfect markets are necessarily crude approximations of the real world. Some of the disharmony may therefore arise because the crude approximation used in one situation may be less applicable to another. Indeed, the crude approximations may obscure the true effects of risk altogether.

A third dimension of disharmony pertains to the challenges of empirical identification. The challenge of empirical identification is well understood in economics generally: social scientists do not have laboratories in which they can experimentally control for all factors, and then carefully vary one (such as risk) so as to uncover its effect. This problem, however, is particularly acute when attempting to measure the effects of risk.

To appreciate this difficulty, consider the challenges of identifying the effects of risk on agricultural production versus the effect of education on wages, a classic topic in labor economics. There is a positive correlation between education and wages, and it may seem reasonable that the higher wages of the more educated are caused by the greater amount of time they spent in school. But maintaining the causal link is difficult. Ability is likely correlated with both education and wages; however, intrinsic ability is usually unobservable. The empirical challenge to measuring the returns to education is to sort out the effects of education separate from intrinsic ability, which is hard to do.

Like labor economists who estimate the returns to education, risk researchers also must control for the effect of convoluting factors statistically associated with risk but not caused by it (like, ability in the education-wage example). Two farms facing different risks are

probably different in other respects also. How can one be sure which differences are attributable to the difference in risk as opposed to other differences, especially when many of the other differences are unobservable? With risk, the identification problem is even more difficult because there are so many ways that risk could influence choices. The researcher needs to control not only for factors besides risk, but also for all the different ways that risk is important, so as not to confound one type of risk effect for another.

Perhaps the most challenging task with empirically identifying the effects of risk involves measuring risk in the first place. That is, a researcher needs measures of risk and production decisions that are different under different circumstances, like the different education levels and wages of different individuals that are used to measure returns from education. Researchers cannot ask farmers about objective measures of risk and production decisions as easily as they can ask people about their levels of education and wages. How does one quantify the level of risk on a farm? And how much does it actually vary from one farm to another or from one year to another? Even if researchers' notion of risk can be clearly communicated to farmers, it seems unlikely that farmers will be

able to communicate risk measures to researchers in a consistent and objective way.

The data most readily available to agricultural risk researchers are data on prices and yields. Prices and yields vary from year to year and from region to region and may serve as a source for identifying some kinds of risk effects. To measure most kinds of risk effects, however, the *variance* in yields must vary from region to region and year to year. Changes in variance over time and space are more difficult to objectively quantify, and are almost surely associated with other factors, such as climate and soil types. The difference in variances across time and space also may be too small to provide enough statistical power to measure a risk effect of interest. In other words, measuring the importance of risk to production decisions may be like trying to measure the returns from education on earnings in a world where nearly everyone has spent the same amount of time in school—the returns may be large or small but the data cannot reveal which is true. Thus, it could be that some of the disharmony in risk research has stemmed from inherent difficulties involved with empirically identifying which of the risk effects we have reviewed are most important for understanding observed behavior.

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Glossary

agency costs	Costs in monitoring or lost efficiency associated with providing appropriate incentives in asymmetric information or “principal-agent” environments.
expected utility theory	A theory for economic behavior that assumes preferences are linear in probabilities. That is, the value of a probability density function of possible states of the world (s), in which $u(s)$ equals the utility should state s arise, is equal to $\sum_s P(s)u(s)$, where $P(s)$ denotes the probability that state s will occur.
risk aversion	Usually a measure of the degree of curvature of a cardinal utility function of wealth. In general, a measure of preference of more certainty as compared to less certainty, all other factors remaining constant.
moral hazard	A situation in which an individual exploits an incentive scheme for personal gain against a greater social cost. An extreme example might be insurance fraud (setting one’s house on fire to collect insurance). More subtle examples include leaving the door unlocked to a car that is theft insured, or surfing the internet while at work (shirking). In the economic literature, moral hazard is synonymous with hidden action information environments.
adverse selection	An asymmetric information environment in which one party cannot visibly distinguish different types or qualities. Without the proper incentive scheme (which is costly) “bad” types will claim to be “good” types.
hidden information	Like adverse selection except the “types” do not learn which type they are until after they have committed themselves to a contract (but before they make an unobservable decision, such as how much effort to exert).
independence axiom	A key underlying assumption (and implication) of expected utility theory. If the vectors $\{\mathbf{p}, \mathbf{q}, \text{ and } \mathbf{r}\}$ denote probabilities over a vector of possible outcomes (i.e., lotteries), and \mathbf{p} is preferred to \mathbf{q} , then the independence axiom implies that $\alpha\mathbf{p} + (1-\alpha)\mathbf{r}$ is preferred to $\alpha\mathbf{q} + (1-\alpha)\mathbf{r}$.
the revelation principle	If an optimal incentive scheme in an asymmetric information environment exists, it will be one that causes all agents to truthfully reveal their types.
transaction costs	The costs associated with exchanging goods and services (as opposed to physically producing them). These costs may include physical costs such as search time and transportation costs as well as agency costs.

Chapter 4—Government Farm Programs

Direct payments from the Federal Government to farmers exceeded \$20 billion per year in the years 1999-2001. Nearly all of these payments were associated with government farm programs that targeted producers of major field crops: corn, soybeans, wheat, rice, and cotton.¹¹ By comparison, total cash receipts for these crops were less than \$40 billion in 2000.¹² Given the magnitude of the payments paid in conjunction with government programs for these crops relative to receipts, they may strongly influence agricultural production. Some of these programs include risk-mitigating features such as price-contingent payments and subsidized crop insurance, and therefore may interact with the risk effects described in Chapters 2 and 3.

This chapter briefly reviews the largest agricultural programs with risk-mitigating features and discusses possible implications for production. To date, there has been little research that examines how government programs influence production via their risk-mitigating features—most farm-program analyses use a “first-order” approach that ignores risk effects discussed in Chapters 2 and 3. Although the report does not formally analyze the effects of these subsidies from the vantage of each of the risk-modeling approaches discussed in Chapters 2 and 3, it does suggest some qualitative predictions of these approaches. Four of the largest programs currently in place are reviewed: marketing loans, lump-sum transfers (sometimes called decoupled payments), disaster relief, and land retirement programs. Government programs may also induce certain unintended consequences separate from or contrary to program goals. Some of these possible consequences are discussed.

Historical Government Payments to Farmers

Figure 5 shows total government farm payments from 1933 to 1995 (in constant 1995 dollars). Government programs for some crops (such as sugar, peanuts, and tobacco) have been realized via trade restrictions and

other mechanisms that do not necessarily bring about direct government payments to farmers.

Figure 6 shows total direct government farm payments from 1996 to 2001.¹³ In this period, there were some notable changes in the structure of agricultural payments. The 1996 farm act curtailed price-contingent income supports for major commodities and replaced them with Production Flexibility Contracts (PFCs). The sizes of these lump-sum payments were determined by the amount of land enrolled in farm programs prior to 1996, and were scheduled to decline after 1997. In subsequent years, however, as prices declined, PFC payments were augmented with Marketing Loss Assistance (MLA) payments, which scaled up the size of already-scheduled PFC payments. MLA payments make up the majority of payments classified as “Emergency Assistance” in figure 6. Emergency assistance payments also include ad hoc disaster relief. This period also experienced rapid growth in subsidized crop and revenue insurance and, in the most recent years, growth in certain loan rates (price-contingent payments, as explained below), most notably, for soybeans.

One notable feature about government farm payments is that they tend to be counter-cyclical with the economic performance of the agricultural sector, especially over the last three decades. Note that payments reached record levels during the 1980’s farm crises, declined as commodity prices increased in the early to mid-1990s, and increased to new record levels during recent years when commodity prices fell.

The counter-cyclical nature of the payments is especially evident at the regional level, as seen in figure 7. The counter-cyclical nature of the payments is evident in all the regions, but especially so in the Heartland and Northern Great Plains, regions where government payments are highest relative to net farm income and net farm income is most variable.¹⁴ It appears as though government payments insure (partially) risks to farm income.

¹¹See Wescott and Young for a breakdown of payments by type and crop in the year 2000.

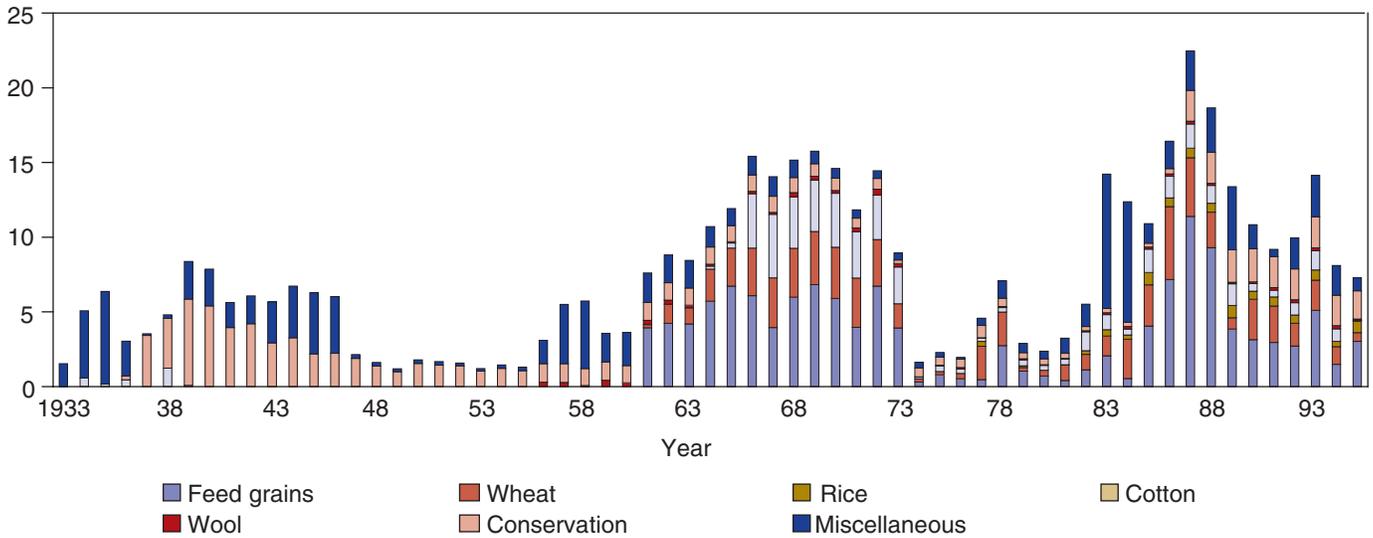
¹²Total cash receipts for agriculture as a whole were about \$194.5 billion in 2001.

¹³The figure excludes insurance indemnity payments, for which the associated premiums were heavily subsidized after 1994.

¹⁴See Heimlich for details on how these farm resource regions are defined.

Figure 5
Historical government farm payments, 1933-1995

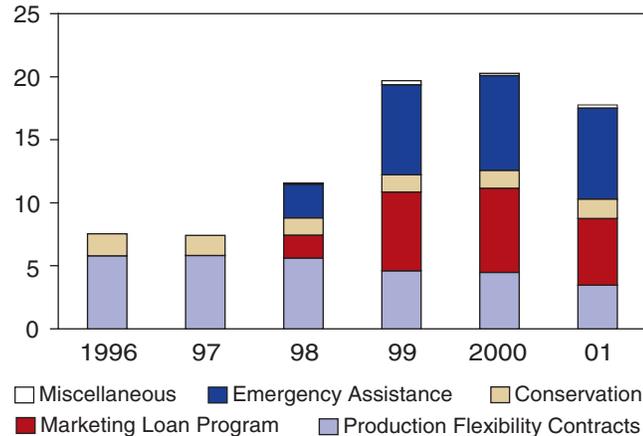
Billions of 1995 dollars



Source: Economic Research Service, USDA.

Figure 6
Government farm payments, 1996-2001

Billions of 1995 dollars



Source: Economic Research Service, USDA.

Relative to both government payments and net farm income, agricultural land values (the dotted line in figure 7) are relatively stable. The relative stability of land values may also suggest a role of insurance played by government payments. The land value data, however, are interpolated between Census years (1978, 1982, 1987, and 1997), so the apparent stability may be a spurious feature of data construction.

Price-Contingent Payments

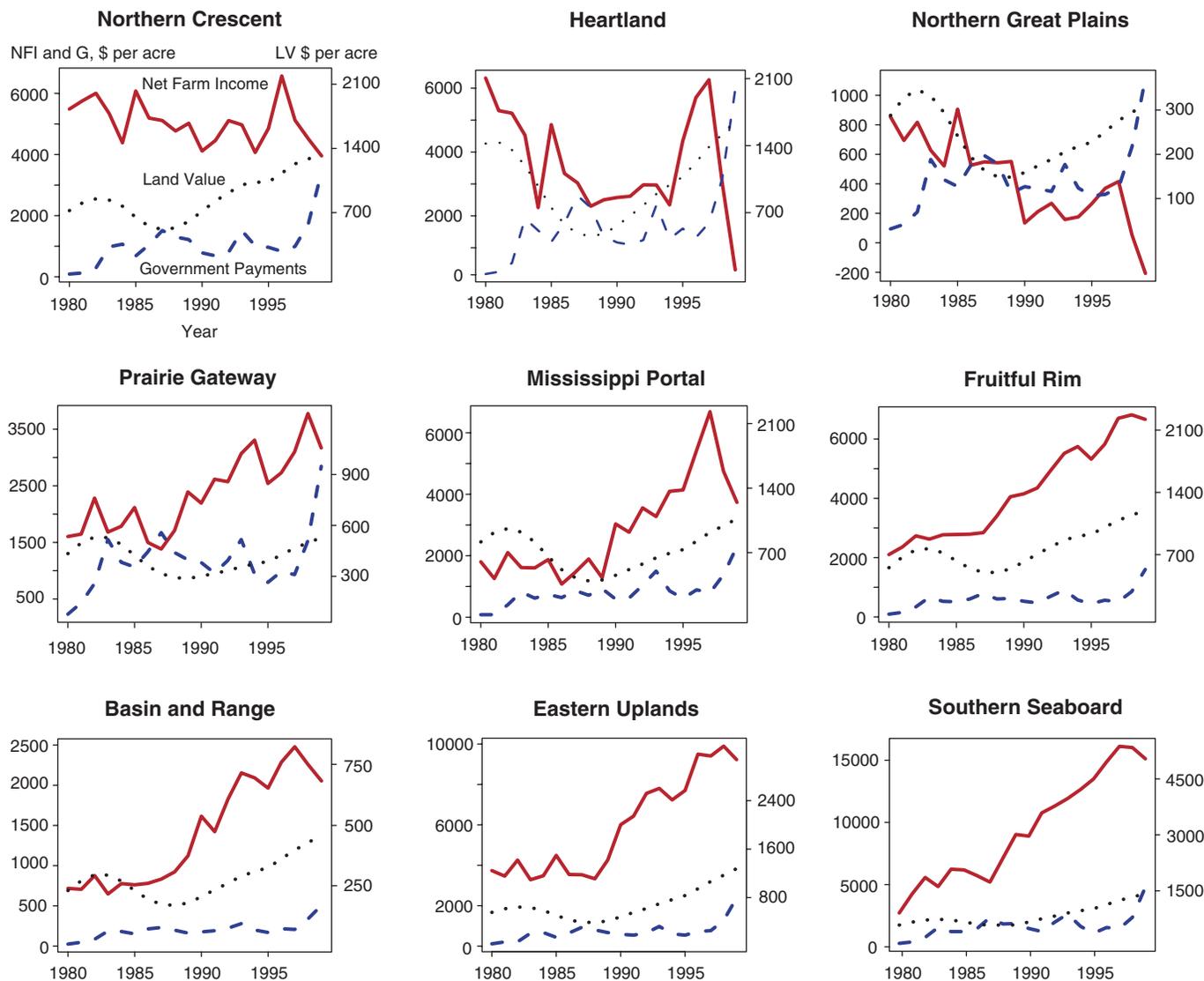
At present, USDA uses the **Marketing Loan Program** to support (in effect) prices farmers receive for certain commodities. Marketing loans allow farmers to borrow the posted “loan rate” for each unit of a commodity produced and stored as collateral. They may later sell the commodity on the open market and repay the loan (if prices are above the loan rate), or default on the loan without recourse (if prices are below the loan rate). Alternatively, farmers can elect to receive a loan deficiency payment for the difference between the loan rate and market-derived price, should the loan rate turn out higher. Thus, the loan rate effectively serves as a floor on prices farmers receive.¹⁵

A price floor affects both the expected return and the level of risk that farmers face. First, by truncating the bottom of the distribution function of anticipated prices, the price floor increases the average or expected price farmers receive. Second, it reduces the amount of downside price risk. In perfect markets, the first aspect is most relevant: the greater average return induces greater production. This effect ultimately entails a certain loss in economic efficiency. Excess production must be stored, destroyed, or

¹⁵More details on the current marketing loan program and how it has changed over time can be found in Westcott and Price.

Figure 7

Comparison of net farm income, government payments, and land values



Notes: The solid line indicates net farm income (NFI), less government payments; the dashed line indicates direct government payments (G); the dotted line indicates agricultural land values (LV). Land values (the right-side axis) are on a scale equal to exactly 3 times that of government payments and net farm income (the left-side axis), so relative values can be visually compared across regions. All values are in 1996 dollars. Net income and government payments data were interpolated from county-level census data on land and buildings with the value of buildings removed. See Heinrich for a more thorough description of the nine farm regions.
 Source: Economic Research Service, USDA.

sold on the world market at a price that is lower than its economic cost.

In the simple two-period approach of Chapter 2, the second effect is zero (recall the equivalence result for price uncertainty). In the dynamic uncertainty approach reviewed in Chapter 2 and in all the approaches of Chapter 3, both effects matter: reduced downside risk and increased expected returns both induce greater pro-

duction. Unlike the first effect, the second one may increase efficiency rather than reduce it.

There also are more subtle general equilibrium effects to consider. As domestic farmers collectively produce more in response to the greater expected returns, the average world price falls. Thus, the greater the loan rate, the lower the world price. If farmers also produce more because of the risk-mitigating features of price supports, then world prices could be pushed even

lower. These general equilibrium effects are largest for commodities for which domestic production comprises a large share of the world market, such as soybeans and especially corn.

Pre-1996 farm payments, which mostly stemmed from the target-price-deficiency-payment program, were contingent on certain features that offset the excess supply they might have induced. The target-price-deficiency-payment did not entail government accumulation of commodities via defaulted loans—it simply paid farmers the difference between a posted target price and the market price on enrolled acreage (if the target price was higher than the market price). Unlike the loan-rate program, the payments were allotted according to base acres and historically based yields, not actual production. Base acres were allocated via a formula of farmers' historical plantings, a formula that has changed over time. Thus, if target prices were especially high in one year then farmers could not quickly increase their acreage to take immediate advantage of it; instead, they had to slowly accumulate their base acreage over time. Pre-1996 programs also offset supply response by requiring that farmers “set aside” (leave fallow) a certain percentage of their acreage in order to participate in the program and receive the subsidies. Although these restrictions are not part of the current loan rate program, base acres still dictate the size of lump-sum decoupled and counter-cyclical payments.

Since the 1985 Food Security Act, eligibility for the loan-rate program and other subsidies does require cross-compliance with certain provisions to conserve soil and wetlands (notably the so-called sodbuster and swampbuster provisions).

Lump Sum or Decoupled Payments

The structure of farm program payments changed markedly in 1996, a time when market prices stood well above target prices and program payments were historically low. Unlike the pre-1996 programs, the amounts of these **decoupled** Production Flexibility Contracts (PFC) and Market Loss Assistance (MLA) payments do not depend on the acreage farmers' plant, nor the crops they plant, nor other current production choices. Economists have long advocated decoupled payments of this kind over subsidies such as price supports because they provide income transfers to farmers without distorting commodity produc-

tion. If markets function perfectly (as described in Chapter 2), then PFC and MLA payments should not influence production.

If, on the other hand, markets are imperfect (as described in Chapter 3), then lump-sum payments hold ambiguous consequences for production. The payments may provide farmers with more resources to finance production. Alternatively, the payments may cause farmers to feel wealthier and more inclined to spend their time in leisure rather than in work, so they may produce less. However, because farmers receiving payments represent a small share of the aggregate labor force, this small shift in labor supply should have negligible consequences in general equilibrium. Compared with the farm programs that these payments replaced, the lump-sum payments may also provide farmers with less insurance against unexpected price declines.

Crop and Revenue Insurance

Although non-subsidized private multi-peril crop insurance is unavailable in agriculture, it is ambiguous whether this “missing market” is a result of asymmetric information (like Akerlof's market for lemons described in Chapter 3), because insurance companies do not have the financial resources to insure widespread disasters, or because government insurance programs have crowded out private insurance markets. Because government agricultural programs have been around for so long, it is difficult to predict what private insurance markets would look like in their absence.

Brief History of Insurance

This section briefly reviews the history of crop insurance programs. (See Coble and Knight and Glauber and Collins for more detailed reviews.)

Congress first authorized Federal crop insurance with establishment of the Federal Crop Insurance Corporation (FCIC) in 1938. The program was initiated as an experiment, limited mostly to major crops in the main producing areas, and participation rates were low. Crop insurance remained experimental until passage of the Federal Crop Insurance Act of 1980.

Since 1980, the crop insurance program has steadily increased the number of crops insured and the level of premium subsidies to induce greater participation. The goal of the subsidies has been to obviate the need for

ad hoc disaster payments. In 1980, the subsidy was 30 percent of the premium. By 1994, the premiums for participating farmers were entirely subsidized for catastrophic risk protection (coverage for 50 percent of average yield at 60 percent of expected price). If farmers elected a coverage level of at least 65 percent of yield at 100 percent of expected price, then the per-acre subsidy was 25 percent larger than the catastrophic premium rate. Program participation also required farmers to pay a \$50 sign-up fee for each crop insured per county.

Beginning in 1996, farmers who elected not to enroll in the crop insurance program with the minimum catastrophic coverage were required to waive their eligibility for Federal disaster assistance that might be made available later in the crop year. Although these provisions are still in effect, disaster relief was provided to both insured and uninsured farmers subsequent to the 1996 provision. In low-yield years, some insured farmers, through a combination of insurance indemnities plus disaster relief, obtained well over 100 percent of their expected returns.

Participation increased markedly with the 1994 subsidies, with about two-thirds of field crop acreage and over 80 percent of eligible acreage insured under the 1994 program. Insured acreage, however, included less than half the eligible farms; and more than half the insured acreage included only catastrophic coverage. Prior to the large 1994 increase in subsidies, participating acres included less than 40 percent of those eligible. Since 1994, the program has expanded coverage to more crops and, under the Agricultural Risk Protection Act of 2000, subsidies for coverage above the catastrophic level have increased.

Implications

Like price supports, federally subsidized crop insurance changes both the average returns and risk from farming. By paying indemnities when yield or revenue is less than a specified value, crop insurance modifies the net-revenue distribution function by truncating the lower end, while the premiums reduce net revenue for all states of nature. If insurance were actuarially fair, then the premium would equal the expected value of the indemnity payment, and average returns would remain unchanged. For most kinds of insurance available in private markets (such as automobile, life, and homeowners insurance), premiums

are larger than indemnities on average—that is how insurance companies cover their expenses and earn profits. With federally subsidized crop insurance, however, the unsubsidized share of the premium is less than the indemnity payment on average—the government loses money on average. Participating farmers therefore enjoy both higher average profits and lower risk from participation.

Because crop insurance is both profitable and risk reducing, one might expect nearly full participation by growers. It is therefore puzzling that such large premium subsidies were required to induce participation. There are at least three explanations for this anomaly. First, because land is heterogeneous, some fields have different yield distribution functions than others, differences that cannot be accurately measured. Farmers, having better information about yield potential than insurers do, may choose to insure only the fields that are profitable to insure. In other words, there is a problem of adverse selection.

Second, farmers may expect to receive disaster relief (discussed in the next section) even if they choose not to participate, in effect receiving free insurance. Although nonparticipating farmers are required to waive their eligibility for disaster relief, in practice both nonparticipating and participating farmers have received disaster compensation in recent years.

A third explanation could be that in the current asymmetric information environment, farmers actually behave as if they are “risk loving.” If farmers are credit constrained (as described in Chapter 3), it is unclear exactly how risk choices are augmented by the constraint. It is possible that farmers face limited liability on the downside (they may declare bankruptcy for a limited cost), but obtain new investment opportunities on the upside, causing them to seek risk, all other factors remaining constant. Indeed, theoretical research using the contracting approach (described in Chapter 3) shows that risk-loving choices result from optimal contracts in limited liability environments (Ghatak and Pandey).

Some argue that farmers who receive crop insurance reduce input use because indemnities compensate for under-applications, a form of moral hazard (Quiggen; Horowitz and Lichtenberg). In general, predictions about input use depend on whether inputs are risk-increasing or risk-decreasing, among other assump-

tions. All else the same, farmers insured from downside risk will have an incentive to choose inputs so as to increase yield risk. If an input is risk-increasing, more will be applied per acre; if it is risk-decreasing, then less will be applied per acre. To the extent that subsidized insurance increases overall returns, there also could be an expansion of acreage farmed (which increases input use (Chambers and Quiggen)).

Coble and Knight provide a recent review of the research that examines crop insurance participation incentives. Research by Young and Vanderveer and Goodwin and Vanderveer examine the effect of crop insurance subsidies on planted acreage.

Disaster Assistance

Congress has regularly provided ad hoc emergency assistance to farmers to partially or totally offset financial losses due to severe weather and other natural disasters (e.g., drought or flood) or stressful economic conditions. Although these programs insure farm income somewhat, the ad hoc nature of the assistance makes this program less amenable to systematic analysis.

In recent years, the overall level of disaster assistance has increased markedly. After accounting for inflation, disaster payments in 2000 were greater than in 1994, the previous record set for these payments due to the 1993 Midwestern floods. Disaster assistance payments from 1991 to 2001, adjusted for inflation, are

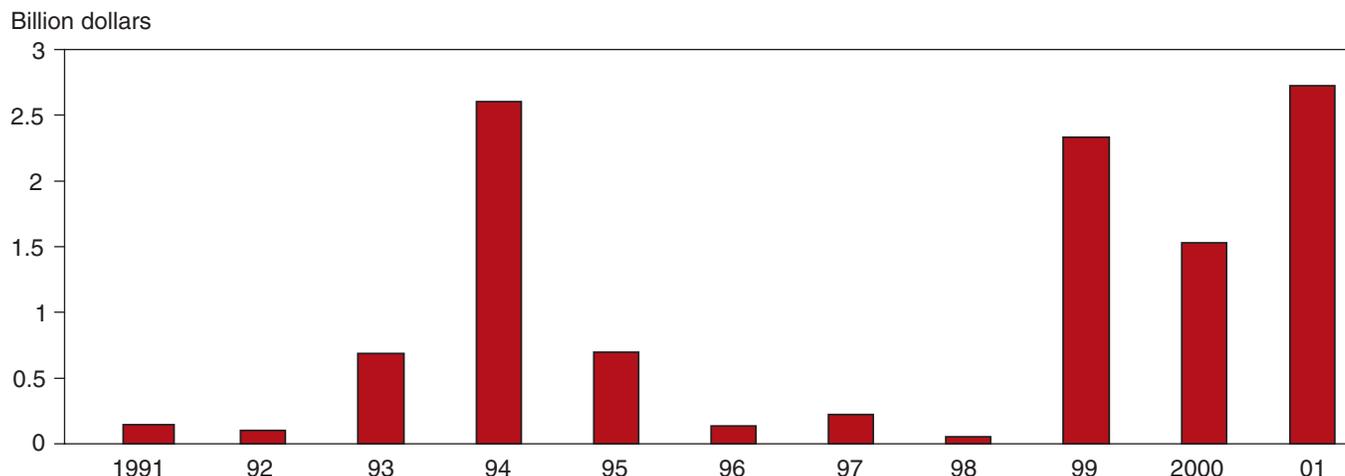
plotted in figure 8. These payments do not include the Market Loss Assistance payments described above, which provided compensation for generally low prices, not for specific disasters.

Land Retirement Programs

Since the 1950s, land retirement programs have served as the largest kind of agricultural conservation program. These programs pay farmers to remove land from cropland production to provide environmental benefits and limit crop supply. At present, land retirement takes place mainly through the Conservation Reserve Program (CRP).

The CRP, USDA’s largest conservation program, pays an annual rent to participating farmers to remove highly erodible or otherwise environmentally sensitive land from agricultural production and shares the cost of establishing land cover, usually in the form of trees or grass. The rental contracts last for 10 to 15 years and are allocated on a competitive basis, with bids weighted according to an index that includes environmental characteristics of the land and the rental payment requested by the farmer. Lands eligible for enrollment must have recently been used in crop production and have a minimum degree of environmental sensitivity. The primary goal of the program is to reduce soil erosion, improve water quality, foster wildlife habitat, and provide other environmental benefits.

Figure 8
Total disaster payments to farmers, 1991-2000, in year 2000 dollars



Source: Economic Research Service, USDA.

Because CRP enrollment substitutes a fixed payment for an uncertain crop return, it affects the income risk associated with participating farm operations and, depending on the size of the rental payment, also may affect the average returns. It is therefore possible that the risk effects described in Chapter 3 will influence production choices on lands not enrolled in CRP. For example, in the no-risk-sharing approach, farmers may be willing to plant new cropland and/or take on new risks since a portion of their income is assured under CRP.

This possible risk effect underlies one rationale for slippage observed in land retirement programs. Slippage is a term associated with the phenomenon that total commodity production decreases proportionately less than the proportion of acres retired. The main reason slippage occurs is because the retired land tends to be of lower-than-average quality and therefore have lower-than-average yields. Another source of slippage could be that farmers simply plant new cropland to substitute for land idled under the program (Wu). Yet another way slippage might occur is through a price-feedback effect: because CRP shifts supply inward, prices increase, which may induce farmers to convert noncropland to cropland. However, because the supply shift is small relative to the world market, there should be only a small price response. The risk effect provides another rationale for this kind of slippage. Before enrolling land in the CRP, farmers may have been unwilling to expand production (and increase risk) due to risk aversion. With reduced risk from CRP, enrolled farmers may be willing to take on additional risk through expanded production. Counter to this supposition, recent research suggests that slippage in the form of noncropland to cropland substitutions is, in fact, small (Roberts and Bucholtz).

Conclusion

Among the risk-modeling approaches reviewed in Chapters 2 and 3, most analyses of agricultural production decisions have utilized either the simple two-period model of Chapter 2 or the no-risk-sharing approach of Chapter 3. Furthermore, except for some of the research on crop insurance, analysis of government programs has mainly used the two-period model of Chapter 2. That is, most analyses ignore risk-coping costs by assuming markets are perfect—so yield and price risks are unimportant—and then, approximate effects of government programs using equivalent per-unit subsidies, in effective, these amount to supply

and demand analyses. One might refer to this approach as a “first-order” analysis, because it examines only incentives that relate to average profits. In addition to expected values, risk effects may also be deemed important. In that case, assessment of these risks, estimates of how farmers and market intermediaries respond to them, and appraisals of how government agricultural programs interact with these responses requires a modeling approach that somehow characterizes the market imperfections causing risk to be important in the first place (like the approaches reviewed in Chapter 3). One might refer to this approach as a “second-order” analysis, because profit variance will play an important role.

Although second-order risk effects may be unimportant for some kinds of questions, they may be important for others. On the one hand, if the analyst wishes to focus on a specific consequence of a government program, such as the acreage response to a higher crop-insurance subsidy, then risk effects might be safely ignored. Because even first-order acreage responses are likely to be small (cropland supply elasticities are highly inelastic), there seems to be little need of a second-order analysis. On the other hand, if the analyst wishes to conduct a cost-benefit analysis of a crop insurance program, then a second-order analysis may be necessary. Because the deadweight loss—a measure of economic inefficiency induced by first-order distortions—is likely to be small, it is possible that the second-order gains from a government program will offset the deadweight loss associated with first-order distortions, even if second-order effects are small in size. The potential second-order benefits provided by these programs might include increased farm productivity (the credit constraints approach of Chapter 3) and consumption smoothing of farm households (all Chapter 3 approaches), both of which could be associated with the farm-income stability they promote. These features, among others, are ignored when the second-order effects associated with risk response are not incorporated into government program analyses.

The practical problem with incorporating risk effects into analysis of government programs is the inadequacy of the current understanding of these effects. Before applying imperfect-markets approaches to analysis of government programs, researchers may first want to try reconciling some of the disharmony among approaches to modeling imperfect markets.

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Glossary

base acres	The number of acres to which many agricultural subsidies are tied. In recent years, Production Flexibility Payments and Market Loss Assistance Payments were determined according to a farm's 1996 base acres. Base acres are determined by a formula of historical plantings, a formula that has changed over the years.
decoupled government payments	Agricultural subsidies that are not tied to the current level of production or planting decisions.
general equilibrium	As opposed to a partial equilibrium, in which prices usually are fixed, a general equilibrium takes into account price feedback from other factors, such as demand.
slippage	The difference between the proportional reduction in land and the proportional reduction in production. The term is usually used in reference to land retirement programs. Within these programs, the total amount produced usually declines less than proportionately with the number of acres idled, resulting in slippage.

Chapter 5—Production Decisions and the Environment

Production choices are resource allocation decisions that determine how much of what crops to produce and how to produce them. These jointly determined decisions include: **intensive-margin** choices, such as per-acre applications of pesticides, fertilizer, or irrigation water; **extensive-margin** choices, such the amount of land used for crops and livestock, the allocation of acreage among different crops, and crop rotations; and **technology adoption** choices, which include machinery, irrigation type, tillage practice, use of precision technologies, and seed type. Technology choice may influence extensive-margin choices, and both technology and extensive-margin choices affect intensive-margin choices.

Chapters 2 and 3 focused on simple examples to illustrate the different ways risk might influence production choices. Some of the examples showed how risk, through its influence on production, may indirectly influence the environment. Chapter 4 explained how government programs such as crop insurance and price supports influence both the expected returns and variability of returns, and therefore may influence production and (indirectly) environmental problems. Chapters 2 and 3 referred to these choices abstractly using the vector \mathbf{x} . This chapter reviews more comprehensively the production alternatives available to farmers and how these alternatives collectively influence productivity, risk, and the environment. This chapter focuses mainly on the basic tradeoffs available to growers and policymakers, rather than the motives that underlie the production decisions actually made.

The Agro-Environmental System

Agricultural production choices affect both production efficiency and the environment by changing the topography and plant and animal life on land and in waterways; by influencing aesthetics, water flows and quality, soil quality and erosion; and by introducing synthetic chemicals into the environmental system. Environmental conditions, such as weather, soil type and fertility, soil moisture, and the stochastic variability of these conditions, in turn, influence grower production decisions. Ultimately, the environmental effects of production choices depend on the resulting mix of crops grown and the production practices used.

Many interest groups are concerned about the effects of production and input choices on worker safety, consumer health, fish and wildlife, ground and surface water quality, air quality, and soil erosion.

Intensive-Margin Choices

Intensive-margin choices usually pertain to per-acre use of variable inputs on agricultural land. The intensive-margin inputs mainly include labor, fertilizers, irrigation water, and pesticides. Holding land quality, crop choice, capital, and technology fixed, these inputs influence profits mainly by their effect on yields, product quality, and cost. The use of these inputs has been associated with various adverse health and environmental effects (USDA, ERS, 2002). Due to these effects, the agricultural economics literature probably has studied these inputs more than the others.

Most analyses of input response to risk on the intensive margin use models akin to the nutrient example in Chapter 2, the no-risk-sharing approach reviewed in Chapter 3, or some combination of the two. Pope and Kramer (1979) discussed a model that underlies many arguments that risk-reducing or information-increasing programs, such as crop insurance or new precision technologies, may encourage increased efficiency and/or decreased use of risk-reducing inputs, such as pesticides.

It remains controversial, however, whether pesticides, irrigation, and fertilizer applications increase, decrease, or have no effect on yield and profit risks (Leathers and Quiggen, 1991 and Horowitz and Lichtenberg, 1993). The conventional wisdom is that pesticide use and irrigation reduce profit risk while fertilizer use increases profit risk, as measured by variance (Leathers and Quiggen, 1991). Horowitz and Lichtenberg (1993) argued, based on an empirical analysis, that pesticides can increase risk in some circumstances. Other authors, such as Babcock and Hennessey (1996) and Smith and Goodwin (1996), questioned their argument and result, suggesting that model specification was a problem. Other research indicates irrigation may increase risk and that fertilizer use may reduce risk under some circumstances. Thus, even within the confines of the no-risk-sharing

approach, it remains ambiguous how risk influences the use of these inputs and vice versa.

Whether or not intensive-margin applications increase or decrease yield variance depends in part on the information available to the farmer at the time of application. Recall the nutrient and irrigation examples in Chapter 2. The more accurate a farmer's assessment of nutrient and water needs, the more precise will be the applications of these inputs, which could lead to more or less applied on average. As a result, technologies that reduce uncertainties about input need may change the use of intensive-margin inputs.

Greater application precision, however, may lead to either increased or decreased yield variance. On the one hand, greater precision may push all yields up toward the maximum growth potential, increasing the average and reducing the variance. On the other hand, other stochastic factors that influence growth (such as sunlight and rainfall) may drive input need (the amount that maximizes yield, all other factors being constant). High input needs therefore may occur when yields are either especially low or especially high. For example, low sunlight may reduce both yields and irrigation needs, while steady rainfall increases yields and reduces irrigation needs.

Following the notation from the nutrient example in Chapter 2, define agronomic need as n' and the amount applied as n^* . Agronomic need is variable and may be uncertain at the time of application. If need is known at application time and the input is costless, then $n^* = n'$. Thus, the relationship between application rates, average return, and return variance is ambiguous and depends on three factors:

- 1) The information available with respect to agronomic need of the input (uncertainty about n').
- 2) The stochastic relationship between marginal needs and yield (covariance of yield and n').
- 3) The relationship between agronomic need and other factors, such as input costs and output price.

Both the information available and application timing (the level and uncertainty about n') are endogenous—they are determined in part by other input decisions. The following subsections discuss specific kinds of intensive margin inputs, possible environmental con-

sequences of their use, and how risk can influence their application.

Pest Controls

Farmers use pesticides, biological methods, and cultural techniques, to prevent yield and quality losses from insects, nematodes, diseases, and weeds. Post-harvest practices are also used to control pests during storage and shipment. Pests can reduce not only the amount of product harvested, but also the product quality and the price received. In addition, counterproductive effects of pesticide use, such as increased pest resistance and the mortality of pests' natural predators, can reduce the efficacy of future pesticide treatments.

Depending on the active ingredient, inappropriate use of agricultural pesticides may create adverse human health effects by contaminating food and drinking water or exposing farm workers, as well as adversely affect the health of desirable wild animals and plants. Some health effects, especially those stemming from chronic exposure to pesticides, are difficult to measure.

Pest infestations are probabilistic events. Some pests may be chronic problems that cause damages year after year, while others may pose infrequent threats of large damage. Pest infestations and the susceptibility of crops to damage can vary within a season and between seasons depending on a variety of factors, such as weather and previous cropping practices.

Some authors characterize pesticides as damage control agents that prevent yield loss when an infestation occurs but have no effect otherwise (Leathers and Quiggin, 1991 and Lichtenberg and Zilberman, 1986). By reducing damages when pest infestations occur, pesticide use will increase average yields and reduce yield variance (similar to figure 2 concerning irrigation in Chapter 2), as long as pest infestations are the only variable factor in the crop-pest system and there are no auxiliary effects. Auxiliary effects include increased pest resistance and eradication of pest predators, pesticide-induced damages to plants (if the pesticide is phytotoxic), and ways pest infestations relate to other stochastic factors that affect profits, such as yield and output price. Horowitz and Lichtenberg (1993) argued that if pest infestations interact with other stochastic factors affecting yields or profits, increased pesticide use can increase risk.

If the benefits outweigh the costs, farmers may use scouting or monitoring to reduce uncertainties regarding pest infestations and damages, and thereby apply pest controls more judiciously. Some research suggests that poor information about the degree of infestation leads to higher application rates (Feder, 1979), but this result is not generally true (as in the nutrient model in Chapter 2).

Some research suggests that producers overestimate average insect and disease damages and consequently over-apply pesticides (Pingali and Carlson, 1985). Research also suggests that younger farmers who have more schooling and who use scouting or Extension Service information make less use of pesticides and more use of more labor-intensive control practices.

Pesticide use increased markedly during the 1960s and 1970s as the percentage of acreage treated with these materials increased, peaking in the early 1980s when total cropland also was historically high. Since the early 1980s, aggregate pesticide use has remained relatively stable (figure 9).

Irrigation

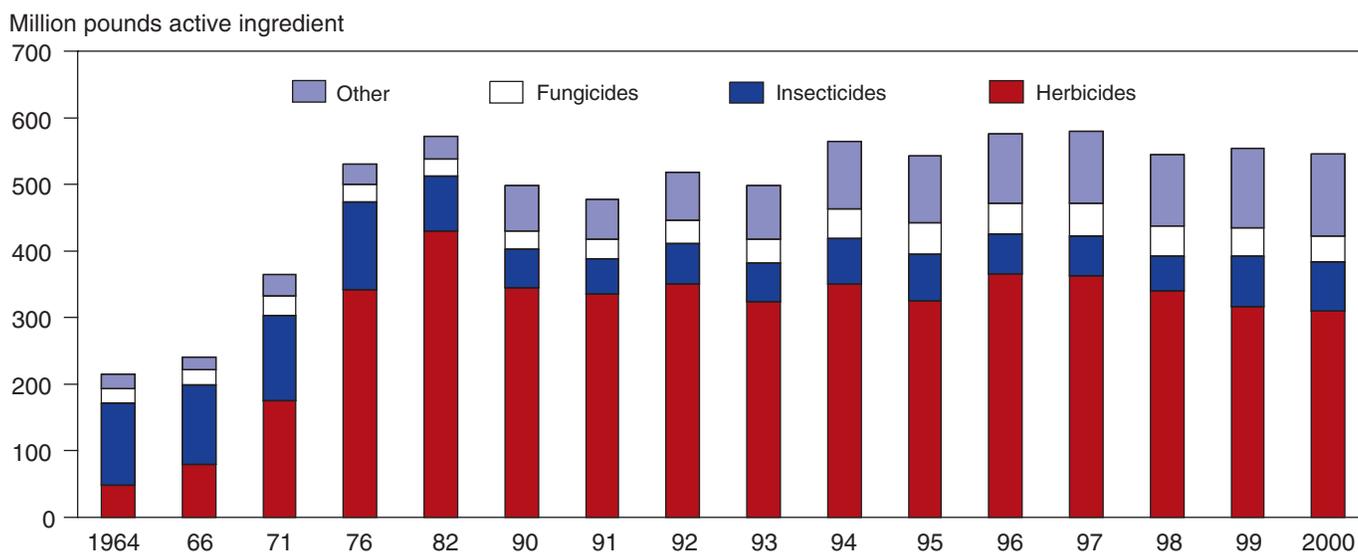
In the most arid regions of the West, where precipitation can be the limiting factor for crop growth, irrigation is essential for production of certain crops, including some high-value vegetable and tree crops. In other areas of the United States, where precipitation can be

sufficient to support crop production in most years, irrigation augments soil moisture during drier periods, prevents associated yield losses, and therefore increases average yields and reduces yield variance.

Irrigation often is the basis for more intensive crop production systems that increase the use of other inputs, such as fertilizers and pesticides. However, irrigation can reduce water available from groundwater or reservoir supplies for other uses. It can also affect water quality through increased nutrient leaching, increased nutrient and salt concentrations in runoff to surface water, or increased salinity in poorly drained soils. Diversion of water for irrigation in the West has reduced or eliminated flows in many streams, which has reduced or destroyed habitat for many species, such as salmon (National Research Council, 1996).

Irrigation may help producers capture peak prices attributable to drought-induced production shortfalls, particularly for price-sensitive local markets such as forage hay, fresh fruit, and vegetables. In many areas of the country, irrigation contributes to higher quality and higher valued fruit and vegetable production, through control of freeze damage and crop cooling to delay early flowering or maturation. Fertilizers, pesticides, and other chemicals may be applied within the irrigation system, providing more controlled application and increased production potential. Irrigation may also be used for manure spreading, thereby reducing

Figure 9
Pesticide use on major crops



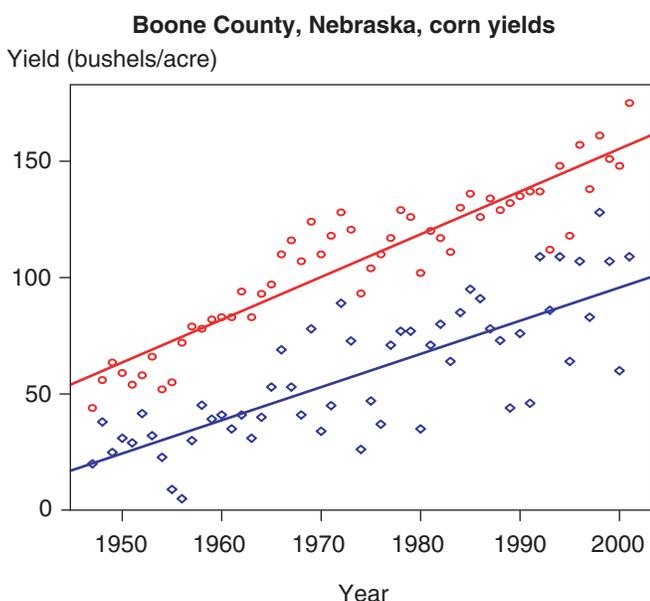
Source: Economic Research Service, USDA.

disposal costs and lowering chemical nutrient applications for combined livestock and forage operations.

Some researchers argue that irrigation is an important risk-reducing input (Boggess et al., 1983). The primary source of risk reduction involves reduced yield variability and crop loss resulting from inadequate soil moisture in the crop root zone. When irrigation supplements rainfall, a probabilistic event, it has the characteristics of a damage control agent, such as a pesticide, and could simultaneously increase expected yield and reduce variance—if managed so that no crop damage occurs. However, the timing and quantity of water applications could influence whether or not irrigation increases or decreases yield risk.

For example, figure 10 plots corn yields in Boone County, Nebraska, a county that has a long history of large plantings of both irrigated and nonirrigated acreage. Although the data suggest that irrigation applications increase average yields and reduce yield variance, some of the difference may occur because irrigated and nonirrigated lands are different in other respects.

Figure 10
Comparing yields of irrigated and nonirrigated corn



Notes: Red indicates irrigated yields; blue indicates nonirrigated yields. The standard deviations of the residuals (differences between actual yields and the fitted trend line) for irrigated and nonirrigated acreage are 11.8 and 17.8 respectively. The coefficients of variation for irrigated and nonirrigated are 0.11 and 0.30, respectively.

Source: National Agricultural Statistics Service, USDA.

Incomplete information about soil moisture and weather has implications for decisions about quantities of irrigated water applied, timing of applications, and crops irrigated (Bosch and Eidman, 1987).

Information value stems from more efficient water application with respect to its marginal return, which varies depending on other stochastic conditions (See the nutrient example in Chapter 2).

Fertilizers

Farmers use chemical fertilizers, manure and other organic materials, and/or crop rotations to replace nutrients withdrawn from the soil during production of certain crops (such as corn). Without augmenting the soil with nutrients, crop yields or quality would decline in many cases. Primary nutrients for crop growth and development include nitrogen, phosphorus, and potassium, but other micro-nutrients are also important. If improperly applied, fertilizers can leach into groundwater or drain into surface water. Nutrients in surface water can cause eutrophication, oxygen depletion, fish kills, and reduction in recreation opportunities. High nitrate levels in drinking water also have adverse human health effects.

Fertilizers, especially nitrogen, have been identified as risk-increasing inputs based on the results of field studies. A risk-averse farmer, therefore, would apply fertilizers less frequently than a risk-neutral one (Leathers and Quiggen, 1991). Fertilizer use may increase the mean and variance of yields by increasing the probability of high yields under some conditions, such as adequate rainfall, and of low yields under other conditions, such as inadequate rainfall when chemical burning can occur. However, some research indicates that fertilizer use reduces the probabilities of lower yields (Babcock and Hennessy, 1996). Some farmers may perceive nitrogen fertilizer as a risk-reducing input, based on their experience (SriRamaratnam and others, 1987).

As with pesticides and irrigation, incomplete information about nutrient availability is an important source of uncertainty. Information and decision criteria, such as those obtained from biophysical simulation models, can influence fertilizer application decisions. Soil and tissue tests provide estimates of nutrient deficits, which can result in more accurate application rates. Precision farming techniques with variable rate technologies can help to minimize the yield variation in a field. To the

extent that uncertainty leads to “over-application,” soil or tissue tests might reduce application rates (SriRamaratnam and others, 1987). However, some studies show that testing might have no effect on application rates or perhaps increase them (Musser and others, 1995). Extreme wet or dry weather can reduce the value of soil tests, to the extent that benefits do not cover costs (Huang, Lu, and Uri, 1999).

Fertilizer loss after application, which is affected by weather, is a stochastic event that creates uncertainty about the amount of the nutrient in the soil available for the crop’s uptake. As a result, farmers may increase the amount of fertilizer applied to ensure that enough of the nutrient is available for the crop (Babcock, 1992).

Extensive-Margin Choices

For crop production, extensive-margin choices entail how many acres of what crops should be grown. Decisions about what crops to grow reflect expectations of returns, including expectations of prices, yields, and costs.

Land and associated natural factors, such as climate, are important factors in crop production. Natural factors such as climate, soil type, fertility, and soil moisture affect yield. Production costs and response to production inputs also affect yield, while the distance from markets or transportation terminals can affect the net returns to crops and alternative uses. Variability of such factors as temperature, rainfall, and distance from markets contributes to regional differences in crops grown and production practices. Variability of natural factors such as soil type, slope, moisture, and fertility within individual operations or fields are sources of spatial yield variability, influencing the choices of crops and production practices.

Natural factors also influence the environmental effects of crop choices. The combinations of crop and management practices, including crop rotations and tillage, and natural factors, such as soil type and slope, affect water runoff into streams and percolation into groundwater, which, in turn, affect soil erosion, and the movement of pesticides and nutrients into aquatic systems. Farm production choices also influence populations of desirable and undesirable wildlife, insect, disease, and plant species by modifying their habitats. Row crops, such as corn, cotton, or soybeans, generally encourage more surface runoff and erosion than

close-grown crops, such as small grains or alfalfa. Continuous production of row crops can result in greater infestations of some pests than some crop rotations (USDA, ERS, 2002).

The choice of crops affects the average level and variability of net returns. In a static, deterministic framework, growers choose crops that maximize net returns; but for a variety of reasons, yields, prices, and costs are uncertain. In particular, yields of some crops may be more susceptible to drought, pests, or other losses than other crops. Some growers may choose crops with potentially high returns that are susceptible to yield losses and protect them with pesticides, fertilizers, and irrigation. Other growers may choose crops with potentially lower returns but with less need for additional inputs. For example, some growers in drought-prone areas might choose to grow irrigated corn or cotton, while others choose to grow nonirrigated sorghum. Some crop rotations may have pest control or fertility benefits, but, in the absence of crop insurance, may also help growers to diversify against revenue losses from price variability and yield losses (Freund, 1956).

Economic incentives, whether created by high output or low input prices or by government subsidies, can encourage changes in crop choices that increase the acreage of some crops and reduce the acreage of others. These changes can have environmental implications. Increases in the acreage of crops with high input use can increase soil erosion and deposit more pesticides and fertilizers into the environment. In some cases, more erosion-encouraging crops could be substituted for soil-conserving crops on less productive (in terms of fertility, soil moisture, or other natural factors that contribute to higher net returns) and more erodible land. For example, high corn prices or program subsidies and low alfalfa prices could encourage growers to increase corn and reduce alfalfa acreage. This crop change would tend to increase erosion on acreage previously growing alfalfa, and to the extent that alfalfa was planted on more erodible acreage, the erosion would be even greater than on the average corn acre.

Technology Adoption Choices

By adopting new technology in the form of new production practices and equipment, growers may be able to produce crops where they could not be previously

grown, increase yields, improve crop quality, or reduce production costs. These decisions affect the level and variability of net returns. Some changes can be minor modifications of current production systems to improve efficiency, such as using a new pesticide or seed variety. In more extreme cases, growers may make major changes in crops grown and production practices that require major investments in equipment and management skills. For example, a grower might change from growing a dryland crop, such as sorghum or hay, to more input-intensive irrigated corn or cotton or, perhaps, high-value fruit or vegetable crops.

These adoption decisions can affect what crops are grown, where they are grown, what inputs are used, and, thus, have environmental implications. An important trend throughout the 20th century was the increased use of agricultural chemicals, machinery, new seed hybrids and varieties, as well as irrigation equipment and reductions in per-acre labor use, all of which contributed to increased productivity. For example, synthetic organic herbicides, first developed during World War II, were used on more than 90 percent of corn acreage by 1980 (Osteen and Szmedra, 1989). These changes contributed to public policy concerns about the health and environmental effects of pesticides, fertilizers, and irrigation. However, some new technologies may improve production efficiency and reduce adverse environmental effects. Precision agriculture methods can apply variable rates of pesticides or fertilizers within a field based on sub-field level information about pest infestations or nutrient needs. Some genetically modified crops can reduce the application of some synthetic organic pesticides.

Growers face a number of risks when adopting new practices or equipment, with incomplete information being a major source of risk. New products might not be accepted in the marketplace, causing product prices to be lower than anticipated. New practices, pesticides, or equipment may not perform as anticipated. Growers may not have the management skills or knowledge to effectively use new equipment and attain the desired results from new practices. The greater the change in production practices and equipment, the greater these uncertainties might be.

Some adoption decisions require investments that create financial risk. Growers might have to purchase specialized irrigation, tillage, or pesticide application equipment. Replanting an orchard to a new crop or

variety may require destroying the old orchard, planting new trees, and waiting for trees to mature to bearing age. When debt is incurred, the grower needs to maintain a cash flow for loan payments. Price or yield variability can be important concerns for investment decisions, because the grower might not have sufficient revenue for loan payments in years when prices or yields are low. To justify taking such a risk, the grower may plant crops that promise a higher return, but might also choose inputs, production practices, or insurance to reduce risks associated with price and yield variability. For example, irrigation may contribute to higher valued crops, higher yields, and reduced yield variability, but the grower incurs debt and higher annual production costs (Boggess and Amerling, 1983). However, growers might diversify crop choices and use pesticides, fertilizers, and irrigation practices to prevent yield or revenue losses (Vandever and others, 1989).

Institutional factors, sometimes unanticipated, such as regulations or other policies, can prohibit or discourage the use of some practices or equipment. For example, the U.S. Environmental Protection Agency's (USEPA) pesticide registration process requires testing and reviews to ensure a safe product, but may slow the introduction of new materials. Alternatively, regulations or policies to discourage currently used practices may encourage the adoption of new ones. For example, USEPA registers safer pesticides while restricting or banning other materials with undesirable environmental effects. In addition, State University Research and Extension programs can provide information that helps growers change pest control practices.

Input Substitution and Environmental Implications

While risk management policies may have no direct health or environmental effects, they can influence the use of inputs and practices that do. Key elements that influence input use are output prices, input prices, and marginal productivities of production factors, as well as the yield or revenue risk effects of inputs. Many production practices can generate environmental benefits: a) reductions in pesticide, fertilizer, or irrigation use; b) changes in cropping patterns to reduce soil erosion and surface runoff; c) planting more-highly erodible acres to soil-conserving crops; and d) increases in the use of information and precision technologies.

However, some practices that could reduce use of pesticides or fertilizers, such as some crop rotations or cultivation practices, can have environmental costs such as increased soil erosion. Programs, policies, or market factors that encourage the use of one or more inputs could discourage the use of others and affect the acreage and output of different commodities. No clear consensus has emerged from empirical economic research about the effects of risk management policies (such as subsidized crop insurance), on crops grown, input used, or other production practices.

Much of the economic literature implies that increasing the use of one risk-reducing input discourages the use of other risk-reducing inputs and encourages the use of risk-increasing ones. The implications are that risk-reducing inputs are substitutes for each other, as are risk-increasing inputs, but that risk-reducing and risk-increasing ones are complements for each other. Some controversy remains about the risk effects of using various inputs and how their use would respond to risk management policies. While much of the literature says that pesticide use and irrigation decrease risk, and fertilizer use increases risk, some economic research supports the opposite conclusions (Babcock and Hennessy, 1996; Horowitz and Lichtenberg, 1993; Leathers and Quiggen, 1991; Smith and Goodwin, 1996). However, several of these authors argue that pesticide and fertilizer use reduce the probabilities of low yields and indemnities, even if variance might increase (Babcock and Hennessy, 1996; Smith and Goodwin, 1996).

An important issue is how crop insurance might affect the use of information and of pest, fertilizer, and irrigation management practices. There are a number of arguments that information and crop insurance can reduce fertilizer, pesticide, or irrigation water use (Feder, 1979; Horowitz and Lichtenberg, 1993). However, to the extent that information and management practices substitute for crop insurance as risk-reducing agents, encouraging crop insurance could discourage their use (Norgaard, 1976). Conversely, if economic incentives changed, increased use of crop rotation, management practices, or information could reduce purchases of crop insurance. None of the empirical research reviewed indicates whether crop insurance would necessarily have a greater or lesser effect on per-acre use of pesticides than other pest management practices. Similarly, crop insurance could discourage the use of management practices or

information that helps to reduce fertilizer or irrigation water use.

However, Loehman and Nelson (1992) showed that an increase in the use of one risk-reducing input does not necessarily mean a decline in the use of another risk-reducing input. They showed that two risk-reducing inputs, two risk-increasing inputs, or a risk-reducing and risk-increasing input could be risk substitutes or complements. Inputs that are production substitutes could potentially be risk substitutes, while production complements could be risk complements, but marginal profits and prices are also factors. Based on their discussion, crop insurance purchases could encourage use of pest monitoring or other information, crop rotations, or other pesticide-free practices as complementary components of systems to reduce pest losses more risk-efficiently than scheduled, prophylactic pesticide use. Similarly, the results of Wu and Babcock (1998) indicate that insurance and nitrogen testing could be complementary in reducing risk, but it is unclear whether soil testing would increase or decrease fertilizer application rates.

Pesticides, fertilizers, or irrigation could also be substitutes or complements in their risk effects. Irrigation or fertilizers can increase the value of the crop to be protected or create conditions for pest losses in some situations and, thus, increase the value of pesticide use as a damage- and risk-reducing agent. Alternatively, irrigation or fertilizers can reduce the potential for pest losses and the value of pesticide use by improving plant vigor. Pesticide use might improve yield response to fertilizer or irrigation.

Risk-management policies or the use of risk-reducing inputs could encourage other extensive margin decisions that increase risk. Crop insurance, especially if subsidized, and disaster payments may have encouraged increased planting of higher value crops that increase the use of pesticides and fertilizer and may be more prone to soil erosion. Those programs may have also encouraged planting of such crops on less productive or more erodible acres (Gardner and Kramer, 1986; Wu, 1999; and Keeton, Skees, and Long, 1999).

Some growers have decreased the use of crop rotations that reduce pest populations, continuously planted higher-value crops, and increased pesticide use to prevent pest damage. For example, preplant methyl bromide use encourages continuous double-cropping of

high-value vegetable crops in Florida, continuous strawberry cropping in California, and replanting of orchards in California without several years of fallow. Soil insecticides allow farmers to grow continuous corn rather than rotating corn with soybeans or other crops to control soil insects.

Conceivably, the use of some inputs, crop diversification, or crop insurance might encourage investment by

reducing yield or revenue risk, especially on high-value crops, and increasing the risk-adjusted return on investment. Therefore, subsidized crop insurance or disaster payments could encourage investments, such as irrigation equipment, to produce higher value crops that ultimately rely on greater intensive margin input use.

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Glossary

intensive-margin choices	In the context of crop production, these choices concern the amount of a variable input used per acre. In the traditional static framework, the optimal amount occurs where marginal productivity equals input price.
extensive-margin choices	In the traditional framework, land should be allocated to the use that generates the greatest return. Land on the extensive margin is at the break-even point for production, because it generates no rent when all variable inputs are optimally allocated. If output prices increase, land rents increase, so that more acreage can be allocated to crop production.
technology adoption	Production takes place within the context of technology that defines what can be produced and how inputs are used in the production process. Technology adoption concerns choices of new outputs, production practices, and equipment. Choices can vary from minor adjustments in the production process, such as a different pesticide or seed variety, to major changes in final outputs produced and production process and large investments in new equipment.

Perspectives

Complicated Interactions

In this report, we have reviewed the agricultural economics literature that examines the interactions of risk, government programs, and the environment. Because this literature is so large, reviewing all of it is a daunting task; and because it is so divergent, no sweeping paradigm exists to efficiently characterize it and put all of it into perspective.

Rather than review all research papers piecemeal, or attempt to fashion a sweeping generalization, this report breaks the overview into its constituent components. First, the report reviews the basic perfect-markets and imperfect-markets approaches to modeling risk, illustrating each approach using a simple example. Next, it provides an overview of the government programs that affect incentives via changes in both the risk and return to production activities. Finally, it examines the nature of agricultural production decisions, how these decisions affect risk and return, and how they may lead to environmental damages.

This report summarizes the basic modeling approaches and the basic issues—the building blocks that make up a more comprehensive view. But it provides little in the way of comprehensive analysis of all the components together—risk, government programs, *and* the environment. These interactions are complex, and can be woven together in many different ways.

Figure 11 illustrates these complicated interactions between risk, government programs, production decisions, and the environment. It shows how exogenous factors (those determined outside the agricultural production system), such as the weather, climate, population, and so on, feed into endogenous choices and factors, such as the economic environment (perfect versus imperfect markets), market mechanisms (private contracts versus spot markets), and production choices. The nature of production, in turn, determines environmental consequences. And the culmination of all these factors collectively determines more traditional welfare measures, such as the amount produced, the cost of production, the distribution of wealth, the smoothness of consumption, and so on. In order to draw conclusions, every model must make simplifying assump-

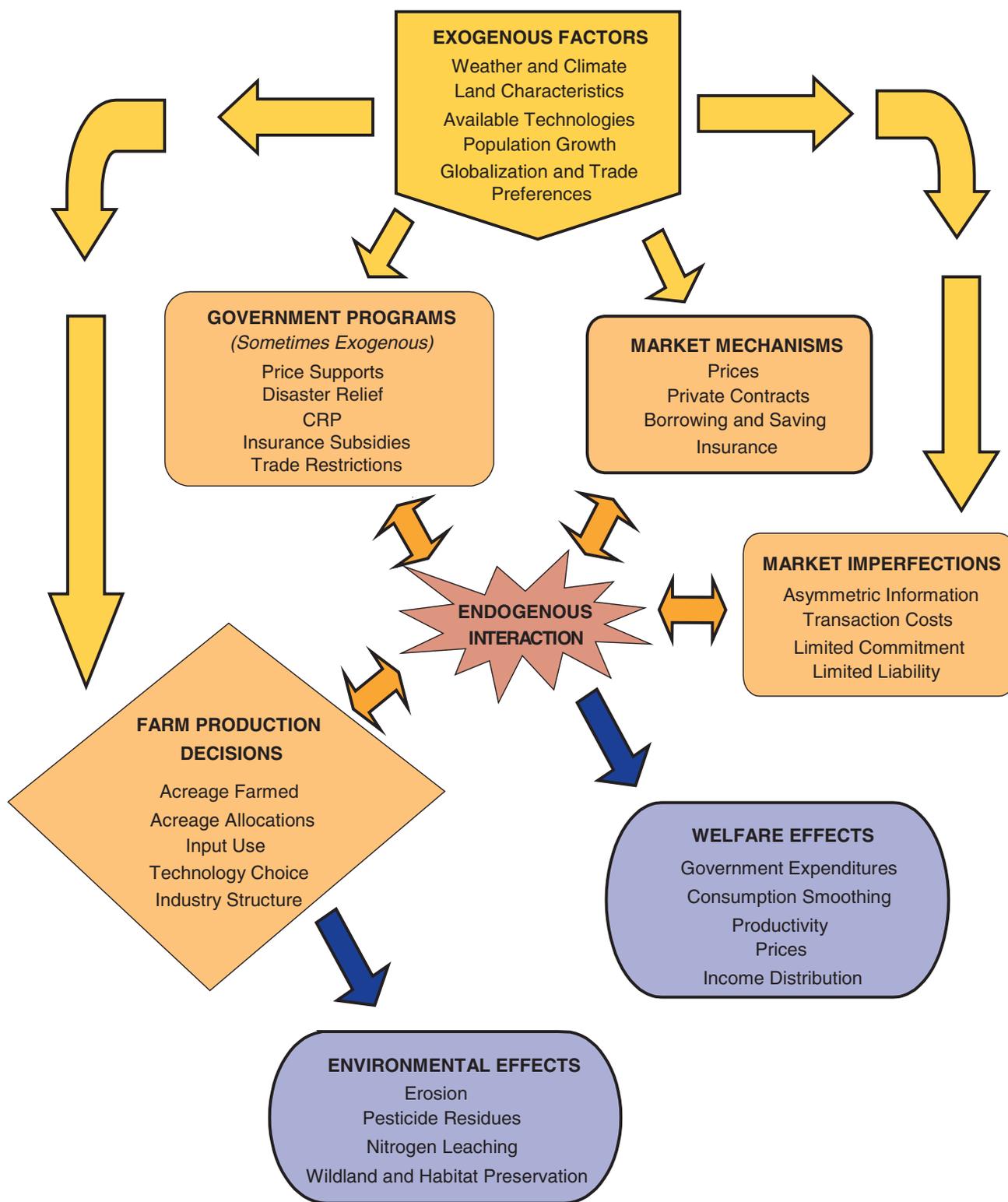
tions about the structure of these components and their interactions.

Some Conclusions

This review of risk, government programs, the environment, and their interactions provides six main conclusions:

- 1) *Risk effects are not synonymous with risk aversion.* A large share of agricultural risk research uses the no-risk-sharing approach described in Chapter 3, an approach that assumes that all consumption smoothing must take place via smoothing of income or profits. Within this approach, risk effects are ultimately tied to farmers' degree of risk aversion, usually characterized by a smoothly concave utility function. In reality, markets do work to share risks, but do so imperfectly. These imperfections imply that risk usually will matter in ways it does not in perfect markets, but not necessarily in a way that can be characterized by a smooth, concave utility function. From the vantage of the contracting approach of Chapter 3, it becomes clear that the way risk influences production decisions depends mainly on the *constraints* imposed by asymmetric information, not by individual *preferences*. In the future, researchers may want to apply the no-risk-sharing approach sparingly and interpret results from this approach judiciously (not as preferences, but as a complicated amalgamation of preferences and constraints on risk sharing).
- 2) *The production consequences that stem from imperfect risk sharing can be observationally equivalent to information-related risk effects.* In some instances, the predictions stemming from information-related risk effects reviewed in Chapter 2 will be observationally equivalent to those of the imperfect risk-sharing approaches reviewed in Chapter 3. Our understanding about the importance of risk would benefit from empirical work that carefully disentangles one kind of effect from the other. One way of doing this is to focus on the stochastic properties of the risks in question. The end of Chapter 2 describes how the transitory nature of yield shocks implies that they

Figure 11
Risk, government programs, welfare, and the environment



should have no effect in a perfect-markets world but do matter when markets are imperfect, and may therefore serve as an effective device to differentiate these two kinds of effects. The problem of observational equivalence is more acute with price shocks, which persist over long time horizons.

- 3) *Static models overlook important longrun risks.* Longrun risks are the most difficult to insure and may be important for understanding longrun decisions, such as capital investment, technology adoption, crop rotations, and tree plantings. Because futures markets typically extend only about 2 years, and because farmers cannot know for certain what crops they will grow in the future, no explicit longrun contingent claims exist. These longrun risks also appear to be insured in part by the countercyclical nature of government program payments. Moreover, these longrun decisions tend to be large-scale and ultimately drive intensive-margin input use, which entail perhaps the most studied of environmental consequences. Although longrun risks could be the most interesting and salient of the risks that interact with government programs and the environment, they also will be the most challenging to assess empirically. Among other reasons, this empirical task will be challenging because longrun risks are important via both the dynamic uncertainty approach of Chapter 2 and the credit-constraints approach of Chapter 3, two views of risk that hold very different policy implications.
- 4) *Risk effects are difficult to identify and easy to misidentify.* To identify the effect of risk, one needs data from different environments with different risks. The problem is that risk is difficult to measure objectively; and it is even more difficult to measure differences in risk over space and time. Furthermore, differences in risk, when they can be identified, usually are closely associated with other kinds of differences. For example, yields on irrigated acreage are less variable than yields on nonirrigated acreage; but irrigation technology also may allow production of crops that are incapable of being produced on nonirrigated land; and irrigated lands may have systematically different soils than nonirrigated land. In general, spatial differences in risks will be heavily confounded by climate, soil type, and other kinds of physical heterogeneity. And different individuals

(i.e., those with more or less risk aversion) may be drawn to more or less risky farming regions. Time-series variation in risk can be more difficult to quantify than spatial differences. Research on agricultural risk could therefore benefit from a more careful search for natural experiments—exogenous sources of identification that are not correlated with other uncontrolled factors. One compelling natural experiment, for example, might be the precipitous increase in crop insurance participation that occurred with the 1994 subsidy increases. The construction and use of improved panel data sets would allow researchers to better control for many types of heterogeneity that confound many empirical analyses.

- 5) *Future research would benefit from a better understanding and accounting of agro-environmental links.* Geographic heterogeneity is intrinsically confounded with risk, as noted in conclusion 4: different farms face different risks, in part because different farms are located in areas with different weather, climatic conditions, and soil types. The environmental consequences of agricultural production decisions also depend on weather, climatic conditions, and soil types. Thus, to understand how risk influences the environment via its effect on production decisions, researchers need a greater understanding as to how different agricultural production decisions affect environmental quality in different locations.
- 6) *Future research would benefit from exploring the practical relevance of experimental violations of the Expected Utility Theory (EUT) for agricultural production decisions.* The penultimate section of Chapter 3 discussed certain psychological phenomena, observed both in experiments and in aggregate economic data, that contradict economists' standard notion of risk aversion. Economists' standard notion of risk aversion hinges on EUT and diminishing marginal utility of consumption. The evidence, however, suggests that individuals display more risk aversion than diminishing marginal utility can plausibly imply, hold preferences for risk that are inconsistent with their preferences for intertemporal substitution, and, in economic experiments, violate the independence axiom of EUT, among many other anomalies. There has been little application of these findings to agricultural production, for which risk remains a central feature. Future work

may benefit from further investigations into the relevance of these psychological phenomena for the microeconomic behavior of farm production decisions under risk.

For Further Reading

Just, Richard E., and Rulon D. Pope. "Past Progress and Future Opportunities for Agricultural Risk Research" in Just and Pope (eds.) *A Comprehensive Assessment of the Role of Risk in U.S. Agriculture*. Dordrecht and London: Kluwer Academic Press, 2002.