Production Economics and Farm Management: a Century of Contributions

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This article is a reflection on the path taken by production economics and farm management over the last century, and the progress made in understanding the economics of the farm. The accumulated knowledge has helped refine our assessment of the efficiency of farm management decisions and the evolving role of agriculture in modern society.

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Over the last century, our association has evolved as both agriculture and academic knowledge have changed in significant ways. Farm economics originally focused on farm-management issues, with close linkages to the agricultural and biological sciences. It then expanded to cover broader issues relevant to the economics of agriculture. In the process, our understanding of the economics of the farm improved dramatically. On the one hand, farm activities provided excellent case studies for empirical and theoretical analyses of technology and economic behavior that spurred important advances in economic theory and empirical methods. On the other hand, agricultural economics benefited greatly from advances in economics, including refinements in economic theory as well as empirical methods. The accumulated knowledge has helped refine our assessment of the efficiency of farm-management decisions and the evolving role of agriculture in modern society.

This article is a reflection on the path taken by production economics and farm management over the last century. There are many contributions. Unfortunately, their large number ensures that no single paper can provide a thorough review of these accomplishments. Some of this review has been provided elsewhere (e.g., Case and Williams 1957; Nerlove 1958; Jensen 1977). This article has the more modest objective of reflecting on some key contributions made over the last century in production economics and farm management, and the progress made in our understanding of the economics of the farm.

Applied Production Analysis

Even before the *Journal of Farm Economics* published its inaugural issue in 1919, important advances had been made in applied production analysis.

Contribution #1: Identifying the role of diminishing returns

The early issues of the *Journal of Farm Economics* also contained pioneering studies in production economics. Spillman made seminal contributions in his analyses of the "Law of Diminishing Returns" (Spillman 1923; 1924; 1933; Spillman and Lang 1924). Working at the U.S. Department of Agriculture (USDA), he had noticed that "successive increments in yield due to successive equal increments in fertilizer tend to form the terms of a decreasing geometric series" (Spillman 1923). On the basis of this observation, he postulates a theoretical model of yield response (the exponential yield curve that now bears his name) and derives from it an expression for profit per acre. He then differentiates the resulting profit expression to find the profit-maximizing decision,

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and “fits” his theoretical model to experimental data to find the profit-maximizing fertilizer application and profit per acre.

Tolley, Black, and Ezekiel (1924) produced an USDA technical bulletin entitled, “Inputs as Related to Outputs in Farm Organization and Cost-of-Production Studies.” This study empirically sets out the concepts of input per unit of output, output per unit of input, least-cost input combinations, and most-profitable input combinations that were subsequently more fully developed in Black (1926).

Contribution #2: Establishing linkages between cost and supply response

Moore (1917), operating under the presumption that there should be “some relation between the percentage change in the price of cotton…and the percentage change in cotton acreage,” examined the relationship using correlation analysis in what appears to be the first attempt to fit a supply curve.

J.D. Black was an important intellectual force in the early development of agricultural production economics. His text (Black 1926) remained a mainstay for two decades, and he fostered a research agenda involving the development of what came to be referred to as *synthetic supply curves*. These supply relationships were to be constructed from observations on actual input–output relationships by a combination of economic and statistical reasoning.

These early contributions can be properly appreciated only when situated in the intellectual climate of the time. At the time, confusion existed among professional agricultural economists about the difference between accounting costs and economic costs. “Cost curves” were then routinely represented by something akin to Marshall’s particular expenses curve as the “*frequency curve of costs, cumulated upward*” (Schultz 1927, p. 194), with lowest costs to the left and highest costs to the right.

Tolley, Black, and Ezekiel (1924) and Black (1924) clearly recognize that such cost curves are irrelevant to supply analysis. Henry Schultz (1927) reiterates this point forcefully in his examination of tariff proposals for U.S. agricultural products. Specifically, he writes:

> Scientifically to determine the effect of a tariff on conditions of supply, we must work not with cost curves but with supply and demand curves. (p. 193)

While arguing that cost curves could not be used in such analyses may seem odd today, in the context in which it was made, it is not only sensible but correct.

Almost immediately following the contributions of Spillman and Tolley, Black, and Ezekiel, Moore (1925) presented empirical estimates of demand and supply for potatoes. In this paper, Moore emphasizes the importance of the coefficient of relative cost of production, which would today be recognized as the reciprocal of the elasticity of size, in determining optimal producer behavior. More importantly, Moore set out to measure that coefficient.

Moore’s (1929) best-known work is also his last: *Synthetic Economics*. While it received a decidedly lukewarm reception, its main contribution was to help incorporate what he referred to as “statistical economics” into mainstream economics (Stigler 1965). Moore’s contribution helped stimulate many later developments in empirical supply and demand analysis, and remains as “one of those landmark achievements that are bound to stand out irrespective of whether or not we make use of them” (Schumpeter 1954, p. 876).

Elmer Working presented his famous paper articulating the identification problem (Working 1927). The identification problem confronting demand and supply-curve estimation was well understood before Working (1927) (see Stigler 1965). Many, however, viewed it as an impossibility result (e.g., Black 1924) and not as a problem to be surmounted. Working (1927) laid the foundation for that effort.

At the very end of the 1930s, a young giant of our profession, T.W. Schultz, engaged in a polemic with the then reigning giant of agricultural economics, J.D. Black. In two articles (1939a; 1939b), Schultz articulated a farm-management research paradigm. In doing so, he confronted Black and others’ attempts to construct supply relationships using a mixture of economic reasoning and statistical analyses of observed input–output ratios from farming operations. Black (1939; 1940) immediately responded.

In arguing against the input–output approach espoused by Black, Schultz (1939b) articulates the idea that agricultural technologies are fundamentally stochastic and that farmers can form only expectations about future events. Schultz (1939b) also argues that farm-management analysis cannot rely exclusively on information about physical production relationships:

> Technological research is primarily in the province of the production specialist in our Land Grant Colleges. They, however, have not addressed themselves to that technology found on farms and thus there is an important gap in the information in this area. But rather than using our resources to obtain this information the task should be shifted to the production departments thus saving our resources for more strictly economic studies. (1939b, p. 583)

Contribution #3: Integrating economic theory and farmers' decisions

While technology always matters, this raises the question about the comparative advantage of economics in analyzing farm activities. This point has remained at the heart of the debate over the relative usefulness of farm-management versus production economics (Jensen 1977), and more recently, of primal versus dual methods (Pope 1982).

As much of the world went to war, important changes in agricultural production analysis were taking place. Many were still focused on analyses relating indicators or indexes of farmer behavior to profitability while placing relatively little reliance on economic theory (Ciriacy-Wantrup 1941). But other important contributions were being made.

Two contemporaneous studies from Iowa State College (Tintner 1944; Tintner and Brownlee 1944) are particularly important. These studies fit Cobb-Douglas production functions (without imposing constant returns to scale) to data drawn from Iowa farm records for 1942 and 1939, respectively. The choice of the Cobb-Douglas function is based on pragmatic grounds: (1) its estimated coefficients are input elasticities; (2) it parsimoniously permits the phenomenon of diminishing returns; (3) it fits the data well. The method of fit was least squares, although both studies recognize that tests of significance were problematic.

Both Tintner (1944) and Tintner and Brownlee (1944) represent a distinct break with the empirical modeling tradition established by Spillman (1923; 1924; 1933) that had attempted to identify the form of input–output relations by observing actual data. Instead, they eschew this approach in favor of econometric convenience.

Tintner (1944, p. 27) simply states "Douglas and his associates have amply demonstrated the usefulness of this approach despite some criticism." Recall, however, that Cobb and Douglas (1928) derived their functional representation on the basis of a close examination of aggregate data. In particular, the Cobb-Douglas specification was chosen not because of its resemblance to a real technology, but because it was consistent with the observed relative constancy of aggregate factor shares in national income. Regardless, the tradition of relying on econometric convenience in modeling purportedly physical representations of technologies became increasingly entrenched in empirical production economics.

Empirical advances were not restricted to econometrics. Stigler (1945), anticipating incipient developments in linear programming, published his solution to the diet problem. Remarking that "The economist uses a production function to describe the relationship between productive services and the quantity of a product" (p. 303). Stigler (1945), by analogy, deploys a "health function" to find the minimum-cost diet consistent with then existing dietary standards. In doing so, he anticipates important mathematical advances that were on the horizon. This would see many later applications of this procedure, including the linear programming formulation of cost-minimizing diets in animal production (e.g., Waugh 1951).

Heady (1948) issued a blueprint for a farm-management, production-economics program that he would undertake along with his colleagues over the next quarter century. He criticized farm management for its focus on farm accounting and unstructured data analysis. Instead, he proposed relying on reasoning based on observed facts and economic theory. His view was that farm management should focus on production economics where the "principles of production…furnish the schematic framework…in solving specific problems" (Heady 1948, p. 202). He recognized that the main factors constraining previous analyses in farm management and production economics were the sparseness of price and physical data that were consistent with the concepts (supply, demand, and marginal cost) in which economists were conversant. And he argued that a major effort should be made in ensuring that that type of data were collected and analyzed.

Space limitations prevent us from accurately cataloguing Heady's major contributions to production economics that followed from this blueprint. These contributions can be organized along two main lines: the econometric estimation of agricultural production technologies (production functions, isoquants, etc.) and programming applications. Following Heady and Dillon (1961) and Dillon (1968), the estimation of agricultural production functions became a standard tool of analysis of agricultural technology. And following the development of linear programming methods (e.g., Dorfman, Samuelson, and Solow 1958), programming models became widely used in the economic analysis of agricultural decisions (starting with Heady and Candler 1960). More recent refinements include the positive programming approach proposed by Howitt (1995).

Besides Heady, three other economists made major contributions to the economics of agriculture in the immediate postwar era. The trio, who all shared a connection to the University of Chicago, are: Zvi Griliches, Yair Mundlak, and Marc Nerlove.

Nerlove's first outstanding contribution was made in his doctoral thesis that was eventually published in book form (Nerlove 1958). His focus is on accurate estimation of agricultural supply response and the use of those supply–response relationships to examine the welfare consequences of U.S. agricultural policies. That work is discussed in more detail below.

Nerlove (1963), in his study of electrical-power generation, became the first economist to estimate a dual cost system. Starting from a self-dual Cobb-Douglas production function, he first developed the associated Cobb-Douglas cost structure. Reasoning that regulation of utilities implied that their input prices and output were predetermined econometrically, he obtained estimating equations, consistent with theory, dual to the Cobb-Douglas production function in which all the right-hand side variables in the regression were predetermined. Thus, the simultaneous-equations-bias problem, characteristic of production-function estimation, was effectively circumvented. Moreover, the parameters of the original production function could be recaptured from the estimated cost structure.

Nerlove (1963) is the first study to fully integrate economic theory into the estimation of a production structure and its associated observed firm behavior. All of the dual cost and profit functions to be postulated and estimated after 1965 rightly count this study as an ancestor.

In the 1950s, relatively little was known about agricultural factor markets. For example, Griliches (1958) writes: "Almost every policy discussion bogs down in disagreement about the quantitative behavior of the various factor markets." Griliches approached this problem in two ways. First, he emphasized that quality differences in measured inputs were important and could seriously affect estimated production parameters. Working in a Cobb-Douglas framework, he showed that omitting inputs, such as management ability, produced biased estimates of the scale elasticity (Griliches 1957b). Second, he (Griliches 1958) estimated one of the first U.S. fertilizer demand curves. One year later (Griliches 1959) he estimated derived demands for fertilizer, capital, and labor and used them to infer a short and long-run elasticity of supply for U.S. agricultural products.

Mundlak published perhaps the most influential paper ever to appear in the *Journal of Farm Economics* (Mundlak 1961). His problem was how to deal with differences in unobserved managerial ability when estimating a Cobb-Douglas production function. His solution is simple, elegant, and effective. When working with panel data, he proposed what is now commonly referred to as a "fixed-effect model."

Mundlak (1961) considered a model where the explanatory variables include a constant term, a set of inputs, a firm-specific but time-invariant variable reflecting managerial ability, and finally an error term. Then he showed that averaging over time and subtracting the result from the original model eliminates the constant term and the time-invariant managerial ability term. Classical regression techniques can then be applied to the transformed data to obtain unbiased and efficient estimates of the remaining parameters. Extensions of this approach continue to serve as the basis for empirical panel-data investigations.

Another important contribution is Mundlak (1963), which addressed two key issues: aggregation and the estimation of multi-output production systems. Production economics would wait more than a decade before multi-output production systems would again be seriously considered econometrically.

Finally, Arrow et al. (1961) identified a significant limitation of the Cobb-Douglas specification: it restricts all Allen elasticities of substitution among inputs to be equal to 1. This stimulated the search for "flexible specifications," i.e., specifications that do not impose a priori restrictions on elasticities of substitution. This proved particularly valuable with the development of dual models in production analysis, as discussed next.

Contribution #4: Using duality theory in the analysis of agricultural production decisions

In the early postwar era, Shephard (1953) established the existence of a duality between the physical production technology and its economic manifestation, the cost function. Unfortunately, Shephard's contribution was not fully appreciated for more than a decade. Despite this lag, the dual approach became a standard method of agricultural production analysis (Pope 1982; Chambers 1988). Researchers who use it in empirical and theoretical analyses of agricultural production problems form a literal roll-call of some of the more prominent names in agricultural-economics research during the last quarter century. The topics covered in these studies vary widely from farm-level applications to more aggregate applications, from applied studies to theoretical studies.

One common thread characterizes this work. The use of a dual formulation allowed researchers to examine structural characteristics of technologies more easily than was previously possible. Both the constancy and the numerical magnitude of elasticities of substitution could be investigated empirically; separability was open to empirical testing; multiple-product technologies could be examined relatively easily; issues of jointness could be addressed empirically; the extent and nature of technical change could be examined; the effect of binding credit constraints upon producer behavior could be examined empirically; and so on. The many applications of the dual approach are a testimony of its usefulness in the investigation of agricultural technology and of farmers' behavior.

A full-length article would be required to do justice to the broad range of these studies. Our discussion is limited to highlighting three contributions that were among the first to realize the implications of duality for agricultural production analysis: Lau and Yotopolous (1971; 1972), Binswanger (1974a; 1974b), and Weaver (1983).

Lau and Yotopolous (1971; 1972) and Yotopolous and Lau (1973), in closely related studies, estimated Cobb-Douglas unit-output-price (normalized) restricted profit functions from Indian data, treating land and capital as fixed inputs. They concentrated on estimation of the restricted profit function and the associated labor share in profit. In this context, they investigated technical efficiency differences between farms of different size, allocative efficiency, as well as scale efficiency. They concluded, on the basis of a simple test, that smaller farms tend to be more technically efficient than larger farms. The Lau and Yotopolous contributions are important for at least two reasons. First, they appear to be among the first to implement empirically the profit function concepts that McFadden had developed during the 1960s. Second, Lau and Yotopolous (1971; 1972) and Yotopolous and Lau (1973) spawned an empirical literature on relative efficiency measurement that continues to expand.

Binswanger (1974a) and Binswanger (1974b) appear to be the first attempts to estimate an agricultural cost technology using flexible functional forms. Binswanger (1974a) set out a catalogue of perceived advantages of using a cost-based approach to characterize the technology: estimating equations have prices (instead of jointly dependent inputs) as "right-hand side" variables; a cost-based approach allowed direct estimation of elasticities of demand and elasticities of substitution; flexible functional forms yielded easily estimable equations (input demands, cost shares); cost-based flexible functional forms permitted easy treatment of non-neutral efficiency differences across firms or farms; and cost-based approaches circumvented collinearity problems arising from an observed tendency of input series to be highly correlated with one another. Using a transcendental-logarithmic (translog) specification of the cost function, Binswanger (1974a) fit factor share equations to a pooled cross-section and time-series sample of U.S. data. The primary focus was on measuring elasticities of demand and Allen elasticities of substitution. He also documented the "biased" nature of technical change in U.S. agriculture.

Weaver (1983) appears to have been the first to estimate a profit-function representation of a multiple-output, multiple-input agricultural production technology. Using data from the North Dakota and South Dakota wheat regions for 1950 to 1970, he estimated an expected profit function. Output prices were replaced by their expected values, and farmers were assumed to maximize expected profit. His specification allowed him to investigate a number of issues including the level of returns to size, the bias of technical change, as well as the elasticities of supply and demand.

Agricultural Productivity

Early studies of U.S. agricultural productivity (e.g., Ducoff and Hagood 1944) typically focused on partial productivity measures, such as land productivity and farm-labor productivity. Partly on the basis of this research, which suggested broad interregional productivity differences, Schultz (1947) argued that U.S. agricultural production was highly inefficient economically.

Contribution #5: Assessing agricultural productivity

The evolution of U.S. agricultural productivity in the twentieth century has been the subject of much research. Improved productivity is captured by an upward shift in the production function. Barton and Cooper (1948), drawing on earlier work by Cooper, Barton, and Brodell (1947), appear to have been among the first to calculate and report index measures of what we would now call total factor (multifactor) productivity. They concluded that "Output per unit of all inputs has shown a steady upward trend since World War I, as a result of a remarkable stability of total inputs and a steady upward trend in…farm output." The combination of output growth with input stability over time has since been repeatedly confirmed despite marked changes in methods and measures used to compute agricultural productivity.

Schultz (1956; 1958), perhaps reflecting the same philosophical bent that led Abramovitz (1956) to label productivity growth "…a measure of our ignorance," suggested that an ideally measured total output to total input ratio would be "one where outputs over inputs…stayed at or close to one." In other words, in an ideal world, an economist would be able to accurately measure and account for all sources of productivity growth. This was clearly not the case at the time that Schultz was writing. Loomis and Barton (1961) reported that between 1910 and 1957 calculated output growth had outpaced calculated input growth 85% to 22%, reflecting a productivity increase of 63%.

In 1960, USDA became the first federal agency to introduce multifactor productivity measures into its statistical program. These measures suggested relatively rapid productivity growth. Using estimates of an aggregate agricultural production function based on a 1948 cross-section, Griliches (1963) was able to eliminate the reported discrepancy between output growth and input growth, thus leaving no "productivity residual." He attributed the difference between his measures and officially reported USDA measures to important quality corrections he made in input calculation (mostly in labor and machinery) and to returns to scale.

As noted above, the Arrow et al. (1961) paper stimulated a search for "flexible" representations of the underlying technology. It suggested that the measurement of productivity growth should not be sensitive to a priori restrictions imposed on substitution relationships among inputs. This led to a major contribution to economic analysis made by Diewert in 1976. Building on the theory of index numbers, Diewert (1976) proposed "superlative index numbers" (including productivity indexes) defined to be exact index numbers associated with a flexible functional representation of the underlying technology. Over time, it became apparent that USDA productivity measurements were not staying abreast of these important developments. In 1980, an American Agricultural Economics Association (AAEA) task force, working in cooperation with the US Department of Agriculture, recommended that USDA base its multifactor productivity measures upon Divisia (Törnqvist) indexes, instead of the Laspeyres indexes that it had been using. Ball (1985), using the Törnqvist approximation to the Divisia index, single-handedly implemented the recommendations of the AAEA taskforce (1980). These changes were incorporated into the official USDA productivity calculations. Later, Ball et al. (1997) refined this work by using Fisher indexes.

These studies documented two findings: (1) U.S. agricultural productivity growth has been consistently high for many decades; and (2) virtually all of U.S. agricultural productivity growth emerged from output growth, presumably as a consequence of technical progress. The significance of these results is highlighted by the work of Jorgenson and Gollop (1992) showing that productivity growth has been much higher in U.S. agriculture than in the nonfarm economy.

Finally, analyzing the sources of technological progress has been of much interest (e.g., Griliches 1963; Huffman and Evenson 1993). The evidence shows that both private and public research in agriculture has generated high rates of return (e.g., Evenson 1967; Chavas, Aliber, and Cox 1997).

Risk

Agriculture faces two important sources of risk: production uncertainty (e.g., due to unpredictable weather effects), and fluctuating farm prices (due in part to an inelastic demand for food). This has stimulated strong interest in studying the effects of risk on farm decision-making.

Contribution #6: Identifying the role of risk in agricultural decisions

Miller (1921), under the heading "Diversity and Rotation of Crops as Insurance," clearly anticipates Heady's (1952b) path-breaking analysis of risk reduction saying "To minimize this risk arrange for from one to four major sources of income. Four chances are better than one."

Schultz (1939b) presented an interesting perspective on firm and farm-management research. He argues that then existing research was deficient:

> Yet, relatively little has been done in farm management to try to show how it might be possible to reduce this divergence between expectations and realizations in spite of the fact that the gap between them is a positive measure of what is probably the most important source of inefficiency and waste in present farming. (p. 586)

For Schultz, these errors meant inefficiencies due to improper input and output mixes.

The key contributions to the economics of risk analysis were Von Neumann and Morgenstern (1944), followed by Arrow (1965), and Pratt (1964). In particular, Von Neumann and Morgenstern proposed a formal foundation to risk analysis based on the expected utility model. Expected utility allowed a separation of two aspects of risk: risk exposure measured by a (possibly subjective) probability distribution, and preferences over outcomes represented by a utility function (Savage 1954). This provided the basis for many empirical analyses of the role of risk in agriculture (Just and Pope 2002; Chavas 2004). Three important examples of early studies using expected utility underscore the usefulness of the approach.

Eidman, Dean, and Carter (1967) is perhaps the first published paper to exploit Bayes' Rule in the analysis of farm decision-making under risk. When applied to turkey production, the main sources of risk are the mortality of the birds (lognormally distributed) and the market price (normally distributed). The analysis examines the value of new information. Responding to the forecast of a regression model and using Bayes' Rule, the optimal strategy given the forecast is developed using the posterior distribution.

Officer and Halter (1968) analyzed three different practical approaches to elicit utility functions. Predictive accuracy was highest, using a Ramsey approach for estimating utility functions in which the respondent chose between two risky alternatives. Using interview methods, Officer and Halter, and a later study by Lin, Dean, and Moore (1974), concluded that a variant of the Ramsey method best estimated utility functions and that farm decision-makers are risk averse.

Lin, Dean, and Moore (1974) studied the behavior of a sample of California farmers. They examined three alternative models of behavior under risk: expected profit maximization; expected utility maximization (based on a direct elicitation of risk preferences); and a "safety-first" model. They found that the expected profit maximization gave poor predictions of farmers' behavior. They also found that the expected utility model gave the most accurate predictions of farmers' behavior.

Contribution #7: Assessing the efficiency of agricultural decisions under risk

In 1952, Markowitz's landmark study of portfolio choice appeared. That same year, generalizing the concept of budgeting, Heady's (1952b) article on crop portfolios appeared. Heady examined the proportion or acreage of crops that would minimize the variance of total farm income. Heady recognized that expected returns are also important and concluded with a discussion of minimizing the coefficient of variation.

A more formal and sophisticated recognition of the trade-offs of means and variances directly using expected utility is found four years later in the influential work of Freund

(1956), who acknowledged Hildreth (1957) for his contribution to his work. Under a normal distribution and an exponential utility function, a linear program with uncertain returns can be converted to a certainty-equivalent (that can be maximized as a quadratic programming problem) defined as the mean minus a weighted variance. The weighting of variance is one-half of the Arrow-Pratt measure of absolute risk aversion. As anticipated, expected net revenue is lower under risk aversion, but expected utility is larger in the optimal program because the variance is reduced. The shadow prices of resources are lower due to risk and risk aversion. Subsequent refinements of inquiries started by Heady and Freund proceeded in two directions. First, adaptations of programming models to risk analysis stimulated empirical applications to agriculture (e.g., Hazell 1971). Second, the literature saw the development of decision models that apply under general probability distributions and utility functions (e.g., Meyer 1987).

Finally, Anderson (1974) was a pioneer in applying stochastic dominance techniques to agriculture. His study smoothed distributions of profit calculated from experimental yields. Consistent with many later findings, Anderson found that mean-variance efficiency did not differ substantially from stochastic dominance results. The rationalization of mean-variance analysis within and without expected utility analysis continued to be a matter of interest and tension.

Contribution #8: Assessing the role of technology and farmers' risk preferences

Binswanger (1980) ran field experiments (where payments were made) as well as hypothetical gambles. The respondents were from 6 villages in India totaling 240 households. The bets were scaled to trace out risk preferences as the size of the bet increased. The study provided refined estimates of farmers' risk preferences. All but one of 118 individuals had utility functions exhibiting risk aversion. Binswanger also argued that the interview methods of obtaining estimates used by Officer and Halter are unreliable.

Just as preferences received focused attention, so also did technology. Day (1965) was the first to carefully analyze experimental yield data, finding that increasing fertilizer leads to negative skewness (longer left tail). Thus, the yield distribution with significant fertilizer is less uncertain and more attractive to farmers. Fuller (1965) examines corn yield with a focus on how carryover and yield history can enhance expected profit and reduce variance.

Developing stochastic production functions seemed a natural way to capture production uncertainty. Just and Pope (1978) proposed a production function specification that can identify separate effects of inputs on the mean and variance of output. Estimation of these production functions allows categorizing inputs as conditionally risk increasing or risk reducing. Such a taxonomy expands the production concepts of marginal product under certainty to allow risk reduction through input use. The empirical analysis presented by Just and Pope (1978) identified fertilizer as being a risk-increasing input. Subsequently, Antle (1983) extended this approach to capture the effects of inputs on higher moments (e.g., skewness) of uncertain production or income.

One of the first econometric projects incorporating risk response in agriculture is found in Behrman (1968). Behrman found that increasing risk, measured by the standard deviations, reduced supply concluding:

> The estimated responses to the relative standard deviations do provide further support for the hypothesis that the agricultural sectors in underdeveloped countries respond negatively to risks. (p. 336)

The second econometric study is that of Just (1974), which nested Nerlove's (1958) adaptive expectations model. Nerlove's model of adaptive expectations is rejected in favor of an expanded adaptive risk model implying that crop supplies fall in response to increased risk. Now, more than three decades after the Behrman and Just studies, a large number of econometric investigations have found empirical support for risk effects in supply response. Though the preponderance of these studies model expectations as a moving average process, the variety of similar findings provides strong evidence that risk does affect supply response.

Using a primal approach by defining expected utility as a function of moments (first, second, and third), Antle (1987) used a Taylor's series approximation coupled with random coefficients to estimate the nature of risk aversion. He found evidence of both risk aversion and aversion to "downside risk" (i.e., the risk of facing "low income" outcomes). Chavas and Holt (1996) provided a workable structural model of U.S. acreage choice among corn and soybeans with uncertain price and production under government programs. Constant absolute risk aversion is rejected. Relative risk aversion and downside risk aversion are estimated to be approximately 6 and 157, respectively. Though these primal studies were successful, the power of duality under certainty led to a similar focus under risk.

Coyle (1992) developed and applied all of the restrictions and economic meaning of the Freund's expected utility function under output price uncertainty. However, the properties possessed by the indirect expected utility functions with simple but workable general empirical approaches are difficult to uncover. More recently, the duality between cost and production for general stochastic technologies has been developed (Chambers and Quiggin 1998). In subsequent work, Chambers and Quiggin (2000) have used the state-contingent approach to show how the cost function and conditional factor demands depend on outputs in all possible states of nature. This allows for possible substitution across states of nature, thus avoiding the non-substitution implied by conventional production functions. More importantly, the recognition that individuals with monotonic preferences minimize cost permits the evaluation of important aspects of supply-response and portfolio-choice behavior independently of any specific assumption on risk attitudes (Chambers 2007; Chavas 2008). Evidence is accumulating on the benefits of this approach (e.g., O'Donnell and Griffiths 2006; Chambers 2007; Chavas 2008).

Contribution #9: Analyzing intertemporal investments

Burt and Allison (1963) examined wheat fallow decisions in the Great Plains, assuming a linear utility function and random soil moisture. They found that returns per acre under the optimal policy were \$25.60, compared to \$22.56 for continuous wheat and \$16.45 for wheat fallow rotations. These calculations illustrate the value of carefully considering dynamic considerations in farm decision-making. Zusman and Amiad (1965) approached the problem differently. Simulation methods, becoming easier to implement, were chosen over stochastic dynamic programming. In an attempt to include substantial complexity into a dynamic model, they built a dynamic simulation model of an Israeli crop-livestock Kibbutz with a number of control and state variables. Weather provided the driving force of risk. The optimal decision function, in the dynamic programming sense, was evaluated on the basis of expected value and coefficient of variation of wealth.

Myers (1989) adapted a consumer capital asset pricing model and focused on storage and intertemporal arbitrage behavior for corn, wheat, and soybeans. Under constant relative risk aversion (CRRA), he found a storage risk premium and relative risk aversion between 1 and 3. In a substantial generalization of the additive expected utility approach used in Myers, Lence (2000) considered aggregate agricultural investment in a recursive utility framework that enabled distinguishing the intertemporal elasticity of substitution from the CRRA risk aversion parameter. He found that farmers are forward looking, risk averse, and prefer an early resolution of risk.

Contribution #10: Assessing the role of crop insurance and land tenure contracts

The Federal Crop Insurance Corporation (FCIC) was established in 1938. Both before and after the FCIC creation, agricultural economists were analyzing and providing input into the formulation of crop insurance policies (e.g., Valgren 1922; Sanderson 1943; Halcrow 1945). This included clear discussions of the problems of moral hazard and adverse selection. Clendenin (1942) is one of the first to survey and determine what characteristics determined participation. The research found that financial strength, crop mix, risk, and premium rates affected demand, and concluded that participation was greater in low-premium counties (Gardner and Kramer 1986). Gardner and Kramer are among the first to do a systematic econometric study of insurance demand. Using reduced form regressions informed by expected utility theory, they examined aggregate demand for insurance by counties in 1979. They found that a larger expected rate of return on insurance leads to increased purchases, while larger variance reduces purchases. Goodwin (1993), examining Iowa corn producers, found inelastic demand (insured acres) for insurance: "Of greatest importance is the finding that counties with low loss-risk have considerably more elastic demands for crop insurance than those counties where producers typically collect high indemnities relative to their premium payments." This suggests a classic difficulty under asymmetric information where any attempt to raise premiums will cause low-risk farms to exit. Just, Calvin, and Quiggin (1999) found that risk aversion plays only a small role, while the subsidy and adverse selection play substantial roles in the decision to participate. As to the measured effect of insurance on input use, chemicals have received the most attention. Methodological issues abound (e.g., simultaneity) and, so far, empirical results do not convincingly answer the question as to whether insurance and chemical-use are complements or substitutes.

In the theory of contracts, agriculture has a central place: contracts are pervasive and relatively simple to describe. Since before Marshall (1920), some agricultural economists have presumed the inefficiency of share contracts over fixed wage and fixed rent contracts in agriculture. Schickele (1941) and Heady (1947) had the view that share contracts are inefficient but Heady mentioned that cost sharing could lead to Pareto optimality. D. Gale Johnson (1950) looked at more general equilibrium considerations, concluding that these "make crop-share tenancy function reasonably well."

Among more recent literature, two questions are evident: "are agricultural contracts competitive?" and "what is the role of uncertainty?" Regarding the first, Bell and Zusman (1976) developed a bargaining model that recognizes the fundamental issue of non-tradable inputs (such as farm skill derived from owned land). They made some headway toward explaining the prevalence of 50:50 share contracts throughout much of Asia. Regarding the second question, Cheung (1969), Stiglitz (1974), Newbery and Stiglitz (1979), Braverman and Stiglitz (1986), and Otsuka, Chuma, and Hayami (1992) provided the conceptual foundations for the modern treatment of moral hazard, and transaction costs in share contracts. However, it was primarily empirical work that advanced a new understanding: risk alone does not lead to greater prevalence of sharecropping. Greater risk brings greater scope for managerial decision-making, greater costs of monitoring, and a greater possibility to reap the rewards as a renter. This implies a lower incidence of share contracts. Roumasset and Uy (1987) developed a model where there are shirking costs that are mitigated by a share contract, but also land shirking (mining) costs which are lowest under a fixed-wage contract. Land conditions (ability to mine the land) affect the cost share. Allen and Lueck (2002) have empirically rejected risk aversion and risk sharing as the primary motive for share contracts but found support for transactions costs as the explanation. Allen and Lueck (2009) have also tackled the question considered in Bell and Zusman: why are crop-share contracts relatively simple with a few discrete shares enduring over time? Developing a matching model between landlords and farmers with moral hazard, they are able to reproduce customary contracts, particularly when the degree of moral hazard is large (related to complexity). Regression analysis supports the conclusion that moral hazard is a root cause of share amount. This vast and important literature on share contracts continues and, among other items, considers both shirking in the application of inputs as well as reported output (de Janvry and Sadoulet 2007).

Contribution #11: Assessing the economics of agricultural production under risk

Agricultural economists have contributed significantly to the economics of risk through expositions, applications, and theoretical developments. Building on Heady (1952b), some of the early influential books on risk are: Anderson, Dillon, and Hardaker (1977), Halter and Dean (1971), and Robison and Barry(1987). Early centers of expertise (UC-Davis, Iowa State, North Carolina State, Oregon State in the United States, and University of New England in Armidale) gained significant understanding of the value of and procedures to apply risk theory to farm management. This created a synergy that enabled many of the innovations and applications of risk analysis. As time progressed, agricultural economists made a significant number of conceptual contributions to the basic theory of risk taking and management throughout both the *AJAE* and other economics journals. These are too numerous to discuss. However, an important contribution was made by John Quiggin (1982), who proposed a generalization of the expected utility model allowing preferences to be nonlinear in the probabilities. Quiggin's generalization has been highly influential. Over the last 20 years, it has helped guide economic research on the characterization of risk preferences. Finally, Chambers and Quiggin (2000) have pushed the frontier of risk analysis using the "state-contingent approach", which applies under very general conditions. They have shown how a general approach to risk and risk preferences can be used in the investigation of risk management. Empirical applications of the approach to agriculture are under way (e.g., Chavas 2008).

Dynamics

The economics of the farm has been strongly influenced by its adjustments to a changing world. Over the last century, the agricultural sector has been totally transformed, especially in developed countries. The changes have been massive, including labor out-migration, mechanization, evolving farm size, and rapid technological progress. Agricultural economic research has studied these adjustments in depth. Below, we review some key accomplishments that shed lights on the structural changes that have faced agriculture over the last century.

Contribution #12: Analyzing agricultural supply dynamics

Cassels (1934) focused on three separate notions of a supply curve: the market curve (supply from existing stocks), the Marshallian short-run normal curve, and the Marshallian long-run normal curve. For differing reasons, he saw the first and the third as virtually impossible to estimate statistically. He viewed the short-run normal curve, which corresponds to one derived in the presence of some fixed or quasi-fixed factors, as more estimable. But he argued that timing effects and observability problems ensure that supply curves are not reversible. He wrote:

> The process of contraction is not an exact reversal of the process of expansion and the supply curve is a one-way curve, each supply curve must be regarded as relating to an established level of output and should be recognized as having two distinct parts, one representing expansion and the other representing contraction. (p. 384)

Drawing on earlier work by Cagan and Koyck, Nerlove (1958) formulated a dynamic supply-response model that consists of basically three equations. The first, based on standard neoclassical theory relates desired acreage to an expected normal price. The second defines the expectations mechanism. The difference in expected normal price between any two adjacent time periods adjusts via a linear equation to the difference between actual price lagged one period and the expected normal price lagged one period. The third equation, via a partial-adjustment model, relates the change in actual acreage between two adjacent time periods to the difference between current desired acreage and actual acreage lagged one time period. Applications of Nerlove's basic ideas percolated throughout all of applied economics and formed the basis for many important advances in other areas. For example, the adjustment mechanism in Jorgenson's neoclassical theory of investment was partially based on the Nerlovian model. Having a dynamic model that is both empirically tractable and consistent with microeconomics, it proved very appealing. It stimulated much empirical work on agricultural supply dynamics (as surveyed by Askari and Cummings 1977), as well as further conceptual refinements.

Many conceptual refinements have focused on investment and capital formation. A fundamental question is: what is the nature of adjustment cost in capital formation? One approach is an extension of Nerlove's model: specify a smooth adjustment cost function for investment and explore its implications for the dynamics of both capital and supply. Another is to consider non-smooth adjustment costs, which typically involves situations where investment costs are (at least partially) sunk. This occurs when an investment creates capital that becomes specialized in a particular use (meaning that employing the created capital in some alternative use is costly). It corresponds to situations where the purchase price of capital is higher than its salvage value, the difference between these two prices being sunk investment cost.

In this context, Johnson and Quance (1972) proposed a theory of "asset fixity" by showing how sunk cost can contribute to a lack of capital adjustments. First, they noted that sunk costs are commonly found in agriculture (whenever the salvage value of capital is less than its purchase price). Second, they showed that sunk costs have adverse effects on the adjustment process in agriculture. Johnson and Quance argued that this asset fixity helped explain why U.S. agriculture was in an "overproduction trap" in the 1930s, 1950s and 1960s. Johnson and Quance's theoretical arguments were criticized by Johnson and Pasour (1981), who argued that the relevant prices for capital and other inputs are not their acquisition prices or their salvage values but their opportunity costs. Combining the Johnson and Pasour critique with a putty-clay framework, Chambers and Vasavada (1983) tested for the presence of asset fixity but found no empirical support for the hypothesis. Even so, the ideas behind the asset-fixity hypothesis have stimulated refinements in our understanding of capital formation.

The analysis of dynamics in agriculture has benefited from significant refinements in analytical tools. This includes the development of dynamic programming as well as optimal control methods developed in the late 1950s and early 1960s. Such developments stimulated inquiries into the dynamics of farm management decisions (e.g., Burt and Allison 1963) and range management (e.g., Karp and Pope 1984). It also helped refine our understanding of optimal replacement decisions (e.g., Burt 1965; Chavas, Kliebenstein, and Crenshaw 1985). Improved dynamic tools continue to enhance our power of analysis of a changing world to this day (e.g., Miranda and Fackler 2002).

In understanding supply dynamics, one of the important challenges is determining whether supply functions are always upward sloping. Jarvis (1974) provided a fundamental insight into this issue by analyzing supply decisions in the cattle industry. He showed that sending adult animals to slaughter has two effects: one is to increase meat supply; the other is to reduce the size of the breeding herd. Building up the breeding herd increases supply in the long run but also means fewer adult animals being slaughtered, potentially yielding a decrease in short-run meat supply.

Contribution #13: Analyzing the role of expectations

Agriculture also provides an interesting setting to study the role of expectations. The role of expectations has received considerable attention over the last century. It started with "naïve expectation" where managers use the latest observation as a predictor of the corresponding variable. In this context, Kaldor (1934) and Ezekiel (1938) showed that naïve price expectations along with production lags can create "cobweb" market dynamics, with associated cycles in prices and quantities.

In place of naïve expectations, Nerlove (1958) proposed the generalization described above that allows for "adaptive expectations," where expectations are revised from one period to the next proportionally to the prediction error made the previous period. Following Muth (1961), rational-expectations theorists assume that informed market participants know about the functioning of markets and the associated price determination process. Hence, expectation formation is an endogenous part of the functioning of markets. In this context, naïve or adaptive expectations (which are backward looking) are not rational. As mentioned above, this has stimulated inquiries into the linkages between agricultural supply dynamics and the nature of farmers' expectations. Empirical research analyzing the role of rational expectations in farm supply decisions includes Eckstein (1984) and Holt and Johnson (1989) for crops, and Rosen, Murphy, and Scheinkman (1994) for cattle. Rosen, Murphy, and Scheinkman (1994) showed that the U.S. cattle cycle appears to be consistent with rational expectations in the presence of serially correlated exogenous shocks. This indicates that rational expectations do not eliminate the possibility of market cycles. Evaluating the exact nature of expectations remains a challenging task. For example, Chavas (2000) presented evidence of heterogeneous expectations among U.S. beef producers.

Contribution #14: Analyzing the process of technology adoption in agriculture

The agricultural industry of most countries has seen rapid productivity growth over the last century. While understanding the connection between technical change and productivity growth remains challenging, some progress has been made. Hicks (1932) first proposed the "induced-invention hypothesis," stating that inventions could be made as a result of changes in the relative prices of factors. Salter (1960) criticized Hicks' induced-invention on the basis that it added no fundamental insight that was not already available from neoclassical theory. Arguing in terms of an enveloping isoquant that enveloped short-run isoquants from below, Salter argued that choice of technique could be rationalized in terms of basic firm theory. These ideas have been developed to form the basis for the "induced-innovation" approach that provides insights into the development of agriculture over both time and space.

Boserup (1965) made a fundamental contribution by analyzing the economics associated with the rise of agriculture some 10,000 years ago. Her key hypothesis is that the rise of agriculture was induced by an increase in population density. Under a low population density, local ecological systems may generate enough food to a hunter-gatherer without him or her exerting much effort, thus providing no incentive to switch to agriculture as long as population density is low. Hence, agriculture would develop only after a rise in population density. It is clear that historically the rise of agriculture was associated with a more intensive use of labor and an increase in land productivity. Boserup (1965) documented how the development and adoption of agriculture was in response to a decline in per capita food availability. This idea stood in sharp contrast with an alternative hypothesis: the Malthusian hypothesis stating that feeding a growing human population can become increasingly difficult under scarce resources. Agricultural innovations have typically been fast enough to keep farm productivity growth ahead of population growth (at least at the world level).

Hayami and Ruttan (1971), Binswanger (1974b), and Ruttan (2001) showed that the adoption of mechanization typically followed an increase in the real wage rate. Farm mechanization was a labor-saving response that substituted capital for relatively more expensive labor. It also contributed to agricultural productivity growth of developed countries in two ways: (1) the land previously used to support animal traction could now be employed to increase food production; and (2) it helped maintain farm output while using less labor. This latter effect led to a decline in the number of farms and a rapid increase in farm size in the U.S.

The second major aspect of technological progress analyzed by Hayami and Ruttan (1971), Binswanger (1974b), and Ruttan (2001) is related to the increased use of fertilizer, especially nitrogen fertilizer. Technological innovations reduced the cost of producing nitrogen fertilizer (using natural gas) in the 1950s and 1960s. This set the stage for agricultural innovations that took advantage of this cheap input. Geneticists worked on developing crop varieties that were more responsive to the use of nitrogen fertilizer. The result was a sharp increase in the use of nitrogen fertilizer in developed countries (as well as many developing countries since 1970). This was associated with rapid increases in the yield of major crops and enhanced agricultural productivity. In this case, genetic selection created new technologies that were biased toward the use of a cheap input: fertilizer. Given that technological progress is the main engine of economic growth, such arguments have been at the heart of the literature on "endogenous growth."

More generally, genetic progress has been a major contributor to productivity gains in agriculture over the last century. An excellent example is hybrid corn. The first commercial corn hybrid was released by the Connecticut Agricultural Station in 1921. Griliches (1957a) investigated the process of adoption of corn hybrids on U.S. farms. He found that the process was typically slow, and many farmers were reluctant to adopt the new hybrids. Then, a few farmers would become "early adopters," and be followed by others. After several years, most farmers would eventually adopt. Griliches (1957a) showed that the adoption curve depicting the number of adopters over time typically has a sigmoid shape. The result was a large increase in agricultural productivity in the U.S. Corn Belt. Such favorable outcomes from genetic selection have persisted to this day in the United States and elsewhere.

In general, increased productivity contributes to feeding the growing world population and benefits consumers by increasing food supply and lowering the real price of food. But does it benefit farmers? In studying this issue, Cochrane (1958) proposed his "treadmill hypothesis." He argued that only farmers who are "early adopters" gain. Early adopters can capture the benefits of productivity gains (in the form of a higher output and/or lower cost) before the output price adjusts. However, when technology adoption becomes widespread, its positive effect on supply induces a downward output price adjustment. And this effect is larger when the demand curve is more inelastic (a typical characteristic of food demand). It means that both consumers and farmers are expected to see a significant decrease in food price. This makes the former better off. But this makes late adopters worse off: they face lower revenue. This is Cochrane's treadmill hypothesis. Schmitz and Seckler's (1970) analysis of the tomato harvester is another example of the distributional effects of technological progress. It documents how mechanization can increase efficiency while generating adverse effects on the welfare of unskilled labor.

Contribution #15: Assessing the role of human capital and managerial ability in agriculture

How does one measure managerial ability? Schultz (1975) proposed to characterize this ability as a service obtained from "human capital." This has focused attention on the determinants of human capital. The stock of human capital is the outcome of past learning and knowledge accumulated over time. The role of education as an investment in human capital has been of special interest. Huffman (1977) documented a positive and significant relationship between education and the speed of farmers' adjustments to changing market conditions.

The main challenge associated with evaluating managerial ability or human capital is its empirical assessment. There is no simple way to measure managerial ability in complex economic environments. On the one hand, as argued by Schultz (1975) and others, there is strong evidence that improving human capital is at the heart of long-term economic growth. On the other hand, precise measurements of managerial abilities remain elusive. This contributed to an academic dichotomy between farm management and production economics (Jensen 1977).

As argued by Taylor (1905), Black (1926), Heady (1952a), and others, production economists have looked for "optimal plans" that would implement efficient allocations in agriculture. Unobserved heterogeneity in managerial skills creates several empirical issues. First, treating management as an unobserved input leads to a "management bias" in the analysis of farm production technology. As discussed above, Mundlak (1961) showed how to deal with this management bias in the presence of panel data. Second, in the analysis of firm-level data, it is not easy to identify measurement errors (e.g., due to unobserved managerial skills) from technical inefficiency. In the stochastic production frontier approach (proposed by Aigner, Lovell, and Schmidt (1977), Battese and Corra (1977), Battese and Coelli (1988), and others), this identification problem has been addressed by imposing a priori assumptions on the distribution of these two effects. The empirical evidence has indicated that measurement errors play a role and should be taken into consideration in evaluating farm technical efficiency.

In contrast, researchers in farm management have taken a more direct approach to the role of managerial abilities. They have relied on "case studies" where the optimality of a farm production plan can vary with the level of managerial skills and the complexity of the economic environment (Case and Williams 1957; Johnson 1957). On the one hand, this search for realism has made it more difficult to make recommendations that would apply to all farmers. On the other hand, scholars of farm management have focused attention on two aspects of agricultural economics that appear relevant. The first is the need to identify more explicitly the role of managerial skills in agriculture. The second is related to the fact that most farms are multi-product enterprises. It means that farm activities need to be analyzed using a system approach. Research on the economics of "farming systems" continues.

Contribution #16: Analyzing the evolving structure of agricultural production

The last century has seen major changes in the structure of agriculture in developed countries. As noted above, massive labor migration out of agriculture has been associated with mechanization and increased farm size (Schultz 1963; Gardner 2002). This raises the question of whether economies of scale generated efficiency gains from larger farms. As found in many industries, the empirical evidence indicates that the average cost function of a farm has a typical L shape: average cost tends to decline for small farm sizes, and then reach a lower plateau for average to large farm sizes (e.g., Hall and Leveen 1978). This suggests three points. First, economies of scale seem to exist for small farms (where average cost declines with farm size). Second, there is no strong evidence that diseconomies of scale exist for large farms. Third, there is a fairly wide range of farm sizes where average cost is approximately constant. This suggests that economies of scale do not provide a strong incentive for farms to become larger. Finding that relatively small farms can be scale-efficient helps explain the prevalence of the family farm.

Over the last century, agriculture has gone through periods of boom and bust. In the U.S., boom periods include 1910–1914 (the "golden era" of agriculture) and the mid 1970s, when strong export demand contributed to increasing farm prices and income. Bust periods include the years immediately after World War I, the 1930s (the "Great Depression"), and the early 1980s. The Great Depression stimulated the development of government programs actively supporting farm income in the U.S. (many of these policies still being in place today). Agricultural policy was motivated in part by a persistent income gap between farm households and urban households. Yet, as documented by Gardner (2002), this income gap vanished in the U.S. in the 1990s. It means that the incidence of poverty among farm households has declined substantially. As argued by Gardner (2002), strong productivity growth, declining food prices, along with improving standard of living for farm households are all positive aspects of U.S. agriculture over the last century. This helps make the overall record of U.S. agriculture a success story.

Challenges for the Future

Much remains to be done. On the one hand, the challenges for agriculture to feed a growing world population remain as pressing as ever. As documented, technological progress has helped make U.S. agriculture grow rapidly. Investments in enhancing future productivity while implementing sustainable farm-management practices remain high priority areas. Addressing these challenges will require renewed efforts. Here, we would like to point to a few directions of inquiry that can help make our next century as productive as the last one. First, there is a need to refine our understanding of the role of risk/uncertainty in agriculture. For example, the current prospects for climate change raise the issue of how farmers will react to it. This can involve "rare events" that have not been observed before. It creates two significant challenges: (1) rare events are difficult to evaluate empirically (suggesting an important role for "ambiguity"); and (2) the question is raised of the waydecision-makers (including farmers) should adjust their management strategies in response to this new uncertainty.

Second, our understanding of the farmers' decision-making process remains incomplete. While farm management studies have typically taken this issue seriously, difficulties in dealing with heterogeneous managerial abilities have limited our progress. The recent interest in behavioral economics appears to provide new opportunities for further explorations of this topic. Farmers may prove ideal subjects for investigating in depth how economic decisions are made. This seems particularly relevant in the analysis of technology adoption decisions. Indeed, the rapid pace of technological progress in agriculture together with the uncertainty associated with new technologies may well provide new and useful insights into human decision-making and the process of innovations.

Finally, farmers are in the business of managing their local ecosystem. We need to refine our understanding of the efficiency of current management practices. This requires analyzing how farm decisions adjust to the dynamics of the relevant ecosystems. When these dynamics go beyond the farm gate, this will also require the development of innovative management strategies and agricultural policies.

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