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VALUING CLIMATE FORECASTS FOR MIDWESTERN GRAIN PRODUCERS

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FOR MIDWESTERN GRAIN PRODUCERS

by

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THESIS

Submitted in partial fulfillment of the requirements
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Climate effects on corn and soybean production on two representative midwestern grain farms are incorporated into production function estimates by using physiologic crop growth simulation models over fourteen years of weather data and different combinations of management decisions. Model producers are assumed to maximize a net return function. Using dynamic programming, the value of the net return functions and the associated optimal crop decisions are identified for different prior climate expectations and different designs of climate forecasts.

Climate forecasts are shown to have more value in east central Illinois than in central Iowa. Much of this value relates to adjusting the amount and timing of nitrogen application for corn production. Climate forecasts are shown to have value in crop selection when the price relationship between corn and soybeans is in a competitive range. Forecasts with more discrete outcome categories have more value than those with fewer categories, although slight decreases in the accuracy of the less detailed forecasts do not detract from their value. Management decisions included in the soybean production functions do not exhibit sufficient flexibility or responsiveness to climate for soybean climate forecasts to have value.

Ambiguity theory is used as an alternative to risk theory to develop different assumptions on the decision maker's prior information. The different assumptions on prior information are shown to strongly impact the value of information.

DEDICATION

To my mother and father, who always believed in me ...

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The successful completion of any advanced degree is not the work of the candidate. Rather, it is a somewhat coordinated effort by many individuals. To the faculty of the Department of Agricultural Economics I offer my sincere thanks for their many contributions toward my professional development. I am especially indebted to my advisor and long time friend, Dr. Steven T. Sonka, for providing me the guidance toward developing useful insight. I would also like to thank the other members of my committee, Dr. Peter J. Lamb, Dr. David A. Lins, and Dr. Robert H. Hornbaker, for their valuable comments and criticisms. Dr. C. Robert Taylor contributed much to my understanding of dynamic programming and the development of the topic. I would also like to express my appreciation to Dr. Steven E. Hollinger, who gathered the weather data and made the growth simulation models usable, and Matt Hughes, without whose assistance I would still be growing soybeans on my computer.

The study of economics is not something one should undertake alone. I am grateful to my fellow graduate students for the many valuable hours spent together developing an understanding of difficult issues. Nor can one completely forego personal income. My graduate studies were supported by the department, the University of Illinois, and the National Science Foundation under grant number ATM 8519035. However, my lifestyle and my sanity were supported by my three girls, Vida, Valerie and Lisa, whose collective understanding and patience was often more than I deserved.

Thank you all for making my dream come true.

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CHAPTER I

THE SETTING

Introduction

U.S. agricultural production has long been characterized by many as being inherently risky. Sources of agricultural production risk include such things as variability in weather and the possibility of pest infestation. Additional risks are prevalent in the overall financial performance of the farm firm. These include input and output price variability, interest rate variability, the effects of financial leverage on earnings, unpredictable machinery breakdowns and hazards of fire, wind and theft.

Numerous authors have addressed various management strategies for dealing with business and financial risks. Host of these strategies have been developed to minimize the negative impacts of risk on the farm firm, rather than to take advantage of upside variation. Most of these authors have addressed a subset of decisions faced by a manager. For example, some authors have developed models that address the desired machinery capacity of a grain farm given field activity constraints and benefits of timely operations. Others have addressed such issues as the optimal financial leverage position, the optimal hedging position, the optimal amount of formal insurance, and the optimal amount of liquidity reserve.

However, risk can also have positive impacts on the firm. This is easily demonstrated by such examples as increased yields due to better-than-average growing conditions or increased revenues from higher-than-expected output prices. It is an inherent challenge to the firm's managers to take advantage of the upside potential in a stochastic world as well as protect the firm from impacts of downside outcomes.

Ansoff describes four management systems appropriate for different rates of change in stochastic elements and their predictability. He points to "management by flexible/rapid response" as an appropriate management system "under conditions in which many significant challenges develop too rapidly to permit timely anticipation (p. 15)."

Many production decisions faced by midwestern grain producers are inter-related and have a time element regarding their planned or ultimate effect. Many such decisions can either provide or preclude the opportunity to re-evaluate decisions at a later time. Flexibility in responding to field, crop and climate conditions, though useful, quickly disappears due to the passage of time once decisions are made. For example, decisions to apply fertilizer early or to plant a particular variety of seed cannot be changed after they are implemented. Thus, managers are often presumed to practice what Ansoff calls management by anticipation.

This presumption is deeply embodied in economics and agricultural economics research by the use of micro models optimizing expected values of objective functions. The source of risk, the perception of its size and its acceptability have been examined in these models throughout the past few decades. This study focuses on a manager's use of forecast information to more accurately "anticipate" states of nature that are relevant to production decisions. More specifically, this study explores the potential use and value of climate forecasts by midwestern grain producers.

This chapter develops the motivation behind the study and enumerates its specific objectives. This is followed by a brief preview of the structure of this report. Detailed discussion of topics raised in this chapter are contained in later chapters.

Climate Forecasts and the Information Age of Agriculture

Sonka describes currently innovative agricultural producers as being in the "information stage" of U.S. agricultural development (p. 80). Agricultural decision makers are using many sources and types of information to assist them in performing their managerial function. These range from commodity price information to soil micro-nutrient analysis and beyond.

Climate information is thought to be useful in making crop production decisions due to the dependence of plant growth on naturally occurring inputs and conditions. In this sense climate is different than weather in that "a climate prediction is a statement of the expected general character of the weather for a period in the future whose length may be a part of a season (one or two months), a season, a year, a decade or even longer" (Lamb *et al*). The desirability of climate information to agricultural producers is described by Sonka et al (1986), who describe the format and characteristics of useful climate forecasts as not yet fully identified.

Hilton identifies the flexibility of the structure of the decision set as one of the key determinants of information value. That is, for information to possess value the decision maker must be presented choices, the selection among which is improved by using the information. Given that midwestern grain production is dependent upon climate outcomes, at issue is which decisions are aided by climate information and in what manner. Clearly such decisions must be characterized by flexibility as well as impacted by climate.

For climatologists developing forecast schemes, an awareness of the characteristics of climate forecasts which make them useful in making crop production decisions would be quite rewarding. Similarly, knowledge of forecast characteristics of little value to crop producers may be useful in avoiding the development of more costly forecast schemes. Perhaps more useful would be an understanding of the characteristics of the decision maker and the decision set which give rise to differential forecast valuations.

Objectives

The specific major objectives of this study are as follows:

1. Identify determinants of the value of climate forecasts to a midwestern corn-soybean farm with emphasis on the design parameters of the forecast and the detail of the setting.
2. Evaluate differences in the value of climate forecasts for farms in different geographic regions.
3. Determine the amount and sources of valuation differences in 1. and 2. above and the sources of valuation differences between this study and similar ones of alternate specification.

As discussed in the next chapter, this is not the first study to address the issue of climate forecast valuation in agricultural production. Previous studies addressed various specific issues such as 1) particular weather events (rainfall), 2) restricted settings (one crop on one acre in one location), or one specific decision (irrigation, fertilization or summer fallow). It is a goal of this study to view the farm firm as being controlled by one decision maker who may incorporate climate information into a variety of decisions. Further, implementation of this goal requires detailed, accurate specification of the model farms and the constraints within which they are operated. The development of these model firms is seen as useful in itself beyond the objectives above.

Organization

The remainder of this report is comprised of six chapters. Chapter II contains a review of relevant literature in the areas of information theory, risk and production economics, modeling farm decisions and prior research in valuing weather and climate forecasts. The specific methods to be employed in the study are developed in Chapter III. These include some of the sources of data for the study, the justification underlying the models used, and a brief discussion of optimization techniques in dynamic economic analysis.

The models are fully developed in Chapter IV. Chapter V discusses the results of preliminary model runs and addresses the value of climate forecasts in different economic settings. Some characteristics of the forecasts are altered in Chapter VI, as well as some of the characteristics of the decision maker, to determine their impact on climate forecast valuations. Chapter VII contains a summary of the results and conclusions drawn from the study, together with recommendations for future research.

CHAPTER II

LITERATURE REVIEW

There are four broad areas of literature relevant to this study. They are 1) risk and stochastic production, 2) information theory, 3) ambiguity theory, and 4) research specific to valuing information and climate forecasts. Each is treated separately, followed by a discussion of the resulting implications to this study.

Risk and Stochastic Production

The development of production risk research has followed a relatively stable course. As noted by Antle (p.1099):

> "The extension of the static neoclassical production model to incorporate price and production uncertainty has led agricultural economists to rationalize observed behavior in terms of the Arrow-Pratt risk aversion concept. This approach has led in turn to qualitative comparative static theorems which are appealing to theorists but have little relation to the decision problems faced by farmers."

The extension of the neoclassical production model as described by Antle can be found in numerous applications. Sandmo developed a model under output price uncertainty to evaluate the comparative statics of supply. Batra and Ullah developed a similar model to examine the comparative statics of input demand. Both investigators assumed a producer who was maximizing the utility of profit. They demonstrated that a marginal increase in risk . (defined by Rothschild and Stiglitz' mean preserving spread) gave rise to a decrease in output and a decrease in inputs respectively. Pope and Kramer extended the neoclassical model to incorporate stochastic technology. Their results indicate that risk aversion on the part of a utility maximizing producer results in the use of more risk-reducing inputs.

While each of these works contributes to the general understanding of risk and production economics, the assumptions underlying the models are strong. First, Sandmo admits the assumption that producers are maximizing a von Neumann-Morgenstern utility function is restrictive. In theoretical work the functional form need not be specified. However, precise specification of the functional form is required to empirically implement this assumption. It is often specified as an exponential utility function (see, for example, SriRamatatnam _et_ _al_).

Secondly, the assumption of risk aversion (and usually the assumption of decreasing or non-increasing absolute risk aversion) on the part of the producer is very restrictive. SriRamaratnam _et_ _al_ found exponential Arrow-Pratt risk coefficients ranged between 0.0000021 and 0.000037 for a sample of fifteen Texas sorghum producers. In discussing their model results they describe the difference between optimal fertilizer rates under profit maximization versus utility maximization as very small. They ascribe this result to the "low level" of risk aversion estimated for producers in the sample.

Therefore, applications of extensions of the static neoclassical model appear to be of little direct usefulness to producers who are unaware of their Arrow-Pratt risk aversion coefficients and/or the specification of their utility functions. Proper application of economic theory to the dynamic setting of crop production decisions under uncertainty appears to center around perceived risk and the response to combinations of risk over time. As pointed out by Antle (p. 1105), "Incorporating risk in production analysis means incorporating probability distribution parameters in decision models." He also indicates dynamic models show production risk generally affects resource allocation regardless of risk aversion. The role of information in this setting is to alter perceptions of risk so as to more precisely identify probability distributions of future outcomes. It is within this framework that literature on information theory is next reviewed.

Information Theory

Information is used to alter expectations. Despite not being mathematically identified, decision makers possess some expectation about the probability distribution of stochastic events. Byerlee and Anderson describe such a setting in which a producer has prior expectations about the probability distribution of stochastic production. The following terms apply within this and subsequent discussions. A prediction is a piece of information or an information set which describes the probability distribution of stochastic events. A predictor or information system is a system which generates predictions. Thus, not only are the events stochastic, but so are the predictions coming from the predictor. That is, there exists a probability distribution of information sets coming from the information system.

Following Hilton, a producer receives returns π given by $\pi(x,\theta)$ where x is a vector of decision variables, θ is a vector of stochastic variables, and the function $\pi(X,\theta)$ embodies input and output price relationships. With prior probability distribution on θ given by $p(\theta)$, the optimization problem for the profit maximizing producer is given by

$$\max_{x} \int \pi(x,\theta)p(\theta)d\theta \qquad 2.1$$

where the integration is over the range of possible values of θ and the solution to which is denoted x .

Now suppose a reliable prediction, k, is generated such that the probability distribution of 8 is now given by $P_k(\theta) - p(\theta|k)$. The optimization problem given this new information set is

$$\max_{x} \int \pi(x,\theta)p(\theta|k)d\theta \qquad 2.2$$

the solution to which is denoted x_k. Given that the information set is reliable, the decisions x are now suboptimal. Therefore, the value of the information set P_k is given by

$$\text{Value of } p_k = \max_{x} \int \pi(x,\theta)p(\theta|k)d\theta - \int \pi(x^*,\theta)p(\theta|k)d\theta \qquad 2.3.$$

This equation says the monetary value of the information set P_k, or the prediction k, is the difference between a) returns from optimal decisions based on the new information set and b) returns from decisions based on prior information evaluated in light of the new information. In other words, the value is the amount of increased returns from decision changes based on new information.

Prediction k is but one of many possible predictions that could have come from a predictor or information system that generates predictions. The value of the information system is given by

$$V = \int \max_{x} \int \pi(x,\theta)p(\theta|k)d\theta p(k)dk - \max_{x} \int \pi(x,\theta)p(\theta)d\theta \quad . \quad 2.4$$

which says the value of the information system is the difference between a) the expected value of returns from the optimal decisions based on the expected prediction and b) the returns from optimal decisions based on prior information.

Byerlee and Anderson employ this valuation model in determining the value of a long-range rainfall forecaster to Australian sheep producers making decisions to conserve fodder for drought years. They show that such a predictor has value to both risk averse and risk prone producers and that no general relationship can be determined regarding a producer's Arrow-Pratt risk aversion coefficient (parametrically varied) and a producer's willingness to pay for forecasts as measured by V in 2.4. This finding is supported by Hilton who found no general monotonic relationship between the degree of risk aversion and the value of information.

Chavas and Pope described four different concepts and measures of information in their literature survey-type article. Two of these are of interest here. The first is entropy, denoted as H, which is the negative of the expectation of the logarithm of probabilities:

$$H = -\Sigma_i \, p_i \ln p_i \qquad 2.5$$

where p_i is the probability of the i^{th} outcome. The more uncertain the outcome the larger is H. However, they state that equation 2.5 does not readily lend itself to economic research valuing information or information systems.

Chavas and Pope's second concept of information derives from decision theory. In this sense information is a "message which alters probability perceptions of random events"(p.707). They go on to describe information valuation methods similar to that used by Hilton and Byerlee and Anderson. However, they describe a time element in decision patterns and information gathering.

Given two time periods (t=1,2), the objective function of a profit maximizing producer can be written as

$$\max_{x_1,x_2} E_1[\pi(x_1,x_2,\theta_1,\theta_2] \qquad 2.6$$

where E_t is the expectation operator based on information available at time t, x_t is the vector of decision variables at time t, θ_t is the disturbance term at time t with a prior probability distribution. Under this specification decisions x_1 and X_2 are made at t=1 based on the prior probability distributions at t=1 for both θ_1 and θ_2.

However, if reliable information becomes available at t-2, expectation E_2 is altered such that the solution for the decision vector x_2 is given by

$$\max_{x_2} E_2[\pi(x_2,\theta_2] \qquad 2.7$$

where the expectation E_2 is operating over an updated probability distribution. It is intuitive that piecing many time periods together requires a dynamic programming application as long as time is modeled discretely. This is more fully explored in the following chapter. It is also intuitive that the earlier the information is known, the better are the decisions forthcoming in earlier periods. This is especially true if θ_t is dependent upon x_t-1.

Hilton describes four determinants of information value. These are:

1) the flexibility of the structure of the decision set,
2) the technology and environment within which the decision maker operates,
3) the degree of uncertainty in the prior expectations, and
4) the nature of the information system, specifically timeliness and accuracy.

These characteristics can be detected in equations 2.1 through 2.7.

Flexibility can be related to the structure of either the variability of decision x (eq. 2.1 through 2.4) or the ability to postpone the x decision to await further information. (2.6, 2.7). That the value of information is dependent on technology and the decision environment is verified by the profit function which is characterized by a production function and a set of prices.

The relationship between the prior and the predictions plays a fundamental role in the solutions to 2.3 and 2.4. The extent to which the priors and the predictions differ, and the extent to which they generate different solutions x^* and x_k, clearly impacts the value of P_k and V. Last, the nature of the information system is relevant in that the accuracy of the prediction forthcoming, P_k, determines the economic impact of the resulting x_k decision.

Ambiguity

Bessler notes that agricultural economics research has not sustained a focus on the formation of expectations over time. Recent literature in decision theory raises interesting questions regarding the foundations of risk analysis. Initiated by Ellsberg, the concept of ambiguity covers a wide spectrum between the two extremes of uncertainty. These extremes are labeled 1) ignorance, in which the decision maker has no knowledge of the possible uncertain outcomes nor of the process by which they are generated, and 2) risk, in which the decision maker has complete knowledge or firm belief in the probability distribution of outcomes (Einhorn and Hogarth, 1985, 1987; Yates and Zukowski). In ambiguous circumstances, some probability distributions may be ruled out, but at least two remain.

Theory of Ambiguity

Following Einhorn and Hogarth (1987)[3], the ambiguity model employs an "anchoring-and-adjustment strategy in which an initial probability is used as the anchor (or starting point) and adjustments are made for ambiguity (p. 46)." The source of the initial probability may be any information, historical or otherwise, available to the decision maker. The subjective probability used in decision making, S(p), is given by:

$$S(p) = p + k \tag{2.8}$$

where p is the anchor probability and k is the adjustment. The adjustment is made from a mental evaluation of higher and lower values of p. If k_g is the effect of simulating higher values of p and k_s is the effect of simulating lower values of p, then

$$k = k_g + k_s \tag{2.9}$$

$$k_g = \theta(1-p) \tag{2.10}$$

$$k_s = \theta p \tag{2.11}$$

where θ is a constant representing the amount of ambiguity present. Furthermore, the decision maker may possess different attitudes toward higher and lower values of p. Therefore., equation 2.11 is rewritten as:

$$k_s = \theta p^{\beta} \tag{2.12}$$

where β represents a relative weighting of higher versus lower probabilities. Combining equations 2.8 through 2.12,

$$S(p) = (1-\theta)p + \theta(1-p^{\beta}) \tag{2.13}$$

Because $S(p) \leq 0$, obvious limitations are placed on k, k_g and k_s. β is restricted to be non-negative by definition. A heavier weighting on probabilities lower than the anchor is denoted by $0<\beta<1$, while $\beta>1$ indicates heavier weighting on those above the anchor.

Forecast Valuation Models in Production Economics

The literature on agricultural production applications of the information valuation models is mostly focused on weather information, although Perrin studied the value of soil test information in Brazilian corn production. As noted earlier, Byerlee and Anderson applied equation 2.4 to value a rainfall forecaster. Doll developed a similar model in which the choice variables were nitrogen application rates and planting densities. He used a Bayesian algorithm to incorporate the probability of incurring one of seven possible production functions dependent upon unspecified weather. Tversky and Kahneman show that updating priors by Bayes's Theorem will not necessarilty generate subjective measures of risk that resemble those of real worl decision makers (Bessler, p.52).

More recently Bosch and Eidman (1985, 1987) have examined the value of soil water and weather information to Minnesota farmers irrigating corn and soybeans. To value information they used a stochastic dominance approach (Meyer) to deduct information value, V, as a cost from $\pi(X,\Theta)$ underneath the integral in equation 2.4. In so doing they could compare distributions of outcomes for producers whose absolute risk coefficients lie within certain bounds to determine the value (cost) of information at which the updated probability distribution of returns no longer stochastically dominated the returns from the prior distribution. They analyzed optimal irrigation under varying levels and combinations of information on soil water, crop transpiration, and rainfall for a 640 acre farm irrigating 260 acres of corn and soybeans. They incorporated output price risk but did not indicate how this was done. They did show that information had value even though it was incomplete. They also demonstrated a decreasing marginal return to increasing levels of information. Part of the results showed a tendency for optimal irrigation to begin earlier for more risk averse producers. This is not surprising in view of Pope and Kramer's results showing generally increased use of risk reducing inputs, such as irrigation, as risk aversion increases. Bosch and Eidman also point out that the empirically estimated value of information may be different when analyzed at the firm level from that calculated from the direct effect on the enterprise making information-based decisions.

Babcock studied the comparative statics of general equilibrium when producers respond to climate forecasts as a sector. He specifically examined the price effects within a binomial distribution of weather events. His empirical application to cotton production suffers from under-specification. However, he did show mathematically that if output demand is inelastic, average industry profits could decrease as a result of improved information accuracy.

In work somewhat related to Bosch and Eidman, Mjelde applied a dynamic programming model to evaluate increased returns from one acre of corn in east central Illinois when climate information became available to improve various corn production decisions throughout the year. Within this context Mjelde sought to identify the determinants of information value with the goal of identifying the parameters of climate forecasts which have greatest value within the forecast system.

In developing his approach, Mjelde simulated the growth of one acre of corn over fourteen years to generate data on the response to management decisions which interact with climate. The production year was divided into eight decision and/or growing periods for which climate forecasts and outcomes could be obtained. Using the data generated by the corn simulation model, transition equations were estimated for the state variables of nitrogen, plant, climate, grain moisture, and October climate. A field condition state variable was added to restrict the number of field operations performed if the growing season climate was poor to add realism. Parameters varied based on decisions of planting date, planting density, seed variety by days to maturity, and the amount of nitrogen within the decision model. A climate index was developed to unify the various weather parameters included in the simulation model, in contrast to Doll's approach of developing a different production function for each year studied and to Babcock's approach of incorporating only May rainfall.

Discrete intervals within the probability distributions of climate were aggregated to simplify the model. The probabilities of obtaining various forecasts and realizations were varied to compare results from alternative forecast specifications. The results indicate that perfect forecasts are not necessary for the forecast system to have value. In fact, more value is attached to forecasts which more accurately predict extreme climate conditions than those with better overall accuracy. Also, more value is attached to forecasts of production stages having more nitrogen-climate interaction. Consistent with intuition, Mjelde also showed that the value of such forecasts generally increases with more lead time.

As Mjelde notes, however, there are certain elements of his problem specification which warrant relaxation or expansion to further evaluate the determinants of climate forecast values. It is to these issues that attention is now focused.

Implications for This Study

The work discussed in the previous section forms a foundation for understanding the valuation of climate forecasts and the contribution of design parameters within the forecast system. Although the work done by Mjelde was specific to this purpose, there exist certain biases (some noted by him) in his results due to the specification of the model.

The value of the forecasts in certain stages was dependent upon the growth process of the corn plant. Adding another crop into the decision model to more closely parallel the corn-soybean rotation witnessed in much of midwestera agriculture should reduce the bias arising from this dependency. Analyzing the whole farm, as in Bosch and Eidman, should shed light on the value of forecasts to a firm rather than an enterprise. Such an analysis can then incorporate more realistic field time constraints.

Within the whole farm context, varying soil types may play a role in valuing information. For example, farms with a larger proportion of well drained soils may place a larger value on certain design parameters than farms with a preponderance of less well-drained soils. This may enter the valuation model in activating field time constraints more quickly for the second group resulting in less flexibility.

In each of the studies discussed earlier there was a dependency on one location for each valuation model. This study should compare the forecast design valuations across geographic regions within the midwest using the same whole farm, multiple soil type setting to identify the source of differences in forecast valuation or design parameter emphasis. Performing this comparison using the same modeling technique should reduce any bias in the comparison arising from the model itself.

The value of climate information may be affected by public institutions. One such institution currently imposed on midwestern grain producers is the U.S: Department of Agriculture's feed grain set aside programs. These programs currently restrict corn acreage for program participants in return for reduced output price uncertainty and direct payments. The effect of these programs on the value of climate forecasts to participating versus non-participating farmers in each region should be investigated to further identify the determinants of climate forecast value.

Finally, the equations which value climate information emphasize decisions based on prior expectations. Remaining consistent with ambiguity theory, the effect of different priors on the value of climate forecasts should be investigated.

Notes

1. Batra and Ullah's use of decreasing absolute risk aversion results in decreased output. For their two-input model, at least one of the input quantities will decrease. The effect on the other depends upon the specification of technology.

2. Non-monetary benefits of information may well exist, especially in the case of optimizing an accurately specified utility function. Information value derived from non-monetary benefits is not included in this study.

3. This discussion is mostly excerpted from Einhorn and Hogarth (1987). It is condensed here for the convenience of the reader.

CHAPTER III

METHODS

This chapter develops the analytical methods used to address the objectives listed in Chapter I. More specifically, the framework of analysis is developed in light of the previous chapter. This is followed by a discussion of the necessary models and data, including an overview of dynamic optimization techniques.

Analytical Framework

Within the context of Hilton's determinants of information value, the structure of the decision set and the technology, environment and motivation characterizing the decision maker are critical elements of analysis. As mentioned earlier, similar studies had a narrow analytical scope. It is desirous to broaden the decision set as much as practicable to detect as many uses for climate information as possible.

To that extent the decision maker here is said to be the manager of a multi-crop midwestern grain farm comprised of more than one field and more than one soil type. The decision maker is modeled to be maximizing profit from expected climate rather than maximizing the utility of expected profit. This assumption avoids the influence of mis-specifying the utility function or risk attitude of the decision maker. As noted by Perrin, it also results in the numerical evaluation of equations 2.3 and 2.4 being an upper limit on information value.

The value of climate information may well be dependent upon geographic location. Investigation of this issue requires duplicating the analysis for more than one location. While not necessarily identical, the locations should provide similar decision settings to avoid encountering influences other than climate and location in evaluating differences in the value of climate forecasts. The selection of two locations for this study is discussed in Chapter IV.

The literature cited earlier as employing similar methods for similar purposes does not appear to address the issue of constraints. Although Mjelde attempted to add some realism to his model, the others did not completely specify the environment surrounding the decision maker. It is well known that the number of days available for field work, the amount and size of field equipment available for use, the size of the farm and the selection of field operations to be performed influence the timeliness of farming operations in the spring (Schwart; Siemens and Hamburg). Mjelde modeled the operator as performing two operations in the spring, constrained by the climate outcome. As such, if spring climate was good for corn growth it was assumed to be bad for field work.

One of the goals of this study is to more fully develop the environment and technology upon which the field work constraint is based. That field availability is related to climate is well established (ASAE). However, it is thought that climate affects growing and field conditions differently. For example, rainfall in a two week period may be sufficient to enhance crop growth, especially in soils with high water retention capacity. However, the number of days available for field work is likely more dependent upon whether this rainfall occurs in one, two, three or more separate events during the period. The accurate specification of the stochastic constraint not only adds realism but should result in more accurate evaluations of constrained optima (White, 1974; Sengupta).

Models

The information valuation equations of Chapter II dictate the use of an optimization method capable of handling both the structure of the decision set and the functional form of the return function. Calculation of the last term of the right hand side of equation 2.3 requires the identification of returns from decisions made with prior information. Evaluation of this equation and 2.4 also requires specification of the profit function, $\pi(x,\theta)$. Thus, an econometric model, an optimization model, and a management simulation model are necessary elements of this study.

The general form of the profit function has the technology specification or production function embedded within it. Specification and estimation of the production function in view of the decisions to be evaluated is a critical element of the analysis. In most of the literature cited earlier the data used to estimate production functions came from county average yields. For example, Michaels used 43 years of yield data over the entire Great Plains to fit a production function for winter wheat based on rainfall and temperature. However, as noted by Freund (p. 258):

> "The main disadvantage of the use of ... averages is that it definitely underestimates the variance since basic data are already averages. This is especially serious in the case of yields ... ."

Perrin developed a series of field experiments to capture actual data from different decisions and locations in one year. Again, a broad structure is desired for the decision set in this study. Accurate estimation of the production functions would require data for each year actual climate is evaluated and for each possible combination of management decisions. As noted by Mjelde, thousands of simultaneous experiments in multiple locations would be required to collect this data. Furthermore, these experiments would have to be replicated over a period of years to determine the influence of climate within the production functions.

This study uses crop growth simulation models to avoid the analytical constraints imposed by collecting actual production data. In so doing, crop response during the growing season and eventual yield can be determined for any number of management combinations and for many years of weather data. Impacts of unusual events such as hail, windstorm, disease and pest infestation are also avoided.

The use of crop simulation models in economic analysis is not new. Mjelde used a corn growth simulation model developed by Reetz for purposes similar to this study. Chen and McClendon used a soybean growth simulation model to identify the optimal planting date of soybeans in Mississippi. Swamy et al also used a soybean growth simulation model to investigate irrigation decisions. Bosch and Eidman used growth simulation models of both corn and soybeans to estimate response functions. A more complete discussion of the growth simulation models used in this study is found in Chapter IV. Also in Chapter IV is the development of the production function specification and its estimation from the output of the growth simulation models.

As in both Mjelde and Michaels, climate in each period of plant development is thought to additively affect the development of the crop. Modeling crop production as continuous over time would not accurately incorporate the notion of climate as being general conditions over an extended period. Furthermore, the structure of the crop production decision set is such that different decisions are available at different time intervals. For these reasons, control theory does not accurately address the optimization problem faced by the decision maker.

Multi-period linear programming models are also inadequate for this study. Such models would simultaneously find optimal decisions for all periods and not allow for updated information as in equations 2.6 and 2.7

A dynamic programming (DP) algorithm is selected because of its flexibility in incorporating both updated information and discrete time intervals. DP also facilitates the discres decision set incorporated into this study.

Following Bellman and Kalaba (as well as Bellman and Dreyfus, Larson and Casti, and White, 1978), the DP algorithm requires the development of a number of components. First, an objective function in the form of equations 2.1 and 2.2 is necessary. The DP method of discrete approximation also requires the identification of state variables to describe the environmental conditions affecting decisions. These environmental conditions, or states of nature, change through time by means of state variable transitions, which are equations describing the changing environment. For example, crop production decisions are based on the condition of the crop at a point in time coinciding with the decision. The condition of the crop is described by state variables. Transition equations for the crop state variables would describe the development of the crop through time. Thus, elements of the crop production functions are used as state transition equations in the DP models. These issues are more fully explored in Chapter IV.

One of the fundamental drawbacks in the use of DP noted by Burt is

Bellman's "curse of dimensionality." The DP algorithm searches over possible paths to determine the optimal policy (decision set) at a point in time. The full dimension of the algorithm is the number of different paths which are evaluated. With discrete approximation each state variable is allowed to take on a specified number of values, where each value represents an interval on a continuum. Furthermore, each decision variable is allowed to take on a specified number of values. The number of different paths available is thus determined by the number of state and decision variables, the number of different values each is allowed to assume, and the number of different time periods (stages) in which the states and decisions are evaluated. Combinatorics dictates that the number of different paths to be evaluated is a multiplicative function of these modeling selections.

Dimensionality thus affects the number of state variables, states, decision variables and decision alternatives which are computationally feasible in the analysis. The effects of dimensionality on the structure of the DP models used in this study are described in the following chapter.

As mentioned earlier, the evaluation of equations 2.3 and 2.4 requires the simulation of returns from prior decisions. Management simulation models are developed for this purpose. . These models incorporate the prices and production functions of the DP models and evaluate net returns with alternate decisions and climate. Because these models allow equations 2.3 and 2.4 to be evaluated in continuous form rather than through discrete approximation, the optimal decisions from the solutions to the DP models are also input into the management simulation models to more accurately assess the value of climate information.

The following chapter develops the complete specification of the constraints, the decision sets, the growth simulation models and the production functions. It also describes the incorporation of these components into the DP and management simulation models.

CHAPTER IV

MODEL PARAMETERIZATION

Introduction

Data required for the dynamic programming models employed in this study arise from the aggregation, blending and integration of numerous components. As described in the previous chapter, the principal components of the DP models themselves are 1) an objective function and the resulting recursive equation, 2) the state variable transition equations, and 3) the choice variables or management decisions. Prior to initiating specification of the three principal model components, many important factors contributing to model development must be addressed to provide a foundation for model construction and a framework for its use. These factors include such elements as basic assumptions about the decision maker's situation, attitude and motivation; the economic conditions affecting the decisions being made; and the types and sources of economic and physical data to be used in specifying the models.

Within the first section of this chapter, the assumptions supporting the DP models are described and the model farms are specified. This is followed by the development of the stages, state variables and management decisions framing the DP models. The latter sections of this chapter describe the generation of the physical data used to estimate the crop production functions, the specification and econometric estimation of the crop production functions, and the conversion of the crop production functions into transition equations for the DP models. The final section describes the integration of the components into the DP models.

Specification of Model Farm

Location and Endowments

The farm firm used in the model must be representative of modern commercial agriculture as practiced by midwestern farmers. That the farm described in the following pages is "representative" can be demonstrated in some respects. However, as will be noted, certain assumptions must be made to avoid conducting extensive surveys of asset holdings and management practices. One of the goals in specifying the farm is to simplify its incorporation into the DP model to enhance its usefulness. Deviations from actual averages or percentages are not of concern if they do hot distort the representativeness of the farm. Because this study addresses differences in climate forecasts between locations, two farms must be specified, one for each location. The two locations selected (Story County, Iowa and Champaign County, Illinois) are thought to be similar in agricultural practices and structure. Therefore, only soil type and climate will differ between the two farm specifications. Input and output prices used in the models are not part of the farm specification and are discussed later in this chapter.

The farm size is set at 640 tillable acres, divided into four 160-acre fields or tracts. The subdivision into four fields is to simplify the DP model while approximating characteristics of actual farm decisions. The size assumption is consistent with commercial farm operations and allows for additional land in pasture, set aside programs, service buildings and so forth. Each farm has a plantable base corn acreage for current government programs of 320 acres, or one-half of the planted acres. This size and corn base allocation compares favorably with the findings of Lattz et al, whose results are summarized in Table 4.1. The average ratio of corn acres to soybean acres on Illinois cash grain farms was 1.08 and 1.03 for 1985 and 1986 respectively, exclusive of set aside acres. Similar data are reported by the Iowa Department of Agriculture for Story County, where the proportion of acres harvested as corn for grain to total acres of crops harvested was 0.51 in 1986. The ratio of harvested corn acres to harvested soybean acres was roughly 1.13 in 1986, again exclusive of set aside acres.

Table 4.1. Average Corn and Soybean Acres on Illinois Cash Grain Farms.

	1986	1985
Number of farms	543	512
Avg. corn acres	285	307
Avg. soybean acres	278	283
Avg. corn acres plus avg. soybean acres	563	590
Ratio of avg. corn acres/ avg. soybean acres	1.03	1.08

Source: Lattz et al, p. 8.

Soil type specification is important insofar as the water retention characteristics of the soil are key driving forces in the corn and soybean physiological growth simulation models. The farms are each allocated two representative, local soil types in proportion to the percentage of cropland in each county having water retention characteristics of the respective soils.

For Story County, the Clarion-Webster-Nicollet soil association covers 62 percent of the county (USDA, 1984). This soil association can generally retain 11.01 inches of water in the top 60 inches of soil. Many other soil associations have similar water retention characteristics, but none covers as broad an area. Collectively, however, they represent sufficient acreage to predominate the county. The Zenor-Storden soil association is representative of soils having a water retention capacity in the range between 5.5 and 8 inches. It has a specific capacity of 6.89 inches. Soil types in this range cover only four to five percent of the county. Soils in the Harlan-Spillville association have a water retention capacity of 9.825 inches and are representative of soils in the water capacity range of eight to ten and one-half inches. Soils in this association occur in only three to five percent of the county, but are similar to soils comprising a much larger proportion of Story County crop land.

Because the farm is divided into four 160-acre tracts, it is assumed that three of the tracts are in the Webster soils and the remaining tract is comprised of Spillville soils. This simplifying assumption imposes 25 percent of the farm be in soil types of the lower water retention capacity.

The predominant soil association in Champaign County is Drummer-Flanagan, which covers 36 percent of the county (USDA, 1982) . It is representative of a number of soil associations in the county with high to very high water retention capacity, having a capacity of 12.08 inches of water in the top 60 inches of soil. The lesser soil types are primarily of moderate to high water capacity. The Elliot-Ashkum and Varna-Elliot-Ashkum associations are representative of and primarily comprise the soils in this category. Each of these associations occurs in six percent of the county. The former has a water retention capacity of 10.44 inches while that of the latter is 10.84 inches.

The Champaign County farm is designated as having one-fourth of its tillable acres (one field) in Ashkum soils. The remaining three 160-acre fields are assigned to be Drummer soils.

Assigning the higher capacity soil types to entire 160-acre fields is not inconsistent with the typical occurrence of these soil types in either county as reported by the USDA. The lower capacity soil types generally occur in areas smaller than 80 acres but in conjunction with other lower-capacity soil types. The simplifying assumption of one 160-acre tract being comprised of the lower-capacity soil types should not materially distort the representativeness of either farm and makes the dynamic programming algorithm computationally feasible.

The allocation of machinery resources to each farm enables more accurate specification of field time constraints. The extensive study of machinery resources and field times by Krenz included 948 corn belt farms. For these farms, the modal tractor horsepower was in the 120-to-139 h.p. range, with a mean of 128.73 h.p. for tractors in this range. These farms averaged 2.5 tractors per farm. The model farms are each allocated two 120 h.p. tractors for field work, slightly below Krenz's mean.

Krenz also found that among the 57 corn belt farms between 600 and 699 tillable acres, the average planter size was 6.95 rows and the average farm had 641 crop acres. Farms in this category had an average combine width of 16.25 feet (or 6.5 30-inch rows). Because of the necessary matching between planter and combine size, it is assumed that both the combine and the planter on the model farms have a capacity of six 30-inch rows. This is not unreasonable in that a twelve row planter may be used in conjunction with a six row combine, making the statistically average planter slightly larger than the corresponding combine as reported.

In addition, Krenz studied the field time use of each piece of equipment. Planters in this category averaged 1.22 acres per hour per row of width. Combines averaged 0.961 acres per hour per row of width. These field times translate to operating speeds of roughly four miles per hour for planting and three miles per hour for combining, which are very reasonable after considering field efficiency.

For the six-row equipment specified in the model farms, these operating times indicate planting can occur at 7.32 acres per hour and combining can occur at 5.766 acres per hour. This converts to roughly twenty-two hours of field operating time to plant an 160-acre field and twenty-eight hours of field operating time to combine the same field. Field time constraints, however, must be developed based on additional factors including field time available per day and field time necessary for seed bed preparation and treatment. These and other aspects of the constraints are developed in the following and later sections.

Constraints Emanating From Endowments

Machinery constraints are a function of climate and operations, given an endowment of machinery and a tillage practice. Incorporating various tillage practices as additional management alternatives based on climate is not computationally feasible. The decision maker is assumed to use a disk-harrow and a field cultivator in the spring prior to planting. Each of these tillage tools is assumed to be 19 feet wide based on the tractor size (120 h.p.). Siemens and Hamburg suggest the productivity of these tools are 9.21 and 10.13 acres per hour, repectively. Therefore, these operations consume 2.76 twelve-hour days or 3.0 eleven-hour days. Added together with the 2 days for planting, each field of corn or soybeans requires 5.0 days to prepare and plant, excluding nitrogen application.

To mathematically specify the constraint for spring field work, climate probabilities and their effect on field work must be identified. For example, the ASAE Standards (1987, p. 94) indicates the probability of a working day in central Illinois on prairie soils during the period April 12 through April 25 is 0.47 at the 50 percent confidence level and 0.19 at the 90 percent confidence level. This is interpreted as follows: during this fourteen day period, 0.47 x 14 - 6.58 working days will occur on average. Also, at least 2.66 working days will occur in 90 percent of the years.

The Illinois and Iowa Agricultural Statistics Services collect data on the number of field work days available in a given time period. From this data the discretized probability distribution of the number of work days available in a given period can be produced. A general summary of the constraints is listed in Table 4.2. Further discussion of the field time constraint specification must await a description of the DP models to prevent confusion.

Stages. Management Decisions and State Variables

The decision maker at each location is assumed to be maximizing the expected value of net returns over variable costs for one crop year. The crop year is divided into thirteen stages which are listed in Table 4.3. These stages are defined time intervals which are relevant to various growth stages of corn and soybeans as identified in Table 4.3. Within each of these growth stages there is a set of decision variables relevant to the

Table 4.2. Summary of DP Model Constraints.

Corn acres		320
Soybean acres		320
Number of work days for preparation and planting of each field	-	5 days per field
Number of work days for spring nitrogen application	-	2 days per field

corn and soybean production process. It is this set of decision variables from which the decision maker selects management choices to fulfill the objective criterion. The choices available at each stage vary as shown in Table 4.4.

The factors influencing the choice among decision alternatives are state variables, which must completely describe the relevant "state" of the corn and soybean growth process at any given stage, and constraints on the decision set. The values which a state variable may take in stage t may be influenced by its value in stage t-1, the decisions made in t-1, and the outcome of climate in t-1. The functions relating the values of state variables in one stage to their values in the next stage are transition equations. Transitions are said to be Markovian if the value of the state variable in period t+1 is dependent upon the value of that state variable in prior period t and not on "the history of the system before its arrival in" period t (Howard, p.4).[2] State transitions are said to be stochastic if the value of the state variable in period t+1 is a function of a random error. Stochastic transitions may or may not follow a Markov process. Table 4.5 identifies each of the state variables and the number of different values

Table 4.3. DP Model and Relevant Growth Stages of Cora and Soybeans.

	Dates				
Stage	Begin	End	Days	Corn	Soybeans
1	10/23	3/31	160	N/A	N/A
2	4/ 1	4/20	20	Germination & Emergence[a]	Germination & Emergence
3	4/21	5/5	15	" "	" "
4	5/6	5/15	10	" "	" "
				Early vegetative growth	Early vegetative growth
5	5/16	5/25	10	" "	" "
6	5/26	6/10	16	" "	" "
7	6/11	6/30	20	Rapid vegetative growth	Vegetative growth
8	7/1	7/15	15	" "	Flowering
9	7/16	7/31	16	Flowering	Flowering & early grain fill
10	8/ 1	8/31	31	Grain fill	Grain fill & maturation
11	9/ 1	9/15	15	Grain fill & Maturation	Senescence
12	9/16	9/30	15	Drydown	Senescence
13	10/ 1	10/22	22	Drydown	N/A

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[a] Planting in later stages will delay germination, emergence and vegetative growth. Planting is available in stages 2 through 6.

Table 4.4. Management Decisions at each Staee of DP Model.

Stage	Starting & Ending Date	Corn	Soybeans	
	10/23 3/31	Nitrogen Application[a]	N/A	
		Amount of N to apply 0, 50, 150, 200, 250 lbs. N per acre		
		Acres on which to apply N 160, 320		
		Soil type Apply N to lesser quality soil		
2	4/ 1 4/20	Nitrogen Application and Plant[b]	Plant[b]	
		Acres to plant 160, 320	Acres to plant 160, 320	
		Hybrid selection	Hybrid selection	
			Champaign	Story
		Full season	Group III	Group II
		Medium season	Group IV	Group III
		Plant density 24,000 plants/acre 32,000 plants/acre	Plant density 100,000 plants/acre 150,000 plants/acre	
		Soil type plant corn on lesser quality soil	Soil type plant soybeans on lesser quality soil	
3	4/21 5/ 5	Same as Stage 2	Same as Stage 2	
4	5/6 5/15	Same as Stage 2	Same as Stage 2	

---

[a] Amount of nitrogen to apply, number of acres to cover, and on which soil types to apply the nitrogen are all components of the Nitrogen Application decision.

[b] Acres to plant, hybrid selection, plant density, and soil type are components of the Plant decision.

Table 4.4. Management Decisions at each Stage of DP Model (continued).

Stage	Starting & Ending Date	Corn	Soybeans
5	5/16 5/25	Same as Stage 2	Same as Stage 2
6	5/26 6/10	Same as Stage 2	Same as Stage 2
7	6/11 6/30	Nitrogen Application	Do Nothing
8	7/ 1 7/15	Do Nothing	Do Nothing
9	7/16 7/31	Do Nothing	Do Nothing
10	8/ 1 8/31	Do Nothing	Do Nothing
11	9/ 1 9/15	Do Nothing	Harvest
12	9/16 9/30	Harvest	Harvest
13	10/ 1 10/22	Harvest	Do Nothing

Table 4.5. DP Model State Variables.

State variable name		Symbol	Number of Different Values at each stage.				
			1	2	3-6	7-8	9-13
corn plant,							
	field 1	CP1	1	1	5	10	10
	field 2	CP2	1	1	7	10	10
soybean plant,							
	field 1	SP1	1	1	5	10	10
	field 2	SP2	1	1	5	10	10
nitrogen,	field 1	N1	17		7	7	1
	field 2	N2	17		7	7	1

each may take at each period. The stages from which the transitions are Markovian and/or stochastic are identified later in this chapter. Each of Tables 4.2 through 4.5 are discussed in the following sections.

Recursive Equation

The general problem, in a deterministic setting, is to maximize returns over variable costs:

$$\max_{X_t} \pi = \sum_{t=1}^{T} B_t \pi_t(X_t, S_t) \qquad 4.1$$

where π_t is net returns over variable costs in period t,

X_t is the set of decision variables in period t,

S_t is the set of state variables in period t,

B_t is a discount factor in period t which effectively charges interest on accumulated costs and earns interest on accumulated net returns above zero, and

t is a subscript denoting the stage, $t \in \{1,...,13\}$.

Following Bellman and Kalaba, the solution to equation 4.1 is an optimal sequence of decisions in periods 1 through 13 which may be found by solving a recursive equation for each period. The general form of the recursive equation for the deterministic model is:

$$\max_{X_t} V_t = B_t \pi_t(X_t, S_t) + V_{t+1} \qquad 4.2$$

where π_t, X_t, S_t and B_t are as before and V_t is the future value of net returns over variable costs for all decisions from period t through T (the current period through the ending period). That V_t embodies all future decisions and returns is evident in the term V_{t+1}.

Due to the stochastic nature of some transitions, equation 4.2 does not encompass the production risk which is of interest here. To do so, 4.2 is rewritten as:

$$\max_{X_t} V_t = B_t \pi_t(X_t, S_t) + E[V_{t+1}] \qquad 4.3$$

where E is the expectation operator. To make equation 4.3 operational, a method of taking expectations must be used. Due to the cumulative nature of crop growth throughout the production cycle, it is easy to see that the expected value of future returns is dependent upon both the current value of state variables (i) and current decisions (k). Effects of future decisions are included in the V_{t+1} term. Thus, equation 4.3 is rewritten as:

$$\max_{X_t} V_t = B_t \pi_t(X_t, S_t) + \sum_{j=1}^{J} p_{ij}^{k} V_{t+1} \qquad 4.4$$

where V_t, π_t, X_t, S_t and B_t are as before and

$i \in \{1,..,I)$,

$j \in \{1,..,J\}$,

$k \in \{1,..,K)$,

$$0\leq p_{ij}^{k} \leq 1, \text{ and}$$

$$\sum_{j-1}^{J} p_{ij}^{k} - 1.$$

The term p_{ij}^{k} is the probability of going from the i^{th} state in period t to the j^{th} state in period t+1 given the decision k in period t (Howard). Because one of the states $j \in \{1,..,J\}$ will occur in period t+1, the sum of probabilities over resulting states (j) for each decision (k) and each beginning state (i) is equal to one. Equation 4.4 thus becomes the general form of the recursive equation. Remaining to be specified are the state transition equations ($S_t - S_t(X_{t-1}, S_{t-1})$), the transition probabilities (p_{ij}^{k}) the single period net return function ($\pi_t(X_t, S_t)$) , and the constraints to be added to equation 4.4.

Net Return Function

The net return function for the entire year is specified as $\pi - \pi(X,S)$. Because π represents returns over variable cost in the crop production process, this can be generalized as

$$\pi = py - rx \qquad 4.5$$

where p is output price, y is output conditioned on inputs, x is a vector of inputs, and r is a vector of input prices. In order to consider climate and its impact on production as the only source of risk in net returns, output and input prices are assumed to be known with certainty at the beginning of the production year.

The consideration of two crops (corn and soybeans) in the model dictates the following dimensions to the problem specified in equation 4.5:

p is a 1x2 vector of corn and soybean output prices, y is a 2x1 vector of corn and soybean output quantities,

r is a 1x6 vector of input prices corresponding to inputs, and

x is a 6x1 vector of inputs (nitrogen, corn seed, soybean seed, bushels dried, other corn inputs, other soybean inputs).

In developing the net return function, production functions for corn and soybeans must be specified. The sequential decisions and climate outcomes to be modeled require developing production functions that are separable in the time dimension. Following Burt and Stauber, as well as Mjelde, a general class of such functions is given as:

$$\psi(Y) = h[\sum_{t=1}^{T} \phi_t(X_t, S_t)] \qquad 4.6$$

where X_t and S_t are as before, h and ϕ_t are arbitrary functions, Y is crop yield, and ψ is a monotonic transformation on yield. To avoid counting revenue from crop growth during periods prior to harvest, a crop condition state variable accumulates the right hand side terms for periods prior to harvest. Because there are two crops, each having its own production process, equation 4.6 is more accurately specified as:

$$\psi(Y) = \begin{bmatrix} \psi_c(Y_c) \\ \\ \psi_s(Y_s) \end{bmatrix} = \begin{bmatrix} h_c[\sum_{t=1}^{T} \phi_{c,t}(X_t, S_t)] \\ \\ h_s[\sum_{t=1}^{T} \phi_{s,t}(X_t, S_t)] \end{bmatrix} \qquad 4.7$$

which indicates separate production functions for corn (subscript c) and soybeans (subscript s) in response to inputs and conditions.

Synthetic Data Generation

As discussed in Chapter III, the specification of the transition equations for the DP models requires estimating the parameters of production functions. The data for the production function estimates are generated from physiologic plant growth simulation models using actual climate data from each location and all combinations of the management options listed in Table 4.4. Development of the corn data is separate from that of soybeans in the following discussion.

Corn Growth Simulation Model

The corn growth simulation model selected for use in this study is that developed by Reetz. It was modified by Hollinger and used by Mjelde. The climate data requirements of the model include daily observations on the following: 1) maximum, minimum and mean temperature, 2) precipitation, 3) evaporation, and 4) solar radiation. These data were obtained from the Illinois State Water Survey, with cooperation from the National Weather Service in obtaining data for Ames.

The corn growth model grows a square meter of corn on a daily basis, deriving daily cumulative plant conditions from physiologic equations describing the status of the crop and the changes it is undergoing as the growing season proceeds. The model output is grams of plant dry matter per square meter accumulated during the growing season. The dry matter is compartmentalized into roots, stalk, leaves, ear and grain. The model also outputs the growing degree days necessary for plant maturity, where growing degree days accumulate daily at the rate of the number of degrees Fahrenheit that the mean daily temperature exceeds 50°F. The corn grain yield of the model is derived from converting grain dry matter at maturity in grams per square meter to 56 lb. bushels per acre at 84.5 percent dry matter. As discussed later, data on the cumulative plant dry matter of the square meter is also saved at each stage during the growing season listed in Table 4.3.

The corn growth model allows for the input of different management decisions. As listed in Table 4.4, the management options selected for study are planting date, seed variety by maturity, planting density and soil type. The corn growth model assumes the nitrogen fertilizer is available at the rate of 150 pounds per acre. Therefore, nitrogen application decisions adjust the model's simulated yields, as discussed below. Management decisions may be exercised at the end of a stage. The five corn planting dates are identical to those used by Mjelde. April 20 is the first planting date available. Alternate planting dates are May 5, May 15, May 25 and June 10. The model was run with both full and medium season corn hybrids and with plant populations of 32,000 (high density) and 24,000 (medium density) plants per acre. The corn growth model was not run with low densities or short season varieties because these options never entered the optimal solution in Mjelde's DP analysis.

To generate the yield data set, the model was run at all combinations of management decisions over both soil types using actual weather data for 1971 through 1985. With the number of model runs being the product of the five planting dates, two hybrids, two soil types, and fifteen years, there are 600 observations generated for each location at one nitrogen level.

Nitrogen - Climate Interaction

The corn simulation model predicts yield based on an assumed nitrogen fertilization rate of 150 pounds per acre. To adjust the yield output of the simulation model for alternative nitrogen fertilization rates, the model developed by Hollinger and Hoeft (1986) and updated by Hollinger (1988) is employed. This adjustment calculates the fraction of maximum yield attainable at different nitrogen levels. This fraction, E_N, is given by the following equation:

$$E_N = \alpha[(N+1)^{\beta}] \tag{4.8}$$

where $a = 1.98 - 5.2666(P/E) + 4.231(P/E)^2$,

$\beta = -0.422 + 1.987(P/E) - 1.621(P/E)^2$, and

P/E is the ratio of total precipitation to total pan evaporation during the period June 11 through July 15, and the subscript N refers to the level of nitrogen fertilizer in the soil. The effect of the interaction between climate and nitrogen thus includes the nitrogen level available in the soil and the amount of precipitation and evaporation during the vegetative growth and silking phases of plant development. Thus,

$$Y_N = Y_{Max} \bullet a(N+1)^{\beta} \tag{4.9}$$

where Y_N is the yield associated with the nitrogen fertilization rate being simulated and Y_{Max} is the maximum yield given the climate conditions that exist for the simulation. However, Y_{Max} is unknown from the corn simulation
Max
model. Therefore, it must be calculated from Y_{150}, which is the output of the simulation model. To do so, equation 4.9 is inverted and Y_N is replaced with Y_{150} as follows:

$$Y_{Max} = Y_{150}/[\alpha(151)^{\beta}] \tag{4.10.}$$

Substituting 4.10 into 4.9 and canceling α's gives:

$$Y_N = Y_{150} \bullet [(N+1)/151]^{\beta} \tag{4.11.}$$

One final adjustment must be made to equation 4.11 before it is operational.

The simulation model uses the units of pounds of nitrogen per acre in assessing the fertilization rate. The coefficients for a and β in equation 4.8 were derived using kilograms per hectare. Thus the denominator within the brackets in equation 4.11 must be converted from 150 pounds of nitrogen per acre (plus one) to kilograms of N per hectare. This is accomplished using conversion factors of 2.205 lbs./Kg. and 2.471 acres/h. The operational form of equation 4.11 becomes:

$$Y_N = Y_{150} \bullet [(N+1)/169.095]^{\beta} \qquad 4.12.$$

Equation 4.12 is used to adjust the yields produced by the corn simulation model for each of 40 management combinations based on the precipitation and evaporation in each year and six different levels of nitrogen fertilization. Nitrogen levels used in the expanded data set are 0, 50, 150, 200, 225, and 267 pounds per acre. Table 4.6 contains the rainfall and evaporation data used in the adjustment.

Table 4.6 Precipitation and Evaporation Data (mm). June 11 to July 15.

	Champaign County		Story County	
Year	Precip.	Evap.	Precip.	Evap.
1971	244	346	151	269
1972	105	284	111	231
1973	150	294	82	279
1974	137	312	92	306
1975	188	314	175	232
1976	163	316	146	327
1977	112	282	57	376
1978	153	308	222	244
1979	75	317	153	228
1980	57	290	91	284
1981	174	273	120	301
1982	171	279	157	217
1983	199	320	281	247
1984	87	273	187	249
1985	197	233	75	301

Soybean Growth Simulation Model

The soybean growth simulation model selected for use in this study is SOYGRO, version 5.41 (Wilkerson *et al*). It was selected over SOYMOD (Meyer *et al*) due to its relative ease of use and adaptability to different soils and plant varieties (Hollinger, 1988). The output of the soybean growth model is very similar to that of the corn model. The soybean plant dry matter accumulation on one square meter of soil is compartmentalized into roots, stems, leaves, pods and seeds. The model seed weight at maturity in grams per square meter is converted to 60 lb. bushels per acre using the same conversion factors as for the corn model.

The soybean growth simulation model also incorporates various management alternatives selected by the user. The management decisions run on this model were planting date, planting density and variety selection. To view the whole farm as under one set of management alternatives, the soybean planting dates are identical to those for corn. Thus, the planting stages for the two models exactly match, as indicated in Table 4.4. Although April 20 may be too early to plant soybeans in either Champaign or Story County, the remaining four planting dates are reasonable. The choice between 100,000 and 150,000 plants per acre reflects a choice between medium and high planting densities. The choice between Group III and Group IV varieties in Champaign County, and between Group II and Group III varieties in Story County indicates a choice between a variety well suited for average climate in each area and a variety that is slightly longer to maturity (Scott and Aldrich). There is also a choice of soil type on which to plant the soybeans. Thus, there are 40 combinations of management alternatives to be simulated over 15 years at each location.

Production Function Specification and Estimation

General Form

The form of the production functions to be used in this study was partially addressed in equation 4.7. However, a more precise specification must be developed, recalling that each equation must be separable with respect to time. The functional form chosen is a logarithmic transformation, such that:

$$\ln Y = \sum_{t=1}^{T} [\beta_t \ln X_t + \gamma_t \ln S_t] \qquad 4.13$$

where ln represents the natural logarithm,

Y, t, X_t and S_t are as before, and

β_t and 7_t are parameters to be estimated.

Management decisions may affect yield in either of two ways. First, a decision may affect only yield potential, with other factors determining the yield outcome. This would be represented graphically as an intercept shift in the production function. With binary choices between soils, varieties and densities, this type of yield potential change is entered into the econometric specification of the production function as a dummy variable. Secondly, there may be interaction between the management decision and another production factor. This would result in a slope shift in the production function, specified econometrically as the product of the decision variable and the other factor. Identifying which management variables interact with climate in later periods will aid in the DP model specification by minimizing the number of state variables that must be carried along through the growing season.

Climate Indices

The inclusion of the appropriate climate data as production function inputs is of central importance in specifying the econometric and DP models. The use of proxies for weather or climate inputs in crop production functions is not new (see, for example, Doll). As described in Chapter II, the climate index of Mjelde and Hollinger is employed to give a general indication of climate in a growing stage without requiring the identification of the particular weather phenomena (e.g. rainfall, evaporation, temperature) that may be causing favorable or unfavorable growing conditions.

The data for the climate index in stages three through ten (see Table 4.3) are generated by arithmetically averaging the percent change in crop dry matter during each stage in each year over all management combination runs of the growth simulation model. The climate index for stage t in year y is given by:

$$CI_{t,y} = \frac{1}{MC} \sum_{i=1}^{MC} \left[\frac{DM_{i,t,y} - DM_{i,t-1,y}}{.5(DM_{i,t,y} + DM_{i,t-1,y})} \right] \qquad 4.14$$

where MC is the number of management combinations and $DM_{i,t,y}$ is the total dry matter weight of the crop accumulated by the growth simulation model at the end of stage t under management combination i in year y. Specific data for the climate indices in each stage and year, for both corn and soybeans in Champaign and Story Counties, are listed in Tables 4.7 through 4.10. These tables include the mean, standard deviation (S.D.) and coefficient of variation (C.V.) for the climate index in each period. It is noteworthy

Table 4.7 Climate Index of Champaign County Corn By Year

	Period						
year	3	4	5	6	7	8	9	10
1971	0.45945	0.58668	0.93761	1.62476	1.70433	0.56851	0.18153	0.36477
1972	0.41966	0.6114	1.27453	1.67099	1.47366	0.74647	0.37407	0.33454
1973	0.67089	0.52541	0.85719	1.59503	1.66397	0.71923	0.26083	0.35057
1974	0.61483	0.32836	0.95272	1.47839	1.57783	1.00912	0.40818	0.31577
1975	0.69909	0.79497	1.33428	1.52917	1.52392	0.55171	0.31113	0.36686
1976	0.6362	0.6067	0.77971	1.56805	1.70452	0.74687	0.2852	0.37467
1977	0.88478	0.87796	1.45252	1.61119	1.39313	0.63237	0.28654	0.26738
1978	0.25041	0.29475	0.84677	1.74804	1.68446	0.56002	0.27303	0.35472
1979	0.45018	0.85148	0.8925	1.66785	1.65941	0.69313	0.267	0.29054
1980	0.80246	0.76215	0.82828	1.69687	1.55439	0.75864	0.30034	0.34327
1981	0.67756	0.24127	0.79788	1.70041	1.662	0.70021	0.26283	0.33214
1982	0.71927	1.20962	1.14854	1.51095	1.45998	0.79368	0.37294	0.33181
1983	0.51411	0.64313	0.58565	1.27702	1.80086	0.74881	0.32035	0.3375
1984	0.51553	0.47498	0.9436	1.51277	1.76131	0.66243	0.26605	0.33919
1985	1.23437	1.11916	0.95034	1.63427	1.42483	0.77094	0.35525	0.24803
mean	0.63658	0.66186	0.97214	1.58838	1.6032	0.71080	0.30168	0.33011
S.D.	0.22397	0.27173	0.22510	0.11302	0.12220	0.11047	0.05560	0.03496
C.V.	0.35184	0.41056	0.23155	0.07115	0.07622	0.15541	0.18431	0.10592

Table 4.8 Climate Index of Champaign County Soybeans By Year

	Period						
year	4	5	6	7	8	9	10
1971	0.78971	0.88104	1.60639	1.58692	0.92073	0.4667	0.58041
1972	0.80492	1.51298	1.52856	1.41184	0.92523	0.52173	0.58861
1973	0.38579	1.37929	1.52533	1.54244	0.8034	0.45412	0.62335
1974	0	1.60508	1.48101	1.59317	1.04718	0.61964	0.71599
1975	0.84803	1.51498	1.44159	1.507	0.89291	0.51047	0.58753
1976	0.82832	0.84497	1.59723	1.5514	0.89328	0.52624	0.65308
1977	1.32685	1.45928	1.37139	1.34952	0.76622	0.47718	0.53829
1978	0.69832	1.39431	1.64796	1.50618	0.7187	0.47519	0.68952
1979	0.84864	0.89312	1.59967	1.5518	0.76507	0.53546	0.62119
1980	1.04745	1.22669	1.50037	1.45757	0.81767	0.48594	0.62015
1981	0.75994	0.79024	1.69125	1.55853	0.85109	0.4512	0.66198
1982	1.70422	1.23899	1.36972	1.43753	0.87093	0.56116	0.60379
1983	0.8085	0.85294	1.5096	1.6457	0.87939	0.53889	0.63881
1984	0.79502	1.34562	1.48287	1.6174	0.81028	0.48095	0.65079
1985	1.26703	0.61897	1.54661	1.42806	0.87168	0.57921	0.59013
mean	0.860849	1.170566	1.526636	1.516337	0.855584	0.512272	0.624241
S.D.	0.378436	0.311633	0.089380	0.081313	0.077815	0.047188	0.044262
C.V.	0.439607	0.266224	0.058547	0.053624	0.090949	0.092116	0.070905

Table 4.9 Story County Corn Climate Index By Year.

	Period						
Year	4	5	6	7	8	9	10
1971	0.60606	0.83410	1.57065	1.78392	0.69510	0.23886	0.31983
1972	0.34286	1.23720	1.69792	1.61120	0.85381	0.37810	0.31291
1973	0.63636	1.01383	1.56058	1.71746	0.78508	0.28154	0.36757
1974	0.29167	0.77777	1.50843	1.70106	0.97348	0.37977	0.33408
1975	0.78462	1.34531	1.43751	1.66504	0.77100	0.34910	0.32929
1976	0.76190	0.73441	1.62520	1.71184	0.89372	0.38204	0.39846
1977	1.08084	1.38463	1.65654	1.41682	0.60365	0.21705	0.22751
1978	0.58333	0.95937	1.68969	1.73926	0.73272	0.30489	0.31808
1979	0.90000	0.91940	1.61853	1.71676	0.83655	0.35873	0.32726
1980	0.74591	0.81482	1.67784	1.57802	0.76867	0.33188	0.36175
1981	0.40724	0.86440	1.69518	1.67653	0.79036	0.28546	0.28446
1982	0.84034	0.88839	1.26386	1.69522	1.08606	0.54970	0.31122
1983	0.66667	0.53613	1.42183	1.81142	0.92570	0.35826	0.35328
1984	0.39286	1.11233	1.47367	1.77616	0.78182	0.30770	0.38760
1985	1.04520	1.03412	1.58476	1.53465	0.93169	0.33564	0.27360
Mean	0.67239	0.96375	1.56548	1.67569	0.82863	0.33725	0.32713
S.D.	0.23487	0.22414	0.12033	0.10025	0.11614	0.07462	0.04283
C.V.	0.34931	0.23258	0.07686	0.05983	0.14016	0.22127	0.13093

Table 4.10 Story County Soybean Climate Index By Year.

	Period						
Year	4	5	6	7	8	9	10
1971	0.75994	0.76645	1.56552	1.64342	0.87596	0.54364	0.10014
1972	0.00000	1.65157	1.53645	1.47597	0.86217	0.56769	0.48660
1973	0.79030	0.87990	1.53349	1.60272	0.90683	0.48779	0.45783
1974	0.21171	0.77429	1.54855	1.56946	0.96694	0.61998	0.47362
1975	0.81484	1.51026	1.31633	1.50198	0.93492	0.58982	0.44282
1976	0.72348	0.74188	1.60034	1.60493	0.93882	0.56742	0.39757
1977	0.50063	1.53701	1.34245	0.99739	0.42138	0.14808	0.57662
1978	0.00000	1.11616	1.66240	1.57149	0.88272	0.52311	0.44311
1979	0.76908	0.84899	1.55247	1.57554	0.90171	0.59246	0.44711
1980	0.37799	0.81617	1.64100	1.49756	0.89329	0.54057	0.40812
1981	0.23829	0.74870	1.62475	1.54500	0.93539	0.38816	0.49424
1982	0.81620	0.83564	1.44591	1.52104	1.01089	0.69464	0.50008
1983	0.76304	0.72650	1.49005	1.64187	1.03416	0.57638	0.45245
1984	0.69832	1.35039	1.39352	1.62563	0.91880	0.56435	0.42787
1985	1.17777	0.63986	1.51735	1.38249	0.84230	0.46339	0.25964
Mean	0.57611	0.99625	1.51804	1.51710	0.88842	0.52450	0.42452
S.D.	0.32871	0.33138	0.10069	0.15466	0.13464	0.12136	0.10846
C.V.	0.57058	0.33262	0.06633	0.10194	0.15155	0.23138	0.25550

that the coefficient of variation of the climate index for stage 7 is low in both the Champaign and Story County corn data, while the coefficient of variation for period 8 is roughly twice that of period 7. Periods 7 and 8 together comprise the time period for which the nitrogen/rainfall/evaporation interaction was employed to adjust the yields of the corn simulation model for various nitrogen levels. Mjelde's corn DP model did not divide this period into separate stages. It is divided into separate stages in this study due to the onset of flowering in soybeans in the midst of the period (see Table 4.3). Also of note in Tables 4.7 through 4.10 is the manner in which the mean climate indices for all crops tend to rise and fall together throughout the growing season. In Tables 4.8 and 4.10 it is evident that soybeans planted in periods 2 and 3 did not progress in period 4 in some years. In fact, the growth simulation model terminated within a few days after the period 2 planting in Champaign (i.e. the plants died) in 1974. Recall that planting occurs at the end of a period.

With the required data at hand, attention is now focused on the estimation of production function parameters.

Production Function Specification

There are four production functions to estimate, both corn and soybeans in each of two locations. Each corn production function has five classes of independent variables. These are non-nitrogen management inputs, climate inputs, nitrogen inputs (quantity; not timing), nitrogen-climate interactions and management-climate interactions. The soybean production functions have three classes of independent variables, as nitrogen inputs and nitrogen-climate interactions are not included.

With these groups of variables, together with equation 4.13 and the management decisions available from Table 4.4, the corn production function can be generally specified as:

$$\begin{aligned}\ln Y_c = & \sum_{i=1}^{4} \alpha_i D_i + \sum_{t=3}^{10} \beta_t \ln CI_t + \gamma_1 \ln N + \gamma_2 (\ln N)^2 \\ & + \sum_{i=1}^{4} \sum_{t=3}^{10} \phi_{i,t} D_i \ln CI_t + \sum_{t=7}^{8} [\delta_t \ln N \ln CI_t + \zeta_t (\ln N \ln CI_t)^2] \qquad 4.15\end{aligned}$$

where Y_c is the yield of corn in bushels per acre,

D_i (i-1,4) are the dummy variables representing the choices between planting dates, soil types, densities and seed varieties,

N is the amount of applied nitrogen in pounds per acre,

CI_t is the climate index in stages three through ten, and

α_i, β_t, γ_1, γ_2, $\text{Ø}_{i,t}$, δ_t, ζ_t are parameters to be estimated.

The structure of the soybean production function is identical to that for corn (4.15) with parameters involving nitrogen (γ,δ and ζ) set at zero.

As discussed in Chapters II and III, for the climate information to have value there must be a decision change based on the information. Therefore, parameters Ø_t, δ_t, and ζ_t are of particular interest. Mjelde found that both δ_t and ζ_t were important elements of the corn production function and DP decision rule. This is not surprising given that the corn data were generated using nitrogen-climate interactions from Hollinger and Hoeft (1986), as is done in this study.

Parameter Estimation

The four production functions were estimated using ordinary least squares in SAS. Because of the power functions involved in the nitrogen adjustment of the corn data, infeasible observations were generated at the extremes of the nitrogen input range (0 and 267), such as growing 400 bushels of corn per acre with no nitrogen input. Therefore, any data in which either a) yield exceeded 220 bushels per acre, or b) yield exceeded 140 bushels per acre and nitrogen input was zero were excluded from the corn regression models. Parameter estimates of the selected regression models are in Table 4.11. The symbols used in the regression models are as follows:

Density = a dummy variable equal to zero at the higher planting density and equal to one at the lower planting density as listed in Table 4.4;

Soil = a dummy variable set equal to zero for fields with the higher water retention capacity and equal to one for the field with the soil of lower water retention capacity;

Variety = a dummy variable equal to zero for the longer season corn hybrid and for the more well-suited soybean variety (Group II in Story County; Group III in Champaign County); equal to one otherwise;

Pdate = a dummy variable equal to zero if the crop is planted in stages 2,3 or 4, and equal to one if planted in stages 5 or 6;

CIi i-{3,10} = the natural logarithm of the climate indices in stages three through ten, respectively, for each year, crop and location as in Tables 4.7 through 4.10;

PCIi i={3,6} = the product of a dummy variable and the log of the climate index, wherein the dummy variable is equal to one if the crop was planted prior to stage i; zero otherwise. Thus the crop can only be affected by additive climate effects if it is already planted;

Table 4.11. Parameter Estimates of Crop Production Functions.

	Champaign County		Story County	
Variable	Corn	Soybeans	Corn	Soybeans
Intercept	4.55916 (65.096)[a]	1.10240 (4.247)	4.79646 (24.455)	3.16164 (14.275)
Density	-0.00512 (-0.805)	-0.00643 (-1.244)	-0.01740 (-1.474)	-0.00762 (-0.432)
Soil	-0.01697 (-2.667)	-0.03015 (-5.834)		0.06596 (3.743)
Variety	-0.08490 (-13.340)	-0.12762 (-18.018)	0.05506 (4.632)	0.16877 (9.578)
PDate	-0.05969 (-6.753)		-0.07380 (-4.558)	-0.04194 (-2.332)
PCI3	0.04393 (3.028)			
PCI4	0.08714 (7.944)		0.01486 (0.805)	
PCI5	0.14020 (5.691)	0.03675 (2.472)	0.20572 (4.435)	
PCI6	0.33891 (16.431)	0.04570 (2.225)	0.47002 (12.850)	
CI7	-0.67528 (-5.407)	10.2964 (8.357)	-0.62917 (-1.650)	5.69650 (7.631)
CI8	0.00830 (0.532)	2.58827 (8.164)	0.40858 (2.784)	-0.44333 (-1.693)
CI9	-0.38744 (-17.019)	-1.35969 (-1.826)	-0.19011 (-4.545)	0.27059 (3.262)
CI10	0.46352 (18.921)	-2.26520 (-1.929)	0.59437 (8.677)	0.71265 (27.723)
$CI7^2$		-13.0226 (-8.854)		-6.19653 (-7.404)

---

[a] Numbers in parentheses are t statistics for the hypothesis that the parameter is equal to zero.

Table 4.11. Parameter Estimates of Crop Production Functions (cont.).

	Champaign County		Story County	
Variable	Corn	Soybeans	Corn	Soybeans
$CI8^2$		2.80376 (4.347)[a]		-0.10267 (-1.80,0)
$CI9^2$		-1.32863 (-2.319)		
$CI10^2$		-2.33424 (-1.909)		
N	0.22683 (5.694)		0.14204 (3.814)	
N^2	-0.01141 (-2.976)		-0.01489 (-4.842)	
NCI7	-0.05929 (-0.711)		0.15871 (2.265)	
NCI8			-0.06319 (-2.312)	
NCI7sq	0.00499 (0.313)			
MSE	0.03693	0.00370	0.04533	0.04658
Adj. R^2	0.7048	0.5667	0.6109	0.7787

---

[a] Numbers in parentheses are t statistics for the hypothesis that the parameter is equal to zero.

CIi^2 = the square of Che log of the climate index in stage i;
i={7,10}
N, N^2 = the log of applied nitrogen in pounds per acre and its square; and
NCIi(sq)= the product of the log of applied nitrogen and the log of the
i = 7,8 climate index in periods 7 and 8, and the square of this product in period 7.

Numerous models were tested for combinations of variables. A discussion of the results of these alternative model runs is incorporated below. Rather than employ strictly quantitative regression model selection techniques (e.g. Akike, R^2),the models reported in Table 4.11 were selected based on adjusted R^2, mean squared error, and reasonableness of parameter estimates.

Examining Table 4.11, it is interesting that the signs of the dummy variable parameters are mostly as expected and the magnitude of their effects is small relative to the intercepts. A set of four dummy variables to describe five planting dates was also run, but found to be insignificant and less descriptive than the Pdate dummy variable and additive PCI_i (i=3,6) effects.[4,5] Of particular note are the few dummy variable effects which are not as expected. First is the absence of the Pdate dummy variable in the Champaign soybean function. The addition of this variable into the equation reduced the adjusted R^2 and was insignificant. Next is the absence of the soil dummy variable in the Story corn function. This variable was also insignificant and, as discussed in Chapter 5, was later dropped as a decision alternative.

The density dummy variable in all equations remains in the estimated functions despite its insignificance for two reasons. First, the parameter estimates are very small, describing the density decision effect as minor in both corn and soybeans. The expected density effect in soybeans is rather small but extant (111. CES.p.10), while the expected density effect in corn is slightly larger (Ibid, p.4). This relationship is borne out in the parameter estimates for Story County, although a larger t statistic is expected for the Story corn density parameter. The density effect in the Champaign corn function is smaller than expected. Both corn density estimates may suffer from a deficiency in the corn growth simulation model to accurately describe density effects.

Variety effects are as expected for both Champaign County crop functions. The shorter season corn hybrid provides a small but statistically significant yield increase in the Story corn function. In contrast, the Group III soybean variety has a larger yield potential than Group II soybeans in the Story County soybean function. This is contradictory to conventional wisdom in soybean variety selection, although "there are no clearly cut areas where a variety is or is not adapted." (Scott and Aldrich, p. 13) The sign of the soil effect in the Story County soybean function is opposite to that expected. The extremely close water retention capacity between the two Story County soils included in the simulation model should result in a smaller difference between the soils (parameter estimate) as well. Examining the combination of dummy variable parameter estimates as a group leads to confidence in all but the Story County soybean function.

Focusing on other parameters, combinations of climate indices, their squares and interactions with nitrogen were examined. Because all climate indices are less than 2.0 and many are less than 1.0, their logs are always less than 1.0 and often negative, leaving parameter interpretation a confusing chore. Within each stage of each model, the climate index and its square (if applicable) were tested for the proper slope, loosely defined as a larger climate index yielding a higher product of parameter estimate(s) and climate data than a smaller climate index. Although this product is sometimes negative, the models are accepted because of the proper relative climate effect. A negative adjustment in a period may be interpreted as failure to experience good climate detracting more from previously developed yield potential. Finally, the parameters on applied nitrogen and its square are as expected, depicting a decreasing marginal yield with respect to nitrogen.

Models were run attempting to discover significant management-climate interactions but none were found. Initially disturbing was the lack of soil type-climate interaction. However, the two locations selected for this study have within them soil types very similar in water retention capacity. As such, only a very small yield potential (intercept) shift was not rejected. Secondly, density-climate interactions were rejected, perhaps again due to the unknown ability of the growth simulation models to completely account for such things as canopy cover-evaporation interactions or root zone competition for soil moisture between neighboring plants. Variety-climate interactions were also rejected.

The resulting adjusted R^2 of each model (Table 4.11) are lower than those reported by Mjelde (0.84) but higher than that reported by Babcock (0.37). Mjelde's corn production function had more inherent variability for the model to explain due to its three densities and three hybrids. Babcock's production function suffers from under-specification, having only nitrogen, May rainfall, their squares and interaction completely describe variation in cotton yields. The models in Table 4.11 have adjusted R^2's ranging between 0.56 and 0.78, which are not unreasonable with respect to cross-sectional data parameter estimates. It is interesting that the addition or deletion of other variables in the model did not often materially change the adjusted R^2 measure. However, such adjustments often affected the reasonableness of other parameter estimates.

The selected models still have some collinearity between exogenous variables, particularly between climate indices and their squares in the soybean functions and between N, N , and nitrogen-climate interactions in the corn functions. However, due to the economic principle of diminishing marginal productivity and the generation of the data via Hollinger and Hoeft's nitrogen-climate interaction scheme, it was subjectively determined that any remaining collinearity should be retained.

Transition Equation Specification

The purpose of estimating time-separable production functions is to incorporate their temporal increments into the transition equations of the respective dynamic programming models. However, there are additional transition equations which must also be specified. Focus is now turned to the development of all of the transition equations. Recall from Chapter III that only state variables require transition equations and that dimensionality problems in obtaining DP solutions emanate from the number of state variables and the number of different values each state variable is allowed to take. Therefore, this section also incorporates a description of state variable reduction through combinations and assumptions.

Nitrogen Transitions

From Tables 4.4 and 4.11, there are nitrogen decisions that affect the corn crop which can be characterized in terms of both amount and timing. The production function parameters in Table 4.11 incorporate the effect of nitrogen available during the growing season, particularly in stages 7 and 8. However, Hollinger and Hoeft (1985) and others have shown that the amount of applied nitrogen may be different than the amount of effective nitrogen available to the corn plant. For purposes of this model, these nitrogen differences are only attributable to the timing of application. Hollinger and Hoeft's (1985) nitrogen leaching model describes the effect of winter precipitation on the amount of fall-applied nitrogen which carries over to spring as effective nitrogen. This transition is given by:

$$SN_2 = N_1 - 0.891*[NK_1 + 1 - (NK_1 + 1)^{\beta}] \qquad 4.16$$

$$\beta = 1.013 - 0.00253*(CI_1 - 380)*D \qquad 4.17$$

where,

SN_2 is the amount of effective nitrogen available at the beginning of stage 2,

N_1 is the amount of fall-applied nitrogen in pounds per acre,

NK_1 is the amount of fall applied nitrogen in kilograms per hectare,

CI_1 is the precipitation during stage 1 in millimeters, and

D is a dummy variable equal to one if CI_1 is greater than 380, zero otherwise.

Data for winter (stage 1) precipitation in both Champaign and Story Counties is contained in Table 4.12. In Champaign County, winter precipitation was below 380 mm for five of the fifteen years, while in Story County winter

Table 4.12 Winter Precipitation. Champaign and Story Counties By Year (mm).

Year	Champaign County	Story County	Year	Champaign County	Story County
1971	284	300	1979	426	227
1972	344	248	1980	318	205
1973	497	405	1981	224	82
1974	520	261	1982	424	279
1975	450	285	1983	436	406
1976	417	279	1984	477	374
1977	311	130	1985	522	276
1978	409	209			
mean				403.9	264.4
S.D.				86.42	90.12
C.V.				0.214	0.341

Table 4.13 Effect of Winter Precipitation on Fall Nitrogen Carry Over.

Winter Precip.	Fall Nitrogen	Effective Nitrogen	Winter Precip.	Fall Nitrogen	Effective Nitrogen
254.0	50	53	415.1	50	37
	100	106		100	70
	150	160		150	101
	200	215		200	132
	250	269		250	163
284.3	50	53	487.0	50	17
	100	106		100	29
	150	160		150	40
	200	215		200	49
	250	269		250	58

precipitation was below 380 mm during thirteen of the fifteen years.

Examples of effective nitrogen available in stage 2 at different fall nitrogen application rates and different winter precipitation levels are contained in Table 4.13. The example precipitation levels used in this table are derived in the following chapter and very useful in the DP model. It is easily seen from Table 4.13 that transition equations 4.16 and 4.17

are deterministic and Markovian. That is, some winter precipitation level will occur (CI_1) and the resulting available nitrogen is also a function of beginning nitrogen (zero) and the fall fertilizer decision, to the exclusion of an error term.

After stage 2, nitrogen transitions are simply additive, in that

$$SN_{t+1} = SN_t + N_t \tag{4.18}$$

where SN_t is the value of the nitrogen state variable at the beginning of stage t and N_t is the amount of nitrogen applied at stage t.

Corn Plant Transition Equations

The corn plant transition equations serve to determine net revenue over variable cost associated with a set of management decisions and climate outcomes. Although climate is instrumental in determining corn yield (Table 4.11), it is not necessary to carry the cumulative climate effects forward in the DP model as a state in and of itself.

The same is true of the non-nitrogen management decisions affecting the corn crop. Planting date, density, soil type and hybrid selection are modeled to impact corn yield and, therefore, net returns. But after decisions are made and implemented it is only the state of the corn plant that is of interest, not how it got there. The growth path of the corn plant after planting is independent of the decisions that placed it in a given state according to the parameter estimates in Table 4.11. This would not be the case had management-climate interactions been detected, whereby more than one state variable would be required to accommodate the divergence in growth paths occurring in the stage(s) containing the interaction.

This not being the case, it is the exponent of the corn production function that is the corn plant state variable (CP):

$$Y = \exp\{CP\} \tag{4.19}$$

Note that a nitrogen state variable is also carried along until stage 8, when the last nitrogen-climate interaction occurs. After stage 8 the nitrogen state variable is combined into the corn plant state variable to reduce the dimensionality of the DP algorithm. It is only in the final stage that equation 4.19 is calculated to determine yield and the resulting net returns.

The management combinations available in Table 4.4 provide the decision maker a selection of the corn production function intercept in Table 4.11 due to the binary choice of dummy variables representing non-nitrogen management decisions. This may be interpreted as selecting yield potential. Referring to the variable symbols in Table 4.11, the sequential order of transition equations is given below. Note that the variable symbol represents the product of the exogenous variable and its parameter. The stage listed is the stage to which the state variable is transitioning. Not indicated below is the existence of separate state variables and transition equations for each of the two corn fields in one location.

Stage 2

$$CP_2 = 0 \tag{4.20}$$

SN_2 = (as in equations 4.16 and 4.17)

Stage 7

$$CP7 = \text{intercept} + \text{density} + \text{soil} + \text{variety} + \text{Pdate} + PCI3 + PCI4 + PCI5 + PCI_6 \tag{4.21}$$

$$SN7 = SN_2 + N_2 + N_3 + N_4 + N_5 + N_6 \tag{4.22}$$

(Note: only one of N_2 through N_6 can be non-zero)

Stage 8

$$CP_8 = CP_7 + CI_7 + \underset{(N)}{SN_8} + \underset{(N^2)}{SN_8^2} + \underset{(NCI7)}{SN_8 * CI_7} + \underset{(NCI7sq)}{(SN_8 * CI_7)^2} \tag{4.23}$$

$$SN_8 = SN_7 + N_7 \tag{4.24}$$

Stage 9

$$CP_9 = CP_8 + CI_8 + \underset{(NCI8)}{SN_8 * CI_8} \tag{4.25}$$

Stage 10

$$CP_{10} = CP_9 + CI_9 \tag{4.26}$$

Stage 12

$$CP_{12} = CP_{10} + CI_{10} \tag{4.27}$$

$$Y_c = \exp\{CP_{12}\} \tag{4.28}$$

A few explanatory remarks are in order. First, note that transitions from stages 2 to 3, 3 to 4, 4 to 5, 5 to 6, and 6 to 7 have been combined into one transition system, stages 2 to 7. This is supported by the variables in the production function and the structure of the decision set. That is, a decision is made in period 2 whether or not to plant, and if so with what combination of density, variety and soil options. If the decision is to plant in stage 2, the transition to stage 7 is from a corn plant state of zero at the beginning of stage 2, with additive intercept and non-nitrogen management effects, and with additive climate effects occurring in stages 3 through 6 (PCI3 through PCI_6). If, on the other hand, a decision is to delay planting in period 2, the decision must be re-addressed in period 3. If planting occurs in stage 3, the value of the crop state variable in stage 7 will be less than that from stage 2 planting by the amount PCI3 in equation 4.21. However, if planting is postponed until stage 5, CP7 will be further reduced by both PCI4 and PCI5 being zero, as well as the parameter estimate for the dummy variable Pdate.

Secondly, equation 4.22 allows for nitrogen application in only one of the planting stages. As discussed later, this is a pre-plant anhydrous ammonia application, the date of which application affects the amount of interest accrual charged to operating expenditures in the net return function.

Equations 4.23 and 4.25 include variable combinations whose parameter symbols are below them in parentheses. These variable combinations are used here to more precisely indicate the structure of the transitions and the timing of the decision effects. For example, in 4.23 the amount of nitrogen which affects the corn plant in period 7 is the amount that will also affect it in period 8. Thus, SN_8 is used to represent N from Table 4.11, where SN_8 is the sum of winter carryover of fall-applied nitrogen, spring pre-plant nitrogen and summer sidedress nitrogen (N7).

Lacking from the system of transition equations is any mention of transition probabilities as in equation 4.4. Although climate is stochastic, it is modeled here in such a manner as to be deterministic in the transition equations. As will be evident in Chapter V, the expectation on climate, with or without information, is a single valued number. Although there is a probability distribution on climate outcomes, the model is run over actual climate sequences in which the climate outcome, and therefore the transition, happen with certainty.

Finally, stages 11 and 13 are not included in the transition system. Stage 11, early September, is irrelevant to corn yield in the production function. Therefore, whatever value of CP_{11} occurs, CP_{12} will be equal to it. The yield obtained from solving 4.28 in stage 12 is assumed to be the yield available for harvest in stage 13 as well. Although it is well known that fall climate and corn maturity date impact yield with regard to field losses and harvest dates, as noted by Mjelde, the literature surrounding these issues is unclear as to the parameterization of the impacts. Mjelde also found the value of fall climate information with respect to planting and harvesting decisions to be very small. The harvest decision was affected by whether or not the corn would dry to storable moisture levels in the field and, if so, what the value of the additional field losses would be relative to the cost of artificial drying. He commented skeptically on the reliability of the equations used from the agronomy literature (pp. 92, 123). Becuase of the relative lack of usefulness of incorporating these weakly defined relationships, the corn DP model in this study is silent as to these issues.

Soybean Transition Equations

The soybean transition equations are much the same as the corn transition equations with the exception of the nitrogen state variable. Again, there are separate state variables and transition equations for each of the two soybean fields.

Stage 7

$$SP7 = \text{intercept} + \text{density} + \text{soil} + \text{variety} + \text{Pdate} + PCI_5 + PCI_6 \qquad 4.29$$

Stage 8

$$SP_8 = SP_7 + CI_7 + CI_7^2 \qquad 4.30$$

Stage 9

$$SP9 = SP_8 + CI_8 + CI_8^2 \qquad 4.31$$

Stage 10

$$SP_{10} = SP_9 + CI_9 + CI_9^2 \tag{4.32}$$

Stage 11

$$SP_{11} = SP_{10} + CI_{10} + CI_{10}^2 \tag{4.33}$$

$$Y_s = \exp(SP_{11}) \tag{4.34}$$

The same rationale is used to combine state variables to get the exponent of the production function as was applied in the corn transitions. Note again that the symbols above are the product of the data and the parameters listed for the respective soybean models in Table 4.11. The yield is calculated at stage 11 (early September) to identify the returns. Fall climate, harvest losses and yields are ignored in the soybean DP model as in the corn model. Information on climate/dry down/shatter loss interactions was insufficient to rely on any mathematical relationship. Perhaps the predicament faced by agricultural engineers in describing this relationship is best explained by Lamp et al, who stated that soybean moisture levels may vary by as much as 20 percentage points between pods on the same stalk. There is no prediction for which if any seed pods will dry more quickly and which may be shatter prone. Thus, the soybeans are assumed to be harvested when they are ready, with no maturity date estimate or plant state being a decision tool in the model.

Each DP model thus far consists of an objective function, a decision set, and state transition equations. A set of prices over which to operate the models and the development of the field time constraint to be imposed remain to be addressed.

Prices

The relationship between input and output prices is instrumental in determining the profit-maximizing level of input use. Accurate spectfication of this relationship is of concern in order to not impose temporary economic phenomena on the model results. Therefore, an average of recent input and output prices is used rather than the latest year's data. Whenever possible this is a three year average. Exceptions are noted in the discussion which follows.

A major input in the production functions specified in this chapter is climate which is a free good and thus has a "price" of zero. Land rental and farm operating overhead items are excluded from the net return function (eq. 4.5) as these expenditures are independent of variable input use. However, field operations are charged a per-acre custom rate which covers the cost of equipment, fuel and labor required to perform each operation (Hinton). Also, potassium and phosphate fertilizers are added at fixed rates per acre of each crop according to base levels recommemded by the University of Illinois Coperative Extension Service.

Table 4.14 lists the prices used in the DP models. Part A includes items whose amounts and, therefore, the total expenditure on which may vary in the DP models. Corn seed price is an average of two years' data due to a change in USDA's reporting methods after 1984. Nitrogen prices are averaged for six years as reported by USDA because annual data are not reported for the seasonal prices desired in the models. Nitrogen application costs and grain drying and hauling costs are priced as custom operations described above. Story and Champaign counties are both in the same USDA price reporting region. Therefore, no locational input price differences are

Table 4.14. Prices Used in DP Model.

A. Items Affected by Decisions	Price	Unit	Source
Corn Seed	$ 66.45	80,000 seeds	USDA, 2 yr avg.
Soybean seed	12.03	bushel	USDA, 3 yr avg.
Fall Nitrogen (80% N)	170.00	ton	USDA, '81-'86
Spring Nitrogen (80% N)	224.00	ton	avg., N. Cent.
Sidedress Nitrogen (32% N)	146.00	ton	Fert. Dist.
Apply Fall or Spring Nitrogen	5.00	acre	Hinton
Apply Sidedress Nitrogen	3.25	acre	Hinton
Haul Grain (corn or soybeans)	0.09	bu.	Hinton
Dry Corn	0.0225	bu. point	Hinton
Interest Rate on Operating Loan	12.90 %		Melichar, 3 yr avg.
Corn Price (Champaign)	2.06	bu.	USDA, '84-'86
Soybean Price "	5.43	bu.	Illinois avg.
Corn Price (Story)	1.96	bu.	USDA, '84-'86
Soybean Price "	5.06	bu.	Iowa avg.

B. Other Inputs ($/acre)	Corn	Soybeans	Source
P_2O_5	$ 6.98	$ 3.91	USDA.CES
K_2O	6.32	-0-	USDA.CES
Field Cultivate	5.25	5.25	Hinton
Disk Harrow	7.50	7.50	Hinton
Apply Mixed Fertilizer	2.00	2.00	Hinton
Plant and Apply Chemicals	10.50	10.50	Hinton
Herbicides and Pesticides	19.00	18.50	Lattz, 2 yr avg.
Row Cultivate	6.25	6.25	Hinton
Combine	29.00	24.00	Hinton

contained in the DP models. Output prices are reported by state. Price differences due to relative transportation costs and regional use patterns are expected and detected in the USDA data.

The inputs in Part B of Table 4.14 are charged on a per acre basis to all acres of the respective crop. These costs are dependent upon the assumptions of seedbed preparation practices described at the beginning of this chapter. Although these assumptions influence the value of the net return function, there are no management decisions in the DP model associated with their implementation. Therefore, relative values of the net return function arising from different management decisions or climate outcomes are not affected by these seedbed preparation assumptions.

Field Time Constraint

One of the questions to be addressed by this study is the impact of a more highly specified field time constraint on the value of climate forecasts. Such constraints may prevent certain combinations of management decisions from being implemented, particularly with respect to planting date. The assumptions on seedbed preparation practices and equipment endowments described earlier play a critical role in developing the field time contraints.

The constraint consists of two parts: the amount of field time required to perform spring operations and the amount of time available. Each of these is addressed seperately below. Within the DP models the constraint is made operational by comparing these two parts. If the amount of time required exceeds the amount of time available, then that set of management decisions is infeasible and dropped from further evaluation. Time comparisons are made on a cummulative basis as described below.

Required Field Time

The calculation of required field time for spring operations is based on the equipment endowments and tillage assumptions decribed earlier as well as the simplifying assumption of having two 160-acre fields of each crop. Required field time is calculated on a per field basis. The same operations are performed on corn and soybean fields with the exception of nitrogen application. Each field requires field cultivation, disking, fertilizer and chemical application and planting in the spring. Row cultivation and harvesting are assumed to be completed on a timely basis. It was determined in the beginning of this chapter that 5.0 days are required for seedbed preparation and planting. Dry fertilizer application is assumed to be hired through the local fertilizer retailer at the rate of $2.00 per acre (Table 4.14), and is thus not material to the constraint. Chemical application is assumed to be incorporated into seedbed preparation and planting activities, requiring no additional field time. Pre-plant spring anhydrous ammonia application is assumed to be performed by the operator. Siemens and Hamburg use a productivity rate of 7.40 acres per hour for a nine-knife applicator with a 120 h.p. tractor. Therefore, an additional 2.0 days (rounded for simplicity) is required for spring nitrogen application if this management option is exercised.

Available Field Time

As discussed earlier, different sources report the probability of a day being available for field operations based on weather and soil conditions.

The ASAE Standards cite no specific reference other than observations for their tables on the probability of a working day. Schwart cites unpublished data from the Illinois Cooperative Crop Reporting Service. Although the probability of a working day for any planting stage in the DP models is interesting, it is insufficient to run the DP models because the actual climate is used for each year in the study. Therefore, to coordinate the constraint emanating from the actual climate in each year, the actual field days available in each planting stage (stages 2 through 6) in each year are required for each location.

These data are published for regions within Illinois in a weekly release of the Illinois Agricultural Statistics Service. The Iowa Agricultural Statistics Service also compiles such data which was not available in published form, but was acquired through personal communication (Block). Table 4.15 lists the number of field days available by planting stage in each year and for each location. Note that in each period the mean number of field days available in Champaign County is less than that for Story County while the coefficient of variation is always higher. The operator is assumed to take advantage of an available field day to perform some operation on some field. In this manner, the cummulative days available by stage becomes the operational constraint. That is, planting the last field cannot occur until the twentieth field day is available; planting is not restricted to having five field days available in the same stage. In addition, the DP model offers a one-half day grace period before identifying a binding constraint. This provides slack for the model operator to work a bit longer on one or two days, or to not stop immediately at the onset of adverse weather, so as to complete an operation.

Table 4.15 Days Available For Field Work

	Period									
	2		3		4		5		6	
Year	Champ.	Ames	Champ.	Ames	Champ.	Ames	Champ.	Ames	Champ.	Ames
1971	15.75	12.6	12.25	8.3	5.25	9.0	7.50	5.8	9.00	10.6
1972	0.00	10.5	4.00	8.1	6.25	5.2	9.25	8.0	10.00	8.0
1973	1.50	0.9	3.50	6.9	6.75	4.0	7.50	9.2	4.50	6.9
1974	6.75	11.9	7.50	10.2	3.50	3.0	1.75	2.3	4.25	6.7
1975	9.00	0.7	4.75	6.0	8.25	7.5	8.25	8.4	4.50	7.5
1976	16.25	14.0	9.25	6.6	7.50	7.4	7.25	6.1	8.00	10.1
1977	13.25	12.2	9.00	11.9	5.75	9.1	9.25	8.4	11.75	11.9
1978	0.75	6.6	6.75	8.9	1.75	6.0	3.50	8.1	11.25	11.3
1979	1.50	2.4	2.25	4.3	6.75	8.1	9.25	8.6	11.75	12.0
1980	2.75	10.2	11.25	15.0	7.50	9.5	4.25	7.3	4.50	6.7
1981	8.25	12.3	3.50	12.2	1.75	8.9	3.25	8.7	8.75	11.6
1982	1.75	2.9	11.00	10.4	9.50	3.9	5.50	0.4	3.50	5.2
1983	0.75	1.2	5.25	8.7	5.00	4.7	3.50	4.4	7.75	9.3
1984	1.00	4.1	4.75	4.3	8.25	7.1	3.50	6.4	7.00	7.4
1985	5.75	12.7	12.00	11.6	7.25	6.9	8.25	8.4	10.75	12.5
Mean	5.67	7.69	7.13	8.89	6.07	6.69	6.17	6.71	7.82	9.19
S.D.	5.68	4.92	3.43	2.94	2.29	2.04	2.61	2.48	2.97	2.32
C.V.	1.00	0.64	0.48	0.33	0.38	0.31	0.42	0.37	0.38	0.25

Summary

This chapter developed the components of the DP models and identifies their parameters. Assumptions underlying the farms and their operators are specified. The production functions for corn and soybeans are identified and estimated. The form of the recursive equation and the state variable transitions are developed as well as the structure of the decision set faced by the manager. The economic scenario is established in the form of input and output prices and the field time constraint is developed.

In the following chapters these components are brought together to run the DP models over actual climate and with various forecasts to address the information value of the forecasts. Some of the economic relationships and assumptions on prior information are also altered to discover any changes in information value derived therefrom.

Notes

1. Womack and Traub report the percentage of cropland idled in set aside programs in 1986 was 0.7 percent in Illinois and 1.5 percent in Iowa. These amounts are not sufficient to alter the assumed corn base of one-half of tillable acres.

2. During the development of dynamic programming methods it became popular to number stages backward to accent the backward chaining solution technique and the remaining number of stages over which the current period's recursive equation is optimized. That tradition is not used here in the interest of clarity.

3. Champaign County solar radiation data for years prior to 1982 were derived from an adjustment to data obtained from West Lafayette, Indiana, according to the method described in Hollinger (1989). This data was not collected in Champaign County prior to 1982.

4. All tests for significance are at the ten percent probability level unless otherwise noted.

5. The separation of the planting dates into two distinct groups approximates the aggregation of five to two planting dates imposed by Mjelde. That aggregation is not imposed here, although the Pdate dummy variable supports Mjelde's simplification.

CHAPTER V

RESULTS AND VALIDATION

Introduction

The forecast valuation methods described in earlier chapters are ready to be employed. Through the development of the dynamic programming optimization models in Chapter IV, optimal decision sets can be discerned for any expected climate sequence.

Within this chapter, the prior (base) climate expectations are developed together with a redefinition of actual climate in each year of the study. The DP models are run for each year for both the prior climate expectations and forecasted climate, again for both crops and both locations. The management simulation models described in Chapter III are then run with actual climate to compare the net returns for each pair of runs, one with the base decision set and the other with the optimal decision set.

The effects of specific model components, such as the field time constraint, multiple fields, multiple crops and multiple soil types, are then examined. This is followed by a brief look at the effects of price relationships on the value of perfect forecasts.

Fifteen Year Historical Prior

Recalling equation 2.3, the information valuation equation, the development of prior (without information) climate expectations is required to derive the net returns from following the base decision set. The base decision set optimizes net returns over prior expectations. The setting of the prior climate expectations requires "some assumptions before they may be established. First, the climate occurring during the fifteen years included in this study is assumed to accurately reflect the range and distribution of possible outcomes. Although this assumption may seem bold, it is required to establish the probability distribution on climate. Second, the decision maker is assumed to be fully aware of this distribution and operate on its expected value. This assumption provides the decision maker with a large amount of knowledge and will be relaxed somewhat in the following chapter.

Actual climate outcomes reported in Tables 4.6 through 4.10 and Table 4.15 provide the distributions on which the decision maker may operate. However, the continuous nature of these distributions is not conducive to either forecasting or dynamic programming. Therefore, the climate outcome possibilities are grouped into discrete intervals. The mean of each interval is the value of the climate index, winter precipitation or available field days, as appropriate, which is then used in the analysis.

The National Oceanic and Atmospheric Administration (NOAA) currently uses three categories in its weather forecasts: above normal, normal and below normal (Brown et al). Normal weather is defined as that which occurs forty percent of the time. Above normal and below normal weather each occur with a discrete probability of thirty percent. This probability distribution on three intervals (30-40-30) aggregates much information in the tails of the distribution. Further distinction of climate information in the extreme categories is thought to have value in midwestern crop production. Therefore, a five-interval distribution is employed in which the middle category is defined as the climate with a 40 percent probability of occurring and the four intervals on either side each have a probability of fifteen percent. This five-category (15-15-40-15-15) discrete distribution is used to capture more information about events occurring in each tail. For discussion purposes the intervals are denoted as excellent, good, average, fair and poor.

The actual climate for a stage within a year is then determined by first ranking all fifteen climate outcomes for a given period and assigning them to one of the five categories based on rank, with actual frequencies of 2, 2, 7, 2, and 2 in the respective intervals. Then the climate which occurs in, for example, the two years represented by excellent climate is assigned the value of the average of the two observations which fall into the excellent category. This procedure is followed for climate indices in all relevant stages, winter precipitation and available field days.

The results of this data transformation are contained in Tables 5.1 through 5.12. The categorical values of winter precipitation and each period's climate index are contained in Tables 5.1 through 5.4. Tables 5.5 through 5.8 identify which category is assigned to each period in each of the fifteen years. Tables 5.9 through 5.12 duplicate this effort for available field days. These tables describe the actual climate used in the DP and management simulation models. To illustrate the use of these tables, within Table 5.5 the climate index for period 3 in Champaign County in 1971 is category 4 (fair). Referring to Table 5.1, the value of the period 3 climate index used for the fair category is 0.4548. This value is used in the management simulation model to incorporate actual climate. It is also used in the Champaign County corn DP model if the forecast is perfect. The expected values at the bottom of Tables 5.1 through 5.4, 5.9 and 5.10 are the weighted averages of the five categories using the probabilities as

Table 5.1 Categorical Values of Climate Index. Champaign County Corn

	Period							
Climate	3	4	5	6	7	8	9	10
Excellent	1.0596	1.1644	1.3934	1.7242	1.7811	0.9014	0.3911	0.3708
Good	0.7609	0.8647	1.2115	1.6839	1.7044	0.7648.	0.3641	0.3097
Average	0.6183	0.6472	0.9115	1.6043	1.6180	0.7167	0.2919	0.3384
Fair	0.4548	0.4017	0.8131	1.5119	1.4668	0.6004	0.2644	0.3032
Poor	0.3350	0.2680	0.6827	1.3777	1.4090	0.5559	0.2212	0.2577
Expected	0.6389	0.6637	0.9797	1.5864	1.6014	0.7107	0.3029	0.3291

Table 5.2 Categorical Values of Winter Precipitation and Climate Index, Champaign County Soybeans

		Period					
Climate	Winter	5	6	7	8	9	10
Excellent	254.0	1.5600	1.6696	1.6316	0.9862	0.5994	0.7028
Good	314.5	1.4861	1.6030	1.5900	0.9070	0.5500	0.6575
Average	415.1	1.1942	1.5272	1.5250	0.8563	0.5054	0.6212
Fair	487.0	0.8490	1.4613	1.4328	0.7848	0.4709	0.5881
Poor	521.0	0.7046	1.3706	1.3807	0.7419	0.4527	0.5594
Expected	402.5	1.1669	1.5266	1.5153	0.8555	0.5123	0.6246

Table 5.3 Categorical Values of Climate Index. Story County Corn

	Period						
Climate	4	5	6	7	8	9	10
Excellent	1.06302	1.36497	1.69655	1.79767	1.02977	0.46587	0.39303
Good	0.87017	1.17477	1.68377	1.75771	0.92870	0.37894	0.36466
Average	0.68355	0.93052	1.58924	1.69770	0.81605	0.33517	0.32782
Fair	0.40005	0.79630	1.45559	1.59461	0.75070	0.28350	0.29784
Poor	0.31727	0.63527	1.34285	1.47574	0.64938	0.22796	0.25056
Expected	0.67100	0.96790	1.56251	1.67294	0.83020	0.33751	0.32704

Table 5.4 Categorical Values of Winter Precipitation and Climate Index, Story County Soybeans

		Period					
Climate	Winter	5	6	7	8	9	10
Excellent	106.0	1.59429	1.65170	1.64265	1.02253	0.65731	0.53835
Good	207.0	1.43033	1.61255	1.61528	0.95288	0.59114	0.49042
Average	265.0	0.86251	1.53484	1.55532	0.91052	0.55474	0.44926
Fair	337.0	0.74529	1.41972	1.48677	0.86907	0.47559	0.40285
Poor	405.5	0.68318	1.32939	1.18994	0.63184	0.26812	0.17989
Expected	264.3	1.01297	1.51594	1.51232	0.88566	0.52072	0.42143

Table 5.5 Actual Climate Index Categories. Champaign County Corn

Year	Period 3	4	5	6	7	8	9	10
1971	4[a]	3	3	3	2	4	5	2
1972	5	3	2	2	4	3	1	3
1973	3	3	3	3	3	3	5	3
1974	3	4	3	5	3	1	1	4
1975	3	3	1	3	3	5	3	1
1976	3	3	5	3	2	3	3	1
1977	1	2	1	3	5	4	3	5
1978	5	5	3	1	3	5	3	2
1979	4	2	3	3	3	3	3	4
1980	2	3	4	2	3	2	3	3
1981	3	5	4	1	3	1	4	3
1982	2	1	2	4	4	3	2	3
1983	3	3	5	5	1	3	3	3
1984	3	4	3	4	1	3	4	3
1985	1	1	3	3	5	2	2	5

Table 5.6 Actual Climate Index and Winter Precipitation Categories, Champaign County Soybeans

Year	Period Winter	5	6	7	8	9	10
1971	1	3	2	2	2	4	5
1972	3	3	3	5	1	3	4
1973	4	2	3	3	4	5	3
1974	5	1	4	2	1	1	1
1975	3	1	4	3	3	3	4
1976	3	4	3	3	2	3	2
1977	2	3	5	5	4	3	5
1978	3	2	1	3	5	4	1
1979	3	3	2	3	5	3	3
1980	2	3	3	3	3	3	3
1981	1	5	1	3	3	5	2
1982	3	3	5	4	3	2	3
1983	3	4	3	1	3	2	3
1984	4	3	3	1	3	3	3
1985	5	5	3	4	3	1	3

---

[a] 1 = Excellent, 2 = Good, 3 = Average, 4 = Fair, 5 = Poor.

Table 5.7 Actual Climate Index Categories. Story County Corn

	Period						
Year	4	5	6	7	8	9	10
1971	3[a]	3	3	1	5	5	3
1972	5	2	1	4	3	2	3
1973	3	3	3	3	3	4	2
1974	5	4	3	3	1	2	3
1975	3	1	4	3	3	3	3
1976	3	5	3	3	3	1	1
1977	1	1	3	5	5	5	5
1978	3	3	2	2	4	3	3
1979	2	3	3	3	3	3	3
1980	3	4	2	4	4	3	2
1981	4	3	1	3	3	4	4
1982	2	3	5	3	1	1	4
1983	3	5	5	1	2	3	3
1984	4	2	4	2	3	3	1
1985	1	3	3	5	2	3	5

Table 5.8 Actual Climate Index and Winter Precipitation Categories, Story County Soybeans

	Period						
Year	Winter	5	6	7	8	9	10
1971	4	3	3	1	4	3	5
1972	3	1	3	4	4	3	2
1973	5	3	3	3	3	4	3
1974	3	3	3	3	2	1	3
1975	3	2	5	3	3	2	3
1976	3	4	2	2	2	3	4
1977	1	1	5	5	5	5	1
1978	2	3	1	3	3	3	3
1979	3	3	3	3	3	2	3
1980	2	3	1	4	3	3	4
1981	1	5	2	3	3	5	2
1982	3	3	4	3	1	1	1
1983	5	5	3	1	1	3	3
1984	4	2	4	2	3	3	3
1985	3	5	3	5	5	4	5

[a] 1 = Excellent, 2 = Good, 3 = Average, 4 = Fair, 5 = Poor.

Table 5.9 Categorical Values of Available Field Days. Champaign County

	Period				
Climate	2	3	4	5	6
Excellent	16.00	12.13	8.88	9.25	11.75
Good	11.13	11.13	7.88	8.75	11.00
Average	4.04	6.75	6.50	6.25	7.86
Fair	0.88	3.75	4.25	3.50	4.50
Poor	0.38	2.88	1.75	2.50	3.88
Expected	5.87	7.18	6.01	6.10	7.81

Table 5.10 Categorical Values of Available Field Days. Story County

	Period				
Climate	2	3	4	5	6
Excellent	13.4	13.6	9.3	9.0	12.3
Good	12.4	11.7	8.9	8.5	11.8
Average	8.4	8.8	6.9	7.5	9.2
Fair	1.8	6.3	4.4	5.1	6.8
Poor	0.8	4.3	3.5	1.4	5.9
Expected	7.6	8.9	6.7	6.6	9.2

Table 5.11 Champaign County Actual Available Field Days Categories

	Period				
Year	2	3	4	5	6
1971	1[a]	1	3	3	3
1972	5	3	3	1	3
1973	3	5	3	3	4
1974	3	3	4	5	5
1975	2	4	1	2	4
1976	1	3	2	3	3
1977	2	3	3	1	1
1978	5	3	5	4	2
1979	3	5	3	1	1
1980	3	2	2	3	4
1981	3	5	5	5	3
1982	3	2	1	3	5
1983	5	3	4	4	3
1984	4	3	1	4	3
1985	3	1	3	2	2

Table 5.12 Story County Actual Available Field Days Categories

	Period				
Year	2	3	4	5	6
1971	2	3	2	4	3
1972	3	3	3	3	3
1973	5	3	4	1	4
1974	3	3	5	5	5
1975	5	4	3	2	3
1976	1	4	3	3	3
1977	3	2	1	3	2
1978	3	3	3	3	3
1979	4	5	3	2	1
1980	3	1	1	3	4
1981	2	1	2	1	2
1982	3	3	5	5	5
1983	4	3	4	4	3
1984	3	5	3	3	3
1985	1	2	3	3	1

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[a] 1 = Excellent, 2 = Good, 3 = Average, 4 = Fair, 5 = Poor.

the weights (15-15-40-15-15). These expected values form the fifteen year historical priors used in equation 2.3 and in the DP models.

The base decisions are derived through the optimization of the DP models given the fifteen year historical priors on climate. Tables 5.13 through 5.16 contain the simulated returns for the base management decisions for each climate sequence in the study (1971 through 1985). The net returns are the returns over variable costs from two 160-acre fields of corn as described previously.

Note in Table 5.13 that the base management decision for Champaign County corn is to plant both fields in stage 4, using a full season hybrid and a medium planting density, and to apply 150 pounds of nitrogen per acre in the spring. Seed cost of the medium planting density is $19.94 per acre compared to $26.58 per acre for the higher planting density. The combination of this cost difference and the low yield penalty for the medium versus high density corn planting described by the parameter estimates in Table 4.11 causes the medium density to be optimal. The preferred base planting date of stage 4 is derived from both the parameter estimates and the fact that interest on planting costs is charged from the date of planting in the DP models. Thus, the marginal revenue gained from planting in stages 2 or 3 is insufficient to overcome the additional marginal cost of early planting given the expected climate of the fifteen year prior. This result, although not necessarily its cause, compares directly with Mjelde's optimal planting in early spring. A field time constraint is encountered in four of the years such that the second field is not planted until stage 5.

The fifteen year prior also contains an expectation that winter

Table 5.13 Champaign County Corn. Decisions and Returns. 15 yr. Prior

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	0	0	5/15	2[a]	150	5/15	2	150	0	0	65,673
1972	0	0	5/15	2	150	5/15	2	150	0	0	58,955
1973c	0	0	5/15	2	150	5/25	4	150	0	0	64,223
1974	0	0	5/15	2	150	5/15	2	150	0	0	36,477
1975	0	0	5/15	2	150	5/15	2	150	0	0	67,013
1976	0	0	5/15	2	150	5/15	2	150	0	0	52,004
1977	0	0	5/15	2	150	5/15	2	150	0	0	61,390
1978c	0	0	5/15	2	150	5/25	4	150	0	0	58,053
1979	0	0	5/15	2	150	5/15	2	150	0	0	51,151
1980	0	0	5/15	2	150	5/15	2	150	0	0	56,341
1981c	0	0	5/15	2	150	5/25	4	150	0	0	58,677
1982	0	0	5/15	2	150	5/15	2	150	0	0	58,032
1983c	0	0	5/15	2	150	5/25	4	150	0	0	38,577
1984	0	0	5/15	2	150	5/15	2	150	0	0	49,967
1985	0	0	5/15	2	150	5/15	2	150	0	0	47,018

[a] In Champaign County, Decision 2 is a full season hybrid planted at medium density; decision 4 is the same but planted in stages 5 or 6.

c Field time constraint prevents earlier planting in these years.

Table 5.14 Story County Corn. Decisions and Returns. 15 Yr. Prior

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	150	150	5/15	2[a]	0	5/15	2	0	0	0	46,893
1972	150	150	5/15	2	0	5/15	2	0	0	0	45,163
1973	150	150	5/15	2	0	5/15	2	0	0	0	46,994
1974	150	150	5/15	2	0	5/15	2	0	0	0	38,294
1975	150	150	5/15	2	0	5/15	2	0	0	0	44,555
1976	150	150	5/15	2	0	5/15	2	0	0	0	38,432
1977	150	150	5/15	2	0	5/15	2	0	0	0	36,858
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	150	150	5/15	2	0	5/15	2	0	0	0	44,786
1981	150	150	5/15	2	0	5/15	2	0	0	0	41,733
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	150	150	5/15	2	0	5/15	2	0	0	0	27,969
1984	150	150	5/15	2	0	5/15	2	0	0	0	52,312
1985	150	150	5/15	2	0	5/15	2	0	0	0	27,553

[a] In Story County, Decision 2 is a medium season hybrid planted at medium density; decision 4 is the same but planted in stages 5 or 6.

Table 5.15 Champaign County Soybeans. Decisions and Returns. 15 yr. prior

	Field 1			Field 2			
Year	Plant Date	Density	Variety	Plant Date	Density	Variety	Returns
1971	5/15	med	III	5/15	med	III	38,660
1972c	5/25	med	III	5/25	med	III	52,727
1973c	6/07	med	III	6/07	med	III	38,408
1974c	5/25	med	III	6/07	med	III	52,826
1975	5/15	med	III	5/15	med	III	39,028
1976	5/15	med	III	5/15	med	III	42,211
1977	5/15	med	III	5/15	med	III	37,543
1978c	6/07	med	III	6/07	med	III	35,703
1979c	5/25	med	III	5/25	med	III	38,281
1980	5/15	med	III	5/15	med	III	39,095
1981c	6/07	med	III	6/07	med	III	37,831
1982	5/15	med	III	5/15	med	III	39,329
1983c	6/07	med	III	6/07	med	III	38,466
1984c	5/25	med	III	6/07	med	III	38,344
1985	5/15	med	III	5/15	med	III	39,325

c Field time constraint prevents earlier planting in these years.

Table 5.16 Story County Soybeans. Decisions and Returns. 15 yr. prior

	Field 1			Field 2			
Year	Plant Date	Density	Variety	Plant Date	Density	Variety	Returns
1971	5/15	med	III	5/15	med	III	51,851
1972	5/15	med	III	5/15	med	III	51,779
1973c	5/25	med	III	5/25	med	III	48,390
1974c	5/05	med	III	5/25	med	III	53,990
1975c	5/25	med	III	5/25	med	III	52,357
1976	5/15	med	III	5/15	med	III	51,291
1977	5/15	med	III	5/15	med	III	24,505
1978	5/15	med	III	5/15	med	III	51,583
1979c	6/07	med	III	5/25	med	III	52,420
1980	5/15	med	III	5/15	med	III	51,345
1981	5/15	med	III	5/15	med	III	39,104
1982	5/05	med	III	5/15	med	III	53,894
1983c	5/25	med	III	6/07	med	III	49,574
1984c	6/07	med	III	5/15	med	III	51,461
1985	5/15	med	III	5/15	med	III	24,377

c Field time constraint prevents earlier planting in these years.

precipitation is such that leaching of fall-applied nitrogen is too great for this practice to be cost effective. The field time constraint is not expected to be encountered given the data in Table 5.9 and the requirement of fourteen field days for planting and spring nitrogen application.

In Table 5.14, the base decision for Story County corn is to apply 150 pounds of nitrogen per acre in the fall and to plant a medium season variety at medium density in stage 4. Again, the interest cost is thought to drive the optimal planting date given the fifteen-year prior climate and field days expectations. The expected winter precipitation of 264.4 mm allows beneficial fall nitrogen application despite the extra six months of interest being charged by the DP model. Note that the field time constraint is never encountered during the years 1971 through 1985. Not only is the expectation on Story County available field days higher than that for Champaign County, the application of nitrogen in the fall results in four fewer days being required for spring operations.

As briefly mentioned in Chapter IV, parameter estimates for soil in the production functions were very low (Table 4.11). Moreover, the choice between soils has no direct cost differential associated with it as do the choices between planting densities and dates. The corn and soybean DP models are run independently after which they are brought together from the whole farm perspective through the field time constraint. In Champaign County, both corn and soybean production function parameters on the Ashkum (lower water retention capacity) soil are small and negative. Thus, both crop DP models would choose two of the Drummer fields. Without soil-climate interactions being detected, the choice of soils as affected by climate forecasts becomes moot. As the sole difference between the two soils in the growth simulation models is water retention capacity, one would expect availability of the Drummer fields for spring operations to be earlier than for the Ashkum field. As it is customary to begin field operations for corn prior to those for soybeans, it is assumed in the Champaign County DP models that corn is planted on two fields of Drummer soil and soybeans are planted on one field of Drummer soil and one of Ashkum.

In the Story County crop production functions, the choice of soils for corn is insignificant and eliminated. The soil parameter estimate in the soybean model is positive, indicating a slight yield boost from the Spillville soil over the Webster soil. These two soils are very similar in water retention capacity. As in Champaign County, the soil type decision is removed from consideration in the Story County DP models. The Story County corn crop is assumed to be grown on Webster fields and the soybean crop is grown on one field each of Webster and Spillville soils. Furthermore, the issue of soil type is henceforth ignored.

The management simulation results of base management decisions for Champaign and Story County soybeans are contained in Tables 5.15 and 5.16, respectively. The base decision in both counties is to plant type III seed at a medium density as early as possible. The field time constraint is noticeably binding in many years, as indicated in the tables. The choice of medium density planting reflects the reduced seed costs of 100,000 versus 150,000 plants per acre. The conversion of the base planting date decision from stage 4 to as early as possible was generated through the assumption that midwestern grain producers would not delay soybean planting if field days were available. This is a reasonable assumption because the soybean reproductive process is initiated by changes in day length, not physiologic maturation as in corn (Scott and Aldrich). If the field time constraint is binding in stage 4 and planting is delayed until stage 5, any economic benefit from further delaying planting until stage 6 is only explicable as a reduction of interest expense on planting costs. This supplementary hypothesis is further examined in the following section.

The net returns in Tables 5.13 and 5.15 may be added together to give net returns for the whole farm from basing optimal decisions on the fifteen year prior. The same is true for the returns in Tables 5.14 and 5.16. With the establishment of net returns from prior information, attention may be directed toward the first term in the right hand side of equation 2.4, the returns from incorporating the predictions from a perfect forecast scheme.

Perfect Forecast - Five Climate Categories

Design

In this chapter, the climate forecasting mechanism is assumed to be capable of predicting which of the five climate categories will occur in each period with perfect accuracy. This scheme is referred to herein as the perfect-5 forecast. Alternate forecast schemes are studied in Chapter VI.

Other assumptions underlying the forecasting mechanism and its use include the following:

1. Perfect forecasts for all periods are available at the beginning of stage 1.
2. The forecast identifies which of five possible outcomes will occur for winter precipitation, available field days in stages 2 through 6, and both corn and soybean climate indices in stages 3 through 10.

3. The decision maker will respond to changes in climate expectations consistent with the models.

Furthermore, as described earlier, the decision maker operates within the structure of the decision set, using full knowledge of the production functions.

The numeric values of the forecasted variables are those contained in Tables 5.1 through 5.4, 5.9 and 5.10. Because the forecasts are perfect predictions of the five climate categories, the forecasts for each year simulated are contained in Tables 5.5 through 5.8, 5.11 and 5.12. Each DP model is run for each year with the perfect predictions to obtain the optimal decision set (optimal policy). The optimal decision set is then input into the management simulation model to calculate net returns from following the optimal policy. As discussed in Chapter III, this two-step approach allows the optimal policy to be determined with the DP method of discrete approximation, yet the net returns are calculated from continuous functions.

Optimal Policies

The optimal policies for each crop, in each location and for each year are listed in Tables 5.17 through 5.20, together with the net returns from the management simulation models. Numbers representing decision sets in the corn tables are the same as those in Tables 5.13 and 5.14. Each of these is discussed seperately.

Champaign County Corn

The optimal decision set and net returns from the management simulation run in each year for Champaign County corn are listed in Table 5.17. In comparison with the fifteen year prior decision set of Table 5.12, three differences are distinct and noteworthy.[1] First, the optimal amount of applied nitrogen increases to 200 pounds per acre for both fields in six years and for one field in two years. Most of these years are associated with good or excellent climate in stages 7 or 8. Planting of one field is delayed until stage 5 in 1978 and 1983, the years in which only one field receives 200 pounds of nitrogen.

Secondly, fall nitrogen application comes into the optimal solution in five of the years. Four of these years (all but 1972) are associated with either excellent or good winter precipitation, the values for both of which are less than 380 mm (Table 5.2) indicating beneficial nitrogen carryover (see Table 4.13). The reason for fall application of nitrogen in 1972 is unclear. It is likely a combination of the lower price of fall fertilizer relative to spring, the desire for approximately 150 pounds of nitrogen per acre, and the relatively low leaching rate of nitrogen with 415.1 mm of precipitation. The only year when both fields have 200 pounds of nitrogen applied in the spring is 1984, a year in which winter precipitation is fair (487 mm).

The third difference between Tables 5.12 and 5.17 is the timing of nitrogen application in 1973. Winter precipitation in 1973 is fair and the spring field time constraint prevents planting and applying nitrogen to both fields by the end of stage 4. In other constrained years fertilizer is applied in the spring and planting is delayed. However, in 1973 the climate sequence is such that planting is preferred to fertilizer application, which is delayed until side dressing is performed despite the increased price.

Note from Table 5.5 that 1973 climate is average almost throughout the growing season. The option of delaying nitrogen application until after planting to circumvent the field time constraint is also available in 1978 and 1983. Both of these years have periods in which climate is excellent or poor, indicating periods of accelerated or lagging growth rates. That nitrogen application in these years is not delayed in favor of planting is interpreted as the marginal revenue from earlier planting in these years, in which the comparative growth rate of the corn crop fluctuates, being lower than the marginal cost of a higher price for side dressed nitrogen and additional interest expense from planting earlier.

It is interesting that in five of the fifteen years the perfect forecast of actual climate does not alter the optimal management decisions for Champaign County corn. Referring to Table 5.5, it is noteworthy that these years (1974, 1975, 1979, 1982 and 1985) represent no special climate sequence other than 1979 in which climate after period 4 is always average. Climate in the remaining four years fluctuates between excellent and fair or poor. There exists no climate information in these years which would drive a change in the amount or timing of nitrogen application, which are the only decision changes deing driven by climate forecasts in Table 5.17.

Story County Corn

The optimal decision sets and management simulation results for Story County corn are in Table 5.18. Note that the field time constraint is never encountered and the choice of a medium season hybrid planted at medium density is never altered. Furthermore, the optimal nitrogen application rate of 150 pounds per acre only changes in 1985, a year in which stage 7

Table 5.17 Champaign County Corn Decision - Perfect 5 Forecast.

	Fall Nit.		Planting						Side. Nit.		Net
			Field 1			Field 2					
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	200	200	5/15	2	0	5/15	2	0	0	0	69,472
1972	200	200	5/15	2	0	5/15	2	0	0	0	62,542
1973b	0	0	5/15	2	0	5/15	2	150	150	0	66,553
1974	0	0	5/15	2	150	5/15	2	150	0	0	36,477
1975	0	0	5/15	2	150	5/15	2	150	0	0	67,013
1976	0	0	5/15	2	200	5/15	2	200	0	0	52,652
1977	150	150	5/15	2	0	5/15	2	0	0	0	63,582
1978c	0	0	5/25	4	200	5/15	2	150	0	0	58,459
1979	0	0	5/15	2	150	5/15	2	150	0	0	51,151
1980	200	200	5/15	2	0	5/15	2	0	0	0	59,800
1981c	200	200	5/25	4	0	5/15	2	0	0	0	62,250
1982	0	0	5/15	2	150	5/15	2	150	0	0	58,032
1983c	0	0	5/25	4	150	5/15	2	200	0	0	38,711
1984	0	0	5/15	2	200	5/15	2	200	0	0	50,543
1985	0	0	5/15	2	150	5/15	2	150	0	0	47,018

b Field time constraint not active but active in base policy in these years,
c Field time constraint prevents earlier planting in these years.

Table 5.18 Story County Corn. Decisions and Returns - Perfect-5 Forecast

	Fall Nit.		Planting						Side. Nit.		Net
			Field 1			Field 2					
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	150	150	5/15	2	0	5/15	2	0	0	0	46,893
1972	150	150	5/15	2	0	5/15	2	0	0	0	45,163
1973	0	0	5/15	2	150	5/15	2	150	0	0	47,905
1974	150	150	5/15	2	0	5/15	2	0	0	0	38,294
1975	150	150	5/15	2	0	5/15	2	0	0	0	44,555
1976	150	150	5/15	2	0	5/15	2	0	0	0	38,432
1977	150	150	5/15	2	0	5/15	2	0	0	0	36,858
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	150	150	5/15	2	0	5/15	2	0	0	0	44,786
1981	150	150	5/15	2	0	5/15	2	0	0	0	41,733
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	0	0	5/15	2	150	5/15	2	150	0	0	28,419
1984	150	150	5/15	2	0	5/15	2	0	0	0	52,312
1985	100	100	5/15	2	0	5/15	2	0	0	0	27,563

climate, the period of nitrogen-climate interaction in the production function, is poor while climate in other periods is average to good (Table 5.7). The only other period in which stage 7 climate is poor is 1977. In that year climate is also poor in periods 8,9 and 10. The production function specification in Chapter IV allows some of the climate deficiency to be offset by the additive effects of the N and N^2 terms, which likely keeps the optimal nitrogen level at 150 pounds in 1977.

Also of interest in Table 5.18 is the timing of nitrogen application in 1973 and 1983. These are the two years in which winter precipitation is above 380 mm (Tables 5.4 and 5.8), causing optimal nitrogen application to be in the spring rather than the fall.

Referring back to Tables 4.7 and 4.9, the climate index data from the corn growth simulation models, and the discussion of their summary statistics in Chapter IV, recall that the coefficient of variation in the climate index is markedly lower in Story County than in Champaign County for every period except stage 9. Also, the mean climate index is higher in Story County in periods 6 through 9. Thus the Story County forecast is predicting generally more favorable climate with less variablility than the Champaign County forecast. As such, it is to be expected that fewer corn crop decision changes are driven by climate information in Story County than in Champaign County.

Champaign and Story County Soybeans

The optimal decisions and management simulation results from using the perfect-5 forecasts for Champaign and Story County soybeans are in Tables 5.19 and 5.20, respectively. These decisions and their results may be compared to those of the fifteen year priors in Tables 5.15 and 5.16. Note again that the optimal planting density and variety decisions do not change throughout the simulation years. The remaining decisions relate to the planting date and field time constraint.

First, in Champaign County the field time constraint is binding in six of the fifteen years. In another four of the years the perfect-5 optimal decisions are the same as those of the fifteen year prior. In the remaining five years (1976, 1977, 1979, 1984 and 1985) the optimal planting date is delayed one or more stages. In 1976 and 1985 optimal planting is delayed from stage 4 to stage 5, indicating that in these years the value of additive yield foregone, as determined by the production function parameter on climate in period 5, is less than the amount of interest on planting costs for ten days. Referring to Table 4.11, the production function parameter estimates, it is immediately apparent that the parameter estimate on PCI5 in the Champaign soybean function is quite low (0.03675). Also, Table 5.6 reveals that period 5 climate was fair and poor in 1976 and 1985, respectively. The combination of interest accrual, the unfavorable climate and low marginal response to climate in period 5 results in delayed planting being optimal in these two years. In 1977 planting is delayed from stage 4 to stage 6, while in 1979 and 1984 planting is delayed from stage 5 to stage 6 (only for one field in 1984). This further delay to period 6 is also likely to be driven by the interest expense on planting costs for an additional period.

The optimal soybean decisions from the perfect-5 forecast in Story County are unchanged from the base decisions in eight of the years simulated. Planting of both fields is delayed from period 4 to period 6 in

Table 5.19 Champ. Ctv. Soybeans. Decisions and Returns - Perfect-5 Forecast

	Field 1			Field 2			
Year	Plant Date	Density	Variety	Plant Date	Density	Variety	Returns
1971	5/15	med	III	5/15	med	III	38,660
1972c	5/25	med	III	5/25	med	III	52,727
1973c	6/07	med	III	6/07	med	III	38,408
1974c	5/25	med	III	6/07	med	III	52,826
1975	5/15	med	III	5/15	med	III	39,028
1976	5/25	med	III	5/25	med	III	42,676
1977	6/07	med	III	6/07	med	III	37,749
1978c	6/07	med	III	6/07	med	III	35,703
1979b	6/07	med	III	6/07	med	III	38,408
1980	5/15	med	III	5/15	med	III	39,095
1981c	6/07	med	III	6/07	med	III	37,831
1982	5/15	med	III	5/15	med	III	39,329
1983c	6/07	med	III	6/07	med	III	38,466
1984b	6/07	med	III	6/07	med	III	38,408
1985	5/25	med	III	5/25	med	III	39,832

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

Table 5.20 Storv County Soybeans. Decisions and Returns - Perfect-5 Forecast

	Field 1			Field 2			
Year	Plant Date	Density	Variety	Plant Date	Density	Variety	Returns
1971	6/07	med	III	6/07	med	III	51,869
1972	6/07	med	III	6/07	med	III	51,796
1973b	6/07	med	III	6/07	med	III	48,517
1974b	6/07	med	III	5/15	med	III	54,140
1975b	6/07	med	III	6/07	med	III	52,484
1976	5/15	med	III	5/15	med	III	51,291
1977	5/15	med	III	5/15	med	III	24,505
1978	5/15	med	III	5/15	med	III	51,583
1979b	6/07	med	III	6/07	med	III	52,484
1980	5/15	med	III	5/15	med	III	51,345
1981	5/15	med	III	5/15	med	III	39,104
1982	5/05	med	III	5/15	med	III	53,894
1983b	6/07	med	III	6/07	med	III	49,637
1984c	6/07	med	III	5/15	med	III	51,461
1985	5/15	med	III	5/15	med	III	24,377

b Field time constraint not active but active in base policy in these years,
c Field time constraint prevents earlier planting in these years.

1971 and 1972, while in 1973 and 1975 planting of both fields is delayed from period 5 to period 6. Due to the field time constraint, planting of only one field is delayed in 1974, 1979 and 1983. Referring again to Table 4.11, the Story County soybean production function does not include parameters on the climate indices during planting stages. Rather, the yield potential is adjusted by the parameter of the Pdate dummy variable if planting occurs in stage 5 or 6. Thus, planting delays from stage 5 to stage 6 are driven solely by decreased interest expense without further yield reduction in the model. In comparison, cost reductions from delaying planting from period 4 to period 6 are offset by decreased marginal revenues, but insufficiently so in 1971 and 1972.

Comparing Tables 5.19 and 5.20, the optimal returns from using the perfect-5 soybean predictor in each county, it is clear that Story County soybean returns may often be over estimated by as much as 20 to 25 percent compared to Champaign County, despite similar costs and a lower soybean price in Iowa. Considering the concerns expressed in the previous chapter regarding the Story County soybean production function, together with these inexplicable results, it is concluded that further inferences drawn from the Story County soybean DP and management simulation models are not well founded.

In both locations the optimal soybean decisions are rarely affected by climate. In fact, differences between the net revenues from the perfect-5 decisions and those of the fifteen year prior are largely attributable to the DP model assumption that interest accrues on planting expenses from the date of planting. This assertion is further examined in the following section.

Valuation of the Perfect-5 Forecasts

With the data available in Tables 5.13 through 5.20, valuation of the perfect-5 predictions and predictors according to equations 2.3 and 2.4 is easily accomplished. To value the prediction, the net returns from applying the decision based on the fifteen year prior is subtracted from the net returns from the optimal decision based on the perfect-5 prediction for each year. To value the predictor, the mechanism that gives rise to the predictions, the expected value (mean) of the predictions is calculated. The results of these calculations are displayed in Table 5.21.

First, it is apparent that the perfect-5 predictor has relatively little value compared to the fifteen year historical prior in all cases

Table 5.21 Value of Perfect-5 Predictions and Predictors.

	Champaign County		Story County	
Year	Corn	Soybeans	Corn	Soybeans
1971	3,799	0	0	18
1972	3,587	0	0	17
1973	2,330	0	911	127
1974	0	0	0	150
1975	0	0	0	127
1976	640	465	0	0
1977	2,192	206	0	0
1978	405	0	0	0
1979	0	127	0	64
1980	3,459	0	0	0
1981	3,574	0	0	0
1982	0	0	0	0
1983	134	0	450	63
1984	576	64	0	0
1985	0	507	10	0
Mean	1,380	91	91	38
Mean/acre	4.31	0.29	0.29	0.12

except Champaign County corn. Earlier discussion centered around the interest expense on soybean planting costs. From Table 4.14, soybean planting costs at medium density seeding are $70.01 per acre. When the optimal decision is to delay planting from period 5 to period 6, 16 days of interest on costs of planting 320 acres of soybeans is saved, which totals $126.69, rounded to $127. When only one field is delayed, half that amount ($63.34) is saved. When planting is delayed from stage 4 to stage 6, the amount of interest saved is $205.87. Note in Table 5.21 that these amounts are often reflected in the value of soybean climate predictions. Other amounts reflect the effects of changes in revenue associated with the change in planting date.

In Story County corn, there is benefit in knowing that nitrogen leaching will occur in 1973 and 1983. Knowing that period 7 climate will be poor in 1985 and adjusting the nitrogen application rate to 100 pounds per acre from 150 pounds saves $10 for the whole farm decision maker with fifteen year historical prior information.

The Champaign County corn climate predictor has the most value. Note that in 1971, 1972, 1980 and 1981 there is roughly $3,500 to be gained from applying 200 pounds of nitrogen per acre in the fall rather than 150 pounds of nitrogen per acre in the spring. Fall nitrogen application saves $2,192 in 1977 without a change in the application rate. In 1976 and 1984 there is approximately $600 to be gained from knowing that period 7 climate will be good or excellent. Of particular interest is the $2,330 to be saved in 1973 strictly from knowing in advance that the field time constraint will be encountered if spring nitrogen is applied before planting. Other than this last issue, there is a tendency for managerial response to favorable predictions, such as fall precipitation and early summer climate. This result compares positively with Mjelde's.

Effect of More Specific Model on Value of Perfect-5 Predictor

The more highly specified nature of the models developed for this study when compared to others such as those of Mjelde and Babcock has been alluded to earlier. The complexities that must be placed in the models may or may not effect the value of climate information described above. The areas of specificity that are of interest include the field time constraints, the multiple fields and multiple soil types of the model farms, the addition of multiple crops (the choice between which is restricted by assumption), and the resulting subdivision of the growing season into more periods, each of shorter duration. These issues are not independent and must be examined together.

The model farms contain two soil types, the difference between which is not substantial enough to influence the growth simulation models. These soil types and their proportions fairly represent the actual soil types in the locations studied. That the choice between soil types is ignored may accurately reflect decision patterns on farms comprised of relatively similar soils. This may not be the case if other locations are included in which soil types differ more markedly and soil-climate interactions can be detected in the growth simulation models.

The combination of the field time constraint, multiple fields and- multiple crops impacts the value of climate information for corn in Champaign County. First, the value of climate information to the farm decision maker determined in the previous section is reduced by the restriction of soybeans being planted to one-half of the fields. This is because climate information was found to be of little value in making soybean decisions and a forecast of very favorable corn climate cannot trigger a shift from soybeans to corn or vice versa.

Secondly, the field time constraint more accurately depicts the field work patterns of mid-size midwestern grain farms. The two week field work intervals in this model portray the constraint and resulting delays as arising from field conditions rather than growing conditions. The design of the constraint severely limits the choices of planting dates available in some years. In contrast, planting in late spring rarely entered the optimal policy in Mjelde's model. His simplification from aggregating five planting dates to two is not contradicted by the models developed in this study. Therefore, it is not critical that the constraint takes away from a larger set of alternatives.

The operations being performed on two fields of each crop, each with its own decision set, also adds realism to the DP models. The results show that in some years there is added value to the Champaign County corn climate forecasts because of the opportunity to separate decisions by fields, especially when the constraint causes a delay in the planting of only one field. Such adjustments come into the optimal policy in 1973, 1978 and 1983. If both fields were required to have the same optimal decision set and the constraint could not differentiate between the fields, the value of the predictor would fall from $1,380 to $1,188.

Another area of different model specification appears to be the method of charging for field operations. In comparing the optimal corn policies with Mjelde's results, it is apparent that he found a number of years in which nitrogen is optimally applied two times during the year even though perfect forecasts are received in advance (pp. 166, 173). Mjelde's nitrogen application cost is less than half the amount used here.

Also, the net returns per acre of corn from perfect forecasts in Mjelde's results average approximately $267, which he properly validates. From Table 5.17, average returns per acre of corn over the fifteen years in this study are $175.89. Input and output price assumptions account for much of this difference. But a large portion is represented by the full cost charge for field operations in this study (Table 4.14) versus Mjelde's charge for fuel. For example, there is a difference of nearly $20 per acre in the cost of combining corn. A total of $34.62 per acre in higher field operations charges is designed into the corn DP model in this study.

The more complex models also encounter Bellman's curse of dimensionality more quickly. Because all state variables must be carried for each field and all decision alternatives for each field are searched in the DP program, the number of iterations required to find the optimal policy is squared by adding a field. To operationalize the DP model there must be a trade off between the number of state and decision variables and the number of discrete values each is allowed to take. Therefore, the complexity of the model restricts the size of both the choice and outcome sets, especially in the corn models. Incrementing the nitrogen choice amount by 25 pounds instead of 50 pounds has an unidentified impact on the value of the climate information. That farmers actually make nitrogen decisions in 25 pound or 50 pound increments is unclear. However, there are likely to be instances where the optimal policy would be to adjust the base amount of nitrogen from 150 pounds per acre, but not up to 200 pounds per acre. The benefit of climate information in such instances is not captured by the complex models. This trade off in dimensionality is a direct result of the number of fields and the number of planting stages.

Influence of Prices on Value of Perfect-5 Predictor

The value of information depends upon differences in returns between decisions based on the forecast and decisions based on prior information. The net return function (eq. 4.5) is a function of both input and output prices. It is well established in micro economic theory that optimal input use is a function of input and output prices (Silberberg, Varian). It is equally well established that the choice of output mix in a multi-product firm is a function of input prices, output prices and the transformation or production function (ibid).

So one would expect that the level of input use or the choice of crops would vary as price relationships change. At issue, however, is whether or not these management decisions change differently at different price relationships depending upon the climate information used by the decision maker. The specific questions addressed in this section are 1) how the value of the perfect-5 corn predictor changes with varying corn/nitrogen price relationships, 2) whether or not there is value in climate forecasts being used to choose between crops, and 3) whether or not soybean climate information becomes of value at different soybean prices. Each of these is addressed separately below.

Corn/Nitrogen Price Ratio

The base prices used in the Champaign County corn DP and management simulation models (Table 4.14) have a base corn/nitrogen price ratio of 14.7 ($2.06/$0.14). Six alternate corn/nitrogen price ratios were developed by fluctuating the price of corn and holding the nitrogen price constant. These ratios (10, 12, 14, 16, 18 and 20) were then used in the corn DP and management simulation models to determine the difference in net returns from the optimal decision based on the fifteen year prior climate expectations and those based on the perfect-5 prediction, for each year and each price ratio. The results of these runs are presented in Tables 5.22 and 5.23 for Champaign County and Story County respectively.

In Champaign County (Table 5.22) it is evident that the value of the predictor (mean difference) increases as the price of corn increases relative to the price of nitrogen. This is expected from earlier results which showed the climate forecasts had value when the decision maker became aware that it was beneficial to use more nitrogen than the base amount, thereby increasing yields. Of course, the value of the marginal yield from the additional nitrogen increases as the corn price is higher.

It is interesting that the Champaign County perfect-5 corn predictor has a value of $1,380 at a corn/nitrogen price ratio of 14.7, yet the values at price ratios of 14 and 16 are well below that amount. It is conjectured that the value of the predictor rises with the corn/nitrogen price ratio until the price ratio itself triggers an incremental increase in base nitrogen application rates. This hypothesis is developed from the base nitrogen application of 200 pounds per acre at price ratios of 16 and above.

To further investigate this relationship the models were run at price ratios of 14.5 and 15.0. The base nitrogen application rate is 150 pounds at the 14.5 price ratio. The value of the perfect-5 predictor is $1,307 which is between the values calculated at price ratios of 14 and 14.7. At a price ratio of 15 the base nitrogen application rate rises to 200 pounds and the value of the predictor drops to $845. The base decision is changed by climate forecasts less frequently and for smaller payoffs at a price ratio of 15 than at 14.7. The information value again rises at price ratios above 15, indicating that the marginal value product of the extra effective nitrogen from fall application increases without additional cost as corn price increases.

The decrease in predictor value at a price ratio of 15 is likely a result of the discrete intervals of the model's nitrogen decision set. Had nitrogen decisions been modeled continuously it is likely that the base nitrogen level would increase with the corn/nitrogen price ratio, resulting in smaller increases in predictor value as the price ratio increases.

While the absolute value of the prediction increases with the corn/nitrogen price ratio, its value as a percentage of expected net returns from the prior (base) decisions falls. Recall that these returns are net returns over variable costs, which excludes land rent, interest on non-operating capital, taxes and general overhead among other costs.

In Table 5.23 the value of the predictor remains low in Story County at all six corn/nitrogen price ratios tested. The value increases markedly from a price ratio of 10 to 12 and then falls at a price ratio of 14. This is because the optimal amount of nitrogen with prior information increases from 100 to 150 pounds per acre between price ratios of 12 and 14. At a price ratio of 12 there are a number of years in which the optimal nitrogen application with the climate prediction is higher than that for the prior. Again, the value of the climate predictor is small compared to expected base

Table 5.22 Perfect Predictor Value at Various Corn/Nitrogen Price Ratios, Champaign County.

	Corn/Nitrogen Price Ratio								
	10			12			14		
Year	Optim. Ret.	Base Ret.	Optim. - Base	Optim. Ret.	Base Ret.	Optim. -Base	Optim. Ret.	Base Ret.	Optim. - Base
1971	29,188	27,254	1,934	46,510	43,553	2,957	63,429	59,852	3,577
1972	24,748	22,839	1,909	40,181	38,161	2,020	55,614	53,488	2,126
1973	25,939	25,939	0	42,181	42,181	0	58,423	58,423	0
1974	8,068	8,068	0	20,120	20,120	0	32,173	32,173	0
1975	28,134	28,134	0	44,628	44,628	0	61,122	61,122	0
1976	18,271	18,271	0	32,582	32,582	0	46,892	46,892	0
1977	25,031	24,439	592	42,152	40,115	2,037	57,942	55,971	1,971
1978	21,884	21,884	0	37,229	37,229	0	52,573	52,573	0
1979	17,711	17,711	0	31,898	31,898	0	46,084	46,084	0
1980	23,014	21,122	1,892	38,063	36,063	2,000	54,260	51,005	3,255
1981	24,188	22,294	1,894	39,734	37,729	2,005	56,527	53,164	3,363
1982	22,233	22,233	0	37,420	37,420	0	52,608	52,608	0
1983	9,086	9,086	0	21,597	21,597	0	34,109	34,109	0
1984	16,933	16,933	0	30,948	30,948	0	45,385	44,962	423
1985	14,995	14,995	0	28,581	28,581	0	42,166	42,166	0
mean:	20,628	20,080	548	35,588	34,854	735	50,620	49,639	981
Value as a Percent of Base			2.73%			2.11%			1.98%

	Corn/Nitrogen Price Ratio								
	16			18			20		
Year	Optim. Ret.	Base Ret.	Optim. - Base	Optim. Ret.	Base Ret.	Optim. -Base	Optim. Ret.	Base Ret.	Optim. - Base
1971	81,359	77,539	3,820	98,662	94,337	4,325	115,965	111,136	4,829
1972	72,771	70,008	2,763	88,683	85,805	2,878	106,178	101,601	4,577
1973	76,058	76,058	0	94,309	92,800	1,509	111,186	109,541	1,645
1974	44,646	44,646	0	57,069	57,069	0	69,492	69,492	0
1975	79,064	79,064	0	96,066	96,066	0	113,067	113,067	0
1976	62,133	62,133	0	76,883	76,883	0	92,447	91,632	815
1977	73,732	72,764	968	91,831	88,92.8	2,903	108,112	105,091	3,021
1978	69,103	69,103	0	84,920	84,920	0	100,736	100,736	0
1979	61,186	61,186	0	75,809	75,809	0	90,432	90,432	0
1980	69,772	67,036	2,736	85,285	82,437	2,848	102,280	97,838	4,442
1981	72,552	69,806	2,746	88,577	85,716	2,861	104,602	101,626	2,976
1982	68,967	68,967	0	84,626	84,626	0	100,284	100,284	0
1983	47,130	47,130	0	60,024	60,024	0	72,917	72,917	0
1984	59,827	59,827	0	74,270	74,270	0	89,455	88,713	742
1985	56,560	56,560	0	70,568	70,568	0	84,576	84,576	0
mean:	66,324	65,455	869	81,839	80,684	1,155	97,449	95,912	1,536
Value as a Percent of Base			1.33%			1.43%			1.60%

Table 5.23 Perfect Predictor Value at Various Corn/Nitrogen Price Ratios, Story County.

	Corn/Nitrogen Price Ratio								
	10			12			14		
Year	Optim. Ret.	Base Ret.	Optim. - Base	Optim. Ret.	Base Ret.	Optim. -Base	Optim. Ret.	Base Ret.	Optim. - Base
1971	17,581	17,581	0	31,014	31,014	0	46,893	46,893	0
1972	17,262	17,262	0	30,624	30,624	0	45,163	45,163	0
1973	18,852	18,157	695	32,768	31,717	1,051	47,905	46,994	911
1974	12,771	12,771	0	25,139	25,139	0	38,294	38,294	0
1975	16,611	16,611	0	29,828	29,828	0	44,555	44,555	0
1976	12,527	12,527	0	25,635	24,841	794	38,432	38,432	0
1977	11,652	11,652	0	23,773	23,773	0	36,858	36,858	0
1978	15,663	15,663	0	29,946	28,670	1,276	43,525	43,525	0
1979	14,410	14,410	0	28,024	27,140	884	41,255	41,255	0
1980	16,880	16,880	0	31,014	30,157	857	44,786	44,786	0
1981	14,728	14,728	0	27,530	27,530	0	41,733	41,733	0
1982	5,304	5,304	0	16,019	16,019	0	27,166	27,166	0
1983	5,841	5,467	374	16,876	16,218	658	28,419	27,969	450
1984	21,638	21,638	0	37,385	35,968	1,417	52,312	52,312	0
1985	5,879	5,879	0	16,721	16,721	0	27,563	27,553	10
mean	13,840	13,769	71	26,820	26,357	462	40,324	40,233	91
Value as a Percent of Base			0.5%			1.7%			.2%

	Corn/Nitrogen Price Ratio								
	16			18			20		
Year	Optim. Ret.	Base Ret.	Optim. - Base	Optim. Ret.	Base Ret.	Optim. -Base	Optim. Ret.	Base Ret.	Optim. - Base
1971	60,988	60,988	0	75,083	75,083	0	89,178	89,178	0
1972	58,993	58,993	0	72,823	72,823	0	86,653	86,653	0
1973	62,371	61,105	1,266	76,837	75,216	1,621	91,303	89,327	1,976
1974	51,070	51,070	0	63,746	63,746	0	77,205	76,622	583
1975	58,291	58,291	0	72,028	72,028	0	85,764	85,764	0
1976	51,271	51,229	42	64,832	64,026	806	77,944	76,823	1,121
1977	49,414	49,414	0	61,969	61,969	0	74,525	74,525	0
1978	57,103	57,103	0	70,682	70,682	0	84,260	84,260	0
1979	54,485	54,485	0	67,715	67,715	0	80,945	80,945	0
1980	58,558	58,558	0	72,330	72,330	0	87,268	86,102	1,166
1981	55,037	55,037	0	68,340	68,340	0	81,644	81,644	0
1982	38,234	38,234	0	49,303	49,303	0	60,626	60,371	255
1983	39,895	39,160	735	51,371	50,352	1,019	63,227	61,544	1,683
1984	67,238	67,238	0	82,165	82,165	0	97,091	97,091	0
1985	38,681	38,681	0	49,808	49,808	0	60,936	60,936	0
mean	53,442	53,306	136	66,602	66,372	230	79,905	79,452	452
Value as a Percent of Base			0.2%			0.3%			0.5%

(prior) returns.

To further examine the impact of the climate -prediction on whole farm returns, charges are developed for the costs not included in the DP models. These charges do not vary with management decisions or climate outcomes contained in the models. Therefore, they are developed on a per acre basis and charged to the enterprise. The USDA (1987) reports that average per acre corn production costs in the Lake States and Corn Belt regions from 1984 to 1986 included $57.52 for net land rent, $18.85 for taxes and insurance and $14.29 for general overhead, for a total of $90.66 per. acre or $29,011 for two fields of corn on the model farms. These costs do not include unpaid labor, depreciation or interest on non-operating capital, although depreciation and interest on machinery and a labor charge are included in costs of field operations. Similar costs for soybean production are $60.26 for net rent, $15.71 for taxes and insurance and $12.60 for general overhead, for a total of $88.57 per acre or $28,342 for two fields of soybeans on the model farms. Table 5.24 shows the result of subtracting these charges ("partial fixed costs") for corn from the mean base returns and comparing the value of the predictor to a closer approximation of net income from the corn enterprise, exclusive of government program payments.

Table 5.24 Relative Value of Perfect-5 Predictor at Various Corn/Nitrogen Price Ratios.

	Champaign County			Storv County		
Price Ratio	Mean Base Ret. Net of Par. FC	Value of Predictor	%	Mean Base Ret. Net of Par. FC	Value of Predictor	%
10	-8,931	548	(6.14)	-15,242	71	(0.47)
12	5,843	735	12.58	- 2,654	462	(17.41)
14	20,628	981	4.76	11,222	91	0.81
16	36,444	869	2.38	24,295	136	0.56
18	51,673	1,155	2.24	37,361	230	0.62
20	66,901	1,536	2.30	50,441	452	0.90

In Champaign County the relative value of the perfect-5 predictor is higher at lower corn/nitrogen price ratios. At a price ratio of 12, for example, the use of the climate forecasts is expected to increase corn net income by 12.58 percent. In contrast, when base net income is expected to be higher, as when the price ratio is above 15, the predictor is expected to increase income by less than 2.5 percent.

The same relationship between price ratios and relative value of the predictor does not hold true for Story County. However, the highest value of the predictor is in offsetting 17.41 percent of an expected $2,654 loss when the corn/nitrogen price ratio is 12. This price ratio is also that which the predictor generated the most events of the optimal nitrogen level being higher than that of the prior (Table 5.23). Otherwise, the value of the corn perfect-5 predictor remains low when compared to the fifteen year historical prior in Story County.

Corn/Soybean Price Ratio and the Choice of Crop

The assumptions underlying the DP models fix the corn/soybean price ratio and restrict the decision maker from choosing a product mix. The crop choice restriction is currently imposed upon participants in federal farm income support programs. At issue is whether there is additional value in climate forecasts to decision makers if this restriction were not imposed. The climate information would have additional value only if it resulted in a decision to switch from one crop to another. The amount of the additional value is the difference between the optimal returns with forecasts from the original base crop and the optimal returns with information from the new crop of choice. That is, the additional value is only the incremental increase from switching crops; not the difference between the whole farm returns with and without climate information.

Table 5.25 shows the difference between net returns from corn and soybeans for both counties when the perfect-5 predictors are used for both crops. These amounts are calculated using the base prices in Table 4.14. In Champaign County corn is preferred to soybeans in all but one year at the base prices. However, contrary to expectations, soybeans are preferred to corn an all but four years in Story County. Not only is the sign opposite to that expected, the magnitude of the difference often favors soybeans by $35 or more per acre. Concern was expressed earlier regarding the potential of the soybean model to be over estimating returns compared to Champaign County and expectations. Those results plus the findings in Table 5.25 preclude reliable further analysis on the choice of crop in Story County. The choice of crop is, however, still a viable issue for the Champaign County models to address.

Table 5.25 Corn Net Returns Less Soybean Net Returns from Optimal Strategy

Year	Champaign	Story
1971	27,013	-4,958
1972	6,228	-6,616
1973	25,815	-1,396
1974	-16,349	-15,696
1975	27,985	-7,802
1976	9,793	-12,859
1977	23,847	12,353
1978	22,350	-8,058
1979	12,870	-11,165
1980	17,246	-6,559
1981	20,846	2,629
1982	18,703	-26,728
1983	111	-21,605
1984	11,623	851
1985	7,693	3,176

Given earlier assertions that optimal output mix is a function of output prices, the optimal returns and choice of crop are compared for a number of corn/soybean price ratios.[3] These ratios are created by maintaining the base corn price of $2.06 and fluctuating the soybean price between $5.00 and $9.00 in 50 cent increments. Table 5.26a presents the optimal net returns for each crop at the stated price ratio, given a perfect-5 climate prediction. The expected base is the mean of net returns at that price using the fifteen year historical prior. If the expected base for corn is greater than that for soybeans, the base choice is to plant all four fields to corn and vice versa. The optimal choice is determined in each year by comparing optimal net returns for corn and soybeans. It is only when the optimal choice is opposite the base choice that the climate information has additional value. Table 5.26b depicts those years in which the optimal choice is different from the base choice and the additional returns resulting from switching crops. The additional value of the predictor is given by the mean of returns from switching crops over the fifteen years.

Progressing through Table 5.26a, it is apparent that corn is the base crop of choice given the fifteen year prior until soybean prices are at above $7.00, or a soybean/corn price ratio of 3.4. In Table 5.26b, the number of times the climate forecasts cause a change in crop selection also increases steadily through a soybean price of $7.00, after which, at higher soybean prices, the choice of crop is altered fewer times. The additional value of the perfect-5 predictor from driving this change in crop selection increases from $639 at a soybean price of $5.00 to $4,592 at a soybean price of $6.50. The additional value falls to zero at soybean prices above $8.00,

Table 5.26a Returns from Corn vs. Soybeans with Perfect-5 Predictors at Various Soybean/Corn Price Ratios. Champaign County

		Soybean Price					
Year	Corn	$5.00	$5.50	$6.00	$6.50	$7.00	$7.50
1971	69,472	33,017	39,578	46,139	52,700	59,261	65,821
1972	62,542	45,958	53,829	61,699	69,570	77,440	85,311
1973	66,553	32,802	39,320	45,838	52,356	58,874	65,392
1974	36,477	46,055	53,928	61,802	69,676	77,550	85,424
1975	67,013	33,356	39,951	46,546	53,142	59,737	66,332
1976	52,652	36,716	43,646	50,575	57,505	64,434	71,363
1977	63,582	32,196	38,652	45,109	51,565	58,021	64,477
1978	58,459	30,315	36,580	42,845	49,109	55,374	61,639
1979	51,151	32,802	39,320	45,838	52,356	58,874	65,392
1980	59,800	33,418	40,019	46,621	53,223	59,824	66,426
1981	62,250	32,272	38,736	45,200	51,663	58,127	64,591
1982	58,032	33,652	40,267	46,881	53,504	60,127	66,751
1983	38,711	32,856	39,380	45,903	52,427	58,950	65,474
1984	50,543	32,802	39,320	45,838	52,356	58,874	65,392
1985	47,018	34,102	40,765	47,428	54,091	60,754	67,418
Mean:	56,284	34,821	41,553	48,284	55,016	61,748	68,480
Expected base:	56,770	33,475	40,079	46,682	53,286	59,889	66,493
Base Choice:		Corn	Corn	Corn	Corn	Soybeans	Soybeans

	Soybean Price		
Year	$8.00	$8.50	$9.00
1971	39,578	46,139	52,700
1971	77,382	78,943	85,504
1972	93,181	101,052	108,922
1973	71,910	78,428	84,946
1974	93,298	101,172	109,045
1975	72,928	79,523	86,118
1976	78,293	85,222	92,151
1977	70,934	77,390	83,846
1978	67,903	74,168	80,433
1979	71,910	78,428	84,946
1980	73,027	79,629	86,231
1981	71,055	77,519	83,983
1982	73,374	79,998	86,621
1983	71,997	78,520	85,044
1984	71,910	78,428	84,946
1985	74,081	80,744	87,407
Mean:	75,546	81,944	88,676
Expected base:	73,096	79,699	86,303
Base Choice:	Soybeans	Soybeans	Soybeans

Table 5.26b Additional Returns from Switching Crop at Various Soybean/Corn Price Ratios. Champaign County Perfect-5 Predictors

	Soybean Price								
Year	$5.00	S5.50	$6.00	$6.50	$7.00	$7.50	$8.00	$8.50	$9.00
1971					10,221	3,651			
1972				7,028					
1973					7,679	1,161			
1974	9,578	17,451	25,325	33,199					
1975					7,276	681			
1976				4,853					
1977					5,561				
1978					3,085				
1979				1,205					
1980									
1981					4,123				
1982									
1983		669	7,192	13,716					
1984				1,813					
1985			410	7,073					
Mean:	639	1,208	2,168	4,592	2,529	366	0	0	0

indicating corn is not competitive with soybeans at this price ratio regardless of the climate.

Thus it seems that at soybean/corn price ratios of roughly 2.9 to 3.4 the Champaign County DP models represent corn and soybeans as competitive crops, the decision between which can be assisted by corn and soybean climate forecasts. However, a closer look at Table 5.26a reveals that within each price column the decision to switch from corn to soybeans is optimal when corn returns are relatively low; not when soybean returns are relatively high. Moreover, at higher soybean prices the decision to switch from soybeans to corn is motivated by higher corn returns, not lower soybean returns. These two observations allow additional value of the perfect-5 predictors from the choice of crop to be attributed to the corn predictor and not the soybean predictor. Although decision makers may not place all cropland in production of the same crop, the potential value of the corn climate predictions for selecting a crop is as great or greater than its value in determining optimal timing and amounts of nitrogen fertilizer application. One caveat should be added: the above analysis is performed in the absence of the effect of the field time constraint on planting dates. Although the model farms are endowed with enough equipment to perform the additional field operations without changing the impact of the constraint, they are not endowed with sufficient labor. To the extent labor can be duplicated, the charge for which is already embedded in the cost of field operations, the effect of the field time constraint remains unchanged.

Influence of Soybean Price on the Value of Perfect-5 Soybean Predictor

Soybean forecasts were previously found to be of little value. To investigate the sensitivity of this result to price assumptions, the Champaign County soybean model was run at the same nine soybean prices as in the previous section to determine whether any management decision changes are prompted by climate forecasts. The results of these runs are presented in Table 5.27. The influence of avoiding one (or two) period's interest expense on planting costs is still detected in the forecast values of 63, 64, 126, 127, 205 and 206. Even with these amounts included, the value of the soybean perfect-5 climate predictor is comparatively negligible.

Summary

The five category perfect climate forecasts were developed to determine their value to Champaign County and Story County corn and soybean producers. The fifteen-year prior expectations on climate were used for this purpose. The optimal policies for soybeans are not affected by the perfect-5

Table 5.27 Comparison of Optimal Returns vs. Base Returns for Various Soybean Prices. Champaign County.

Price:		$5.00			$5.50			$6.00	
Year	Optimal	Base	Value	Optimal	Base	Value	Optimal	Base	Value
1971	33,017	33,017	0	39,578	39,578	0	46,139	46,139	0
1972	45,958	45,958	C	53,829	53,829	0	61,699	61,699	0
1973	32,802	32,739	63	39,320	39,257	63	45,838	45,775	63
1974	46,055	46,055	0	53,928	53,928	0	61,802	61,802	0
1975	33,356	33,356	0	39,951	39,951	0	46,546	46,546	0
1976	36,716	36,253	433	43,646	43,176	470	50,575	50,070	505
1977	32,196	31,990	206	38,652	38,447	205	45,109	44,903	206
1978	30,315	30,315	0	36,580	36,580	0	42,845	42,845	0
1979	32,802	32,676	126	39,320	39,194	126	45,838	45,712	126
1980	33,418	33,418	0	40,019	40,019	0	46,621	46,621	0
1981	32,272	32,272	0	38,736	38,736	0	45,200	45,200	0
1982	33,652	33,633	19	40,267	40,257	10	46,881	46,880	1
1983	32,856	32,856	0	39,380	39,380	0	45,903	45,903	0
1984	32,802	32,739	63	39,320	39,257	63	45,838	45,775	63
1985	34,102	33,629	473	40,765	40,252	513	47,428	46,875	553
Mean	34,821	34,729	92	41,553	41,456	97	48,284	48,183	101

Price:		$6.50			S7.00			$7.50	
Year	Optimal	Base	Value	Optimal	Base	Value	Optimal	Base	Value
1971	52,700	52,700	0	59,261	59,261	0	65,821	65,821	0
1972	69,570	69,570	0	77,440	77,440	0	85,311	85,311	0
1973	52,356	52,293	63	58,874	58,811	63	65,392	65,329	63
1974	69,676	69,676	0	77,550	77,550	0	85,424	85,424	0
1975	53,142	53,142	0	59,737	59,737	0	66,332	66,332	0
1976	57,505	56,963	542	64,434	63,856	578	71,363	70,750	613
1977	51,565	51,359	206	58,021	57,815	206	64,477	64,271	206
1978	49,109	49,109	0	55,374	55,374	0	61,639	61,639	0
1979	52,356	52,230	126	58,874	58,747	127	65,392	65,265	127
1980	53,223	53,223	0	59,824	59,824	0	66,426	66,426	0
1981	51,663	51,663	0	58,127	58,127	0	64,591	64,591	0
1982	53,504	53,504	0	60,127	60,127	0	66,751	66,751	0
1983	52,427	52,427	0	58,950	58,950	0	65,474	65,474	0
1984	52,356	52,293	63	58,874	58,811	63	65,392	65,329	63
1985	54,091	53,498	593	60,754	60,121	633	67,418	66,744	674
Mean	55,016	54,910	106	61,748	61,637	111	68,480	68,364	116

Table 5.27 (cont.) Comparison of Optimal Returns vs. Base Returns for Various Soybean Prices. Champaign County.

Price:	$8.00			$8.50			$9.00		
Year	Optimal	Base	Value	Optimal	Base	Value	Optimal	Base	Value
1971	77,382	77,382	0	78,943	78,943	0	85,504	85,504	0
1972	93,181	93,181	0	101,052	101,052	0	108,922	108,922	0
1973	71,910	71,847	63	78,428	78,365	63	84,946	84,883	63
1974	93,298	93,298	0	101,172	101,172	0	109,045	109,045	0
1975	72,928	72,928	0	79,523	79,523	0	86,118	86,118	0
1976	78,293	77,643	650	85,222	84,536	686	92,151	91,430	721
1977	70,934	70,728	206	77,390	77,184	206	83,846	83,640	206
1978	67,903	67,903	0	74,168	74,168	0	80,433	80,433	0
1979	71,910	71,783	127	78,428	78,301	127	84,946	84,819	127
1980	73,027	73,027	0	79,629	79,629	0	86,231	86,231	0
1981	71,055	71,055	0	77,519	77,519	0	83,983	83,983	0
1982	73,374	73,374	0	79,998	79,998	0	86,621	86,621	0
1983	71,997	71,997	0	78,520	78,520	0	85,044	85,044	0
1984	71,910	71,847	63	78,428	78,365	63	84,946	84,883	63
1985	74,081	73,367	714	80,744	79,990	754	87,407	86,613	794
Mean	75,546	75,424	122	81,944	81,818	127	88,676	88,545	132

forecasts. Rather, they are controlled by seed costs and the constraint on available field time. The value of corn climate predictions is very low in Story County, where winter precipitation is sufficiently low in 85 percent of the years studied to allow fall nitrogen application without costly leaching. Moreover, the higher expected climate index and its lower variability during critical periods of nitrogen-climate interaction in Story County provide less incentive to adjust nitrogen levels from optimal application rates of the fifteen year prior.

In Champaign County, however, the amount and timing of optimal nitrogen application is aided by the perfect-5 predictor. The value of the predictions increases with the corn/nitrogen price ratio until the base nitrogen decision increases, after which it falls due to the large intervals in the discrete nitrogen decision set. Additional value for the corn climate forecasts is found if the choice between planting corn and soybeans becomes a management alternative, which is currently constrained by the terms imposed on government program participants.

Some of the assumptions imposed on the analysis conducted in this chapter are quite strong. Three of these are of particular interest. Bestowing the fifteen year prior on the decision maker grants a large amount of prior information not known to be used in such decisions. Secondly, converting what is now a three category forecast into a five category forecast may provide the decision maker with information which is not deliverable by current climate forecasting techniques. The assumption that the forecasts are perfect may also be beyond current capabilities. Each of these assumptions is relaxed somewhat in the following chapter to determine the value of climate forecasts with a different set of assumptions.

Notes

1. Differences in field number are inconsequential since both fields are the same soil type. Planting field 1 in stage 4 and field 2 in stage 5 is equivalent to planting field 2 in stage 4 and field 1 in stage 5.

2. Net land rent is the weighted average return to land owners from both cash and crop share rent.

3. The preference for one crop over another may be influenced by multi-year phenomena such as pest and disease infestation and control, chemical carryover, and so forth. These issues are ignored here in the interest of preserving the one-year, multi-period DP models.

CHAPTER VI

APPLICATION OF MODEL TO VARIOUS CLIMATE FORECAST SCHEMES AND ALTERNATE PRIORS

Introduction

The models developed in Chapter IV were employed in Chapter V to value climate forecasts under the assumptions that the decision maker has prior knowledge of the fifteen year historical climate probability and that the climate forecast mechanism is capable of producing perfectly accurate climate forecasts for each stage at the beginning of the production year. Moreover, the climate forecast mechanism was assumed to be able to distinguish among any of five possible climate outcomes. These assumptions were previously noted as possibly being restrictive. This chapter addresses the value of climate forecasts when these assumptions are relaxed. The specificity and accuracy of the forecasts are altered first. This is followed by a changes in the assumption of the decision maker's prior information. These analyses are preceded by a discussion of the parameters of a climate forecast, of which specificity and accuracy are only two.

Parameters of a Climate Forecast

Other than winter precipitation, the climate forecast used in these analyses is a prediction of general field or growing conditions occurring during a particular period. The question of which weather phenomena (rainfall, evaporation, temperature, solar radiation, wind velocity, etc.) are causing the conditions to occur is left to climatologists to address.

There are other characteristics of a climate forecast which may impact its value. These include specificity, accuracy, lead time, spatial resolution and duration of a forecast period (Mjelde).

To value the differences in duration of a forecast period requires allowing the length of stages in the dynamic programming models to vary. Valuing spatial resolution in the current context means allowing climate forecasts and outcomes to vary over the 640 acres of the model farm. Although measurement of certain weather phenomena, especially rainfall, may vary over an area of this size during an event, modeling different climate over this relatively small geographic region for a minimum period of two weeks is not seen as a productive exercise. Therefore, duration and spatial resolution are not addressed in this study. Lead time, accuracy and specificity are discussed separately below.

Lead Time

The concept of forecast lead time refers to how long in advance of a period the forecast for that period is received. In the analyses of Chapter V lead time was indirectly specified by assuming the forecast for all periods were received at the beginning of stage 1. A closer evaluation of lead time is warranted only in the Champaign County corn model because of the very few decision changes after stage 1 in the other models resulting from climate information.

The dynamic programming method facilitates the evaluation of the optimal policy at any stage given the value of the state variables. Recall from the state transition equations (4.16, 4.20 - 4.27) that the corn DP state variables at any stage are a function of prior decisions as well as climate outcomes. Without sufficient lead time the decision maker is assumed to base a decision on prior information. For example, without information available at stage 1 about period 7 climate, a period of nitrogen-climate interaction, a decision may be implemented to apply 150 pounds of nitrogen in the fall although the optimal amount would be 200 pounds. If the period 7 climate information is forthcoming in periods 2 through 6, will the decision maker apply another 50 pounds of nitrogen? If so, the difference in net returns between applying the 200 pounds in one fall application versus applying it in two applications of 150 pounds in the fall and 50 pounds in the spring or summer is the value of the lead time component of the forecast for period 7.

In the Champaign County corn optimal policies of Chapter V only the amount and timing of nitrogen application changed from the base policy. These decisions were based mainly on forecasts of winter precipitation (stage 1 climate) and climate in stages 7 through 10, particularly stages 7 and 8. Clearly there can be no lead time adjustments made to stage 1 forecasts; either a forecast is received in the fall or it is of no value in determining whether or not to apply fall nitrogen. The lead time of forecasts for periods 7 through 10 was examined as they relate to the amount and timing of optimal nitrogen application.

The analysis specifically addressed whether or not it is optimal to perform a second application of nitrogen when climate forecasts for later periods are not received until after the first nitrogen application is performed based on the fifteen year prior. In all model runs, including those discussed later in this chapter, it is never advantageous to apply additional nitrogen in periods after planting if the forecasts are received after planting. In addition, if it is optimal to apply fall nitrogen but forecasts for periods 7 through 10 have not been received, then the amount applied is the amount based on the prior (150 pounds). Again, no supplementary nitrogen application occurs, at planting or sidedressed, in any model runs when summer forecasts are received after stage 1.

An analysis of Table 5.17 indicates there are four years in which the perfect-5 forecast elicits fall fertilization at 200 pounds per acre. Management simulation runs for these years with 150 pounds of fall-applied nitrogen indicate an average increase in net returns of $1,434 for these four years, or an expected value of $382 over the fifteen year period. In addition, only four instances of spring fertilization above 150 pounds per acre are found in Table 5.17. The average value of the predictors for these years is $438, or $117 over the fifteen year period. Further subtracting the $2,330 gain from delaying nitrogen application in 1973, or $155 per year, leaves $726 of the $1,380 value attributable to the winter precipitation forecast.

Mjelde often found multiple applications of nitrogen in the optimal policy. Differences in cost of nitrogen application between his model and the current one may be the cause of this disagreement. The cost of 50 pounds of nitrogen per acre at $.14 per pound is $7.00 per acre. However, if another application charge is assessed at $5.00 per acre, the effective cost of the additional fertilizer rises to $.24 per pound. The DP model determines that the discrete additional return per acre from this incremental 50 pounds is less than its $12.00 cost. It is not clear what level of nitrogen Mjelde used as a prior nor whether an additional application charge was assessed (pp. 163, 164, 166). It is evident however, that the initial application charge is $2.19 per acre and the spring nitrogen price is $.153 per pound. In addition, the allowable discrete values for the nitrogen state variable provide for an additional 50 pounds to be counted as 83 pounds (p. 173). Therefore, the effective cost of nitrogen in Mjelde's model is $.092 per pound without an application charge and $.119 per pound with an application charge.

In summary, this analysis shows that lead time is crucial to climate information value in corn production because of the irreversibility of prior actions and the relatively large incremental cost of repeating operations. Further, perfect-5 forecasts of growing season climate received in the spring have an expected value of $117. Receiving these forecasts in the fall adds another $382 to the expected value of perfect-5 predictions of growing season climate.

Accuracy

In the context of this study accuracy refers to the correctness of the forecast in identifying which climate outcome will occur. This is most easily described by Table 6.1, parts a - c. Table 6.1a describes a 3-category forecast that is perfectly accurate. Whichever category is predicted actually occurs with 1.0 probability. This is the accuracy of the forecast evaluated in the previous chapter. Part b. describes a forecast which is not perfectly accurate, but has a relatively narrow dispersion. If an outcome of average is predicted, there is a fifteen percent chance of actually obtaining an outcome of good, a fifteen percent chance of poor, and a 70 percent chance of obtaining the predicted outcome of average. Note in this 3-category example that if extremes of good or poor are predicted there is a zero probability of obtaining the opposite extreme. In contrast, the wider dispersion of outcomes in part c. describes a lower accuracy in both the lower probability of obtaining the category predicted and the non-zero (.25) probability of obtaining an extreme outcome opposite to that predicted.

Each row in Table 6.1a-c must sum to 1.0 as some outcome will occur regardless of the prediction. The probability of getting a prediction of a certain category depends upon the processes generating the forecasts and

Table 6.1 Forecast Accuracies: Probability of Outcome Given Prediction

a. Perfect Accuracy

	Outcome		
Prediction	Good	Average	Poor
Good	1.00	.00	.00
Average	.00	1.00	.00
Poor	.00	.00	1.00

b. Narrow Dispersion

	Outcome		
Prediction	Good	Average	Poor
Good	.70	.30	.00
Average	.15	.70	.15
Poor	.00	.30	.70

c. Wide Dispersion

	Outcome		
Prediction	Good	Average	Poor
Good	.50	.25	.25
Average	.25	.50	.25
Poor	.25	.25	.50

outcomes. For climate forecasts, the probability of getting a particular forecast is probably best measured by the historical probability of that outcome. The accuracy of forecasts is of interest in this study to determine the effect of different accuracies on forecast values.

Specificity

Specificity is related to accuracy. In a continuous distribution, the above examples could describe accuracy in terms of the moments of a probability distribution function. The probability distributions on climate used in this study are highly discrete, with five categories used in the analyses of Chapter V and three categories of predictions and outcomes used later in this chapter. The concept of specificity in the context of this study relates to both the number of categories or discrete intervals into which the climate distribution is divided and the cumulative probability contained in each interval. Questions of interest pertain to forecast valuation differences arising from changing the number of categories and from changing the cumulative probability in each interval. The former investigates the effect of less specific forecasts while the latter addresses the issue of less specificity being compensated by more specific extremes. This is discussed in more detail later in the following sections.

Perfect Forecast - Three Climate Categories

Earlier discussion described the conformation of current NOAA forecasts as being divided into three categories. In this forecast design the normal category contains the central forty percent of historical cumulative probability and each of the two extreme categories contain thirty percent.

In this section the value of this forecast scheme to the model farm decision maker is determined and compared to the five category scheme of Chapter V. To do so, the winter precipitation, climate index and available field days data of Tables 4.7 through 4.10, 4.12 and 4.15 are grouped by NOAA categories. That is, the highest 30 percent, the middle 40 percent and the lowest 30 percent of the outcomes in each period are grouped together. For discussion purposes these intervals are referred to as good, average and poor, respectively.

The numerical data for the good climate category predicted by the forecast is the mean of the 30 percent of outcomes which fall into that category. The mean of the middle 40 percent of outcomes is used as the forecast data for the average category, and so forth for the poor category. These numerical forecast data are contained in Tables 6.2 through 6.7. The categories predicted in each year for each crop and location are presented in Tables 6.8 through 6.13. This construct of the forecast allows for less specificity, but perfect accuracy is still assumed. That is, there are fewer categories being predicted than in Chapter V analyses, causing the numerical climate variables being predicted to be slightly different. However, whatever category of climate is predicted occurs with a probability of 1.0. Hence, this forecast scheme is referred to as the perfect-3 predictor.

To value the perfect-3 predictor the DP models are run, with variable values obtained from Tables 6.2 through 6.7, to identify optimal policies with the perfect-3 climate forecasts received at the beginning of stage 1. The assumption of the fifteen year prior is maintained. The base policies and net returns of Tables 5.13 through 5.16 remain the same. Then the

Table 6.2 Categorical Values of Perfect-3 Cliamte Index. Champ. Co. Corn

	Period							
Climate	3	4	5	6	7	8	9	10
Good	0.9102	1.0146	1.3025	1.7041	1.7428	0.8331	0.3776	0.3653
Average	0.6183	0.6472	0.9115	1.6043	1.6180	0.7167	0.2919	0.3384
Poor	0.3949	0.3348	0.7479	1.4448	1.4379	0.5782	0.2428	0.2804

Table 6.3 Categorical Values of Perfect-3 Winter Precipitation and Climate Index. Champaign County Soybeans

		Period					
Climate	Winter Precip.	5	6	7	8	9	10
Good	284.3	1.5231	1.6363	1.6108	0.9466	0.5747	0.6801
Average	415.1	1.1942	1.5272	1.5250	0.8563	0.5054	0.6212
Poor	504.0	0.7768	1.4159	1.4067	0.7633	0.4618	0.5737

Table 6.4 Categorical Values of Perfect-3 Climate Index. Story County Corn

	Period						
Climate	4	5	6	7	8	9	10
Good	0.96660	1.26987	1.69016	1.77769	0.97923	0.42240	0.37885
Average	0.68355	0.93052	1.58924	1.69770	0.81605	0.33517	0.32782
Poor	0.35866	0.71578	1.39922	1.53517	0.70004	0.25573	0.27420

Table 6.5 Categorical Values of Perfect-3 Winter Precipitation and Climate Index. Story County Soybeans

		Period					
Climate	Winter Precip.	5	6	7	8	9	10
Good	156.5	1.51231	1.63212	1.62896	0.98770	0.62423	0.51439
Average	265.0	0.86251	1.53484	1.55532	0.91052	0.55474	0.44926
Poor	371.3	0.71424	1.37455	1.33835	0.75045	0.37186	0.29137

Table 6.6 Categorical Values of Perfect-3 Available Field Days. Champ. Co.

	Period				
Climate	2	3	4	5	6
Good	13.56	11.63	8.38	9.00	11.38
Average	4.04	6.75	6.50	6.25	7.86
Poor	0.63	3.31	3.00	3.00	4.19

Table 6.7 Categorical Values, of Perfect-3 Available Field Davs. Story Co.

	Period				
Climate	2	3	4	5	6
Good	12.89	12.68	9.13	8.75	12.02
Average	8.36	8.78	6.88	7.53	9.19
Poor	1.32	5.29	3.91	3.23	6.38

Table 6.8 Perfect-3 Climate Index Categories. Champaign County Corn

Year	Period 3	4	5	6	7	8	9	10
1971	3[a]	2	2	2	1	3	3	1
1972	3	2	1	1	3	2	1	2
1973	2	2	2	2	2	2	3	2
1974	2	3	2	3	2	1	1	3
1975	2	2	1	2	2	3	2	1
1976	2	2	3	2	1	2	2	1
1977	1	1	1	2	3	3	2	3
1978	3	3	2	1	2	3	2	1
1979	3	1	2	2	2	2	2	3
1980	1	2	3	1	2	1	2	2
1981	2	3	3	1	2	1	3	2
1982	1	1	1	3	3	2	1	2
1983	2	2	3	3	1	2	2	2
1984	2	3	2	3	1	2	3	2
1985	1	1	2	2	3	1	1	3

Table 6.9 Perfect-3 Winter Precipitation and Climate Index Categoreies, Champaign County Soybeans

	Period						
Year	Winter Precip.	5	6	7	8	9	10
1971	1	2	1	1	1	3	3
1972	2	2	2	3	1	2	3
1973	3	1	2	2	3	3	2
1974	3	1	3	1	1	1	1
1975	2	1	3	2	2	2	3
1976	2	3	2	2	1	2	1
1977	1	2	3	3	3	2	3
1978	2	1	1	2	3	3	1
1979	2	2	1	2	3	2	2
1980	1	2	2	2	2	2	2
1981	1	3	1	2	2	3	1
1982	2	2	3	3	2	1	2
1983	2	3	2	1	2	1	2
1984	3	2	2	1	2	2	2
1985	3	3	2	3	2	1	2

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[a] 1 = Good, 2 = Average, 3 = Poor.

Table 6.10 Perfect-3 Climate Index Categories. Story County Corn

	Period						
Year	4	5	6	7	8	9	10
1971	2[a]	2	2	1	3	3	2
1972	3	1	1	3	2	1	2
1973	2	2	2	2	2	3	1
1974	3	3	2	2	1	1	2
1975	2	1	3	2	2	2	2
1976	2	3	2	2	2	1	1
1977	1	1	2	3	3	3	3
1978	2	2	1	1	3	2	2
1979	1	2	2	2	2	2	2
1980	2	3	1	3	3	2	1
1981	3	2	1	2	2	3	3
1982	1	2	3	2	1	1	3
1983	2	3	3	1	1	2	2
1984	3	1	3	1	2	2	1
1985	1	2	2	3	1	2	3

Table 6.11 Perfect-3 Winter Precipitation and Climate Index Categoreies, Story County Soybeans

		Period					
Year	Winter Precip.	5	6	7	8	9	10
1971	3	2	2	1	3	2	3
1972	2	1	2	3	3	2	1
1973	3	2	2	2	2	3	2
1974	2	2	2	2	1	1	2
1975	2	1	3	2	2	1	2
1976	2	3	1	1	1	2	3
1977	1	1	3	3	3	3	1
1978	1	2	1	2	2	2	2
1979	2	2	2	2	2	1	2
1980	1	2	1	3	2	2	3
1981	1	3	1	2	2	3	1
1982	2	2	3	2	1	1	1
1983	3	3	2	1	1	2	2
1984	3	1	3	1	2	2	2
1985	2	3	2	3	3	3	3

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[a] 1 = Good, 2 = Average, 3 = Poor.

Table 6.12 Perfect-3 Available Field Days. Champaign County

	Period				
Year	2	3	4	5	6
1971	1[a]	1	2	2	2
1972	3	2	2	1	2
1973	2	3	2	2	3
1974	2	2	3	3	3
1975	1	3	1	1	3
1976	1	2	1	2	2
1977	1	2	2	1	1
1978	3	2	3	3	1
1979	2	3	2	1	1
1980	2	1	1	2	3
1981	2	3	3	3	2
1982	2	1	1	2	3
1983	3	2	3	3	2
1984	3	2	1	3	2
1985	2	1	2	1	1

Table 6.13 Perfect-3 Available Field Days. Story County

	Period				
Year	2	3	4	5	6
1971	1	2	1	3	2
1972	2	2	2	2	2
1973	3	2	3	1	3
1974	2	2	3	3	3
1975	3	3	2	1	2
1976	1	3	2	2	2
1977	2	1	1	2	1
1978	2	2	2	2	2
1979	3	3	2	1	1
1980	2	1	1	2	3
1981	1	1	1	1	1
1982	2	2	3	3	3
1983	3	2	3	3	2
1984	2	3	2	2	2
1985	1	1	2	2	1

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[a] 1 = Good, 2 = Average, 3 = Poor.

optimal policies resulting from the DP model runs are input into the management simulation models using the actual five-category climate of Tables 5.1 through 5.12. Net returns from using the fifteen year prior are subtracted from those of the perfect-3 forecasts to value the predictions and predictors. The optimal policies and returns from these model runs for both Champaign and Story counties and for both corn and soybeans are presented in Tables 6.14 through 6.17.[1]

Beginning with Champaign County corn (Table 6.14), the perfect-3 predictor induces minor changes in the optimal policies from those of the perfect-5 predictor (Table 5.17). The base policy of planting a medium density, full season hybrid (decisions 2 and 4) does not change. However, the amount and timing of nitrogen application does change in a few instances. Notably, the perfect-3 prediction of available field days in 1973 does not induce nitrogen sidedressing, resulting in an encounter with the field time constraint. Secondly, in 1978 fall fertilizer application is induced at the level of 250 pounds per acre. This may result from a higher numerical climate index prediction for period 8.

Story County corn decisions (Table 6.15) are altered very little from the perfect-5 optimal policies (Table 5.18). Most noticeable is the failure of the perfect-3 predictor to warn of nitrogen leaching in 1973 and 1983. In a few other years the amount of applied nitrogen is changed from 150 pounds to 100 pounds per acre (1972, 1977, and 1981). Changes in the numerical climate index being predicted resulting from the aggregation of climate outcome intervals are thought to drive these results.

Regarding soybeans, the optimal policies for Champaign County (Table 6.16) are identical to those of the perfect-5 predictor (Table 5.19). In

Table 6.14 Champaign County Corn Decision and Returns - Perfect 3 Forecast

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	200	200	5/15	2	0	5/15	2	0	0	0	69,472
1972	150	150	5/15	2	0	5/15	2	0	0	0	61,126
1973c	0	0	5/15	2	150	5/25	4	150	0	0	64,223
1974	0	0	5/15	2	150	5/15	2	150	0	0	36,477
1975	0	0	5/15	2	150	5/15	2	150	0	0	67,013
1976	0	0	5/15	2	200	5/15	2	200	0	0	52,652
1977	150	150	5/15	2	0	5/15	2	0	0	0	63,582
1978c	250	250	5/15	2	0	5/25	4	0	0	0	56,632
1979	0	0	5/15	2	150	5/15	2	150	0	0	51,151
1980	200	200	5/15	2	0	5/15	2	0	0	0	59,800
1981c	200	200	5/15	2	0	5/25	4	0	0	0	62,250
1982	0	0	5/15	2	150	5/15	2	150	0	0	58,032
1983c	0	0	5/25	4	150	5/15	2	150	0	0	38,577
1984	0	0	5/15	2	200	5/15	2	200	0	0	50,543
1985	0	0	5/15	2	150	5/15	2	150	0	0	47,018

c Field time constraint prevents earlier planting in these years.

Table 6.15 Storv County Corn Decision and Returns - Perfect 3 Forecast

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	150	150	5/15	2	0	5/15	2	0	0	0	46,893
1972	100	100	5/15	2	0	5/15	2	0	0	0	43,986
1973	100	100	5/15	2	0	5/15	2	0	0	0	45,277
1974	150	150	5/15	2	0	5/15	2	0	0	0	38,294
1975	150	150	5/15	2	0	5/15	2	0	0	0	44,555
1976	150	150	5/15	2	0	5/15	2	0	0	0	38,432
1977	100	100	5/15	2	0	5/15	2	0	0	0	35,893
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	150	150	5/15	2	0	5/15	2	0	0	0	44,786
1981	100	100	5/15	2	0	5/15	2	0	0	0	40,331
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	150	150	5/15	2	0	5/15	2	0	0	0	27,969
1984	150	150	5/15	2	0	5/15	2	0	0	0	52,312
1985	100	100	5/15	2	0	5/15	2	0	0	0	27,563

Story County the perfect-3 predictor induces earlier planting in a few years. Otherwise, the base decisions of a medium density planting of group III seed are left intact.

The values of the perfect-3 predictions and predictors are presented in Table 6.18. The value of the Champaign County corn prediction in 1978 is negative because the returns from following the optimal perfect-3 policy of Table 6.14 are less than the returns from following the fifteen year prior policy of applying 150 pounds of nitrogen in the spring. A greater number of predictions have a negative value in the Story County corn results. Again, this is due to lower returns from following the perfect-3 optimal policies than from following the fifteen year prior policy of applying 150 pounds of nitrogen in the fall. The values of the soybean predictions and predictors remain low, with most of the value attributable to interest accrual as before.

Thus, the reduced specificity of the perfect-3 predictor causes the expected value of the Champaign County corn forecasts to drop by $380, or 27.5 percent. In addition, reduced specificity in the Story County perfect-3 corn predictor causes the expected value of the prediction to fall from $91 to -$350.

Earlier discussion of the theory of information value discussed the possibility of negative information values. The conventional wisdom is that if the decision maker knew that the use of the information would cause lower returns, then it would not be incorporated into the decision making process and thus would have no value. Therefore, information value cannot be negative. This may be true in the Story County perfect-3 corn climate predictor. However, in Champaign County the decision maker does not know

Table 6.16 Champaign Soybean Decision and Returns - Perfect-3 Forecast

	Field 1			Field 2			
Year	Plant Date	Density	Hybrid	Plant Date	Density	Hybrid	Returns
1971	5/15	low	III	5/15	low	III	38,660
1972c	5/25	low	III	5/25	low	III	52,727
1973c	6/07	low	III	6/07	low	III	38,408
1974c	5/25	low	III	6/07	low	III	52,826
1975	5/15	low	III	5/15	low	III	39,028
1976	5/25	low	III	5/25	low	III	42,676
1977	6/07	low	III	6/07	low	III	37,749
1978c	6/07	low	III	6/07	low	III	35,703
1979b	6/07	low	III	6/07	low	III	38,408
1980	5/15	low	III	5/15	low	III	39,095
1981c	6/07	low	III	6/07	low	III	37,831
1982	5/15	low	III	5/15	low	III	39,329
1983c	6/07	low	III	6/07	low	III	38,466
1984b	6/07	low	III	6/07	low	III	38,408
1985	5/25	low	III	5/25	low	III	39,832

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

Table 6.17 Story County Soybean Decision and Returns - Perfect-3 Forecast

	Field 1			Field 2			
Year	Plant Date	Density	Hybrid	Plant Date	Density	Hybrid	Returns
1971	6/07	low	III	6/07	low	III	51,869
1972	5/15	low	III	5/15	low	III	51,779
1973b	6/07	low	III	6/07	low	III	48,517
1974c	5/05	low	III	5/25	low	III	53,991
1975b	6/07	low	III	6/07	low	III	52,484
1976	5/15	low	III	5/15	low	III	51,291
1977	5/15	low	III	5/15	low	III	24,505
1978	5/15	low	III	5/15	low	III	51,583
1979b	6/07	low	III	6/07	low	III	52,484
1980	5/15	low	III	5/15	low	III	51,345
1981	5/15	low	III	5/15	low	III	39,104
1982	5/05	low	III	5/15	low	III	53,894
1983b	6/07	low	III	6/07	low	III	49,637
1984c	6/07	low	III	5/15	low	III	51,461
1985	5/15	low	III	5/15	low	III	24,377

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

Table 6.18 Value of Perfect-3 Predictions and Predictors

	Champaign County		Story County	
Year	Corn	Soybeans	Corn	Soybeans
1971	3,799	0	0	18
1972	2,127	0	-1,177	0
1973	0	0	-1,718	127
1974	0	0	0	1
1975	0	0	0	127
1976	648	465	0	0
1977	2,192	206	- 965	0
1978	-1,421	0	0	0
1979	0	127	0	64
1980	3,459	0	0	0
1981	3,574	0	-1,402	0
1982	0	0	0	0
1983	0	0	0	63
1984	576	64	0	0
1985	0	507	10	0
Mean	1,000	91	- 350	27
Mean/acre	3.12	0.29	-1.09	0.08

the use of climate information might cause lower returns than the prior. It is assumed that the perfect forecast is better information than the prior and, is, therefore, incorporated into the decisions. On average, the use of the information is expected to be beneficial. It is the coarseness of the perfect-3 forecasts' detail which lower their value compared to the perfect-5 predictor. The lack of detail may generate responses which cause lower returns than those of the fifteen year prior. The decision maker is unaware when these instances might arise. Thus, the economic value of a prediction for any one year is allowed to be less than zero in this study. The mathematical value of a predictor, the expected value of the predictions, may be negative, but its economic value cannot be less than zero.

Perfect Forecast - Three Climate Categories. Low Extreme Probability

The reduced specificity of the perfect-3 predictor adversely impacts the value of the corn climate forecasts as shown above. The source of this reduced value is thought to be the reduced specificity in forecasts of extreme climate conditions. To examine this issue, the distribution of the perfect-3 (or NOAA) categories is rearranged such that 15 percent of the cumulative probability lies in each of the extreme categories of good and poor while 70 percent is encompassed in the average category. This forecast scheme is referred to as the perfect-3L predictor, The "L" representing low probability in the extreme categories.

Tables 6.19 through 6.24 contain the numerical climate indices, winter precipitation and available field days calculated for each perfect-3L forecast category. These data are calculated in the same manner as before, using the mean of the raw data which fall into each probability interval. Tables 6.25 through 6.30 display the perfect-3L climate category occurring in each year for each crop and each location. Again, the perfect-3L predictor forecasts a category with 100 percent accuracy. However, the numerical climate index used in optimization is slightly different than that used for the perfect-5 or perfect-3 predictors. The perfect-5 extreme categories of excellent and poor are the same as the perfect-3L extreme categories of good and poor. The difference arises in the perfect-3L average category encompassing the perfect-5 categories of good, average and fair, the central 70 percent of the cumulative probability.

Tables 6.31 through 6.34 present the perfect-3L optimal policies. The Champaign County corn predictor fails to forecast favorable winter precipitation in two years. It also does not induce sidedressing of nitrogen in 1973 to avoid the field time constraint. A few other slight changes from the perfect-5 optimal nitrogen application rates are detectable.

The Story County corn predictor correctly forecasts the unfavorable winter precipitation in 1973 and 1983. However, it induces lower nitrogen application rates in 1971 through 1975, 1977 and 1981. These years contain many episodes of average and poor climate in stages 7 through 10 (Table 6.27). Comparing numerical climate indices used in the perfect-3 and perfect-3L forecasts (Tables 6.4 and 6.21), in each of these stages the numerical climate indices for perfect-3L forecasts of average are less than those of the perfect-3 forecasts. Thus, the benefit of more specific forecasts of extreme climate is partially offset by the aggregation of intervals in the center of the distribution.

Optimal soybean policies are relatively unchanged in both locations (Tables 6.33 and 6.34). There are fewer instances of early planting being induced relative to the perfect-3 predictor. There are also fewer occasions when planting is delayed to save interest accrual.

The value of the perfect-3L predictions and predictors is displayed in Table 6.35. Clearly the penalties associated with aggregating the central 70 percent of the distribution outweigh the benefit of more specificity in the extreme categories. Over the fifteen years in this study there are adjustments in nitrogen application rates based on differences in climate between average and nearby categories of good and fair in the perfect-5 scheme. These differences are not as well identified in the perfect-3 predictor and non-existent in the perfect-3L predictor. Tables 5.5 through 5.8 indicate that few years encompass many periods of extreme actual

Table 6.19 Categorical Values of Perfect-3L Climate Index. Champ. Co. Corn

	Period							
Climate	3	4	5	6	7	8	9	10
Good	1.0596	1.1644	1.3934	1.7242	1.7811	0.9014	0.3911	0.3708
Average	0.6145	0.6421	0.9482	1.6020	1.6062	0.7043	0.3001	0.3359
Poor	0.3350	0.2680	0.6827	1.3777	1.4090	0.5559	0.2212	0.2577

Table 6.20 Categorical Values of Perfect-3L Winter Precipitation and Climate Index. Champaign County Soybeans

		Period					
Climate	Winter Precip.	5	6	7	8	9	10
Good	254.0	1.5600	1.6696	1.6316	0.9862	0.5994	0.7028
Average	409.9	1.1845	1.5290	1.5201	0.8525	0.5073	0.6218
Poor	521.0	0.7046	1.3706	1.3807	0.7419	0.4527	0.5594

Table 6.21 Categorical Values of Perfect-3L Climate Index. Story Co. Corn

	Period						
Climate	4	5	6	7	8	9	10
Good	1.06302	1.36497	1.69655	1.79767	1.02977	0.46587	0.39303
Average	0.66594	0.95052	1.58213	1.68987	0.82465	0.33373	0.32907
Poor	0.31727	0.63527	1.34285	1.47574	0.64938	0.22796	0.25056

Table 6.22 Categorical Values of Perfect-3L Winter Precipitation and Climate Index. Storv County Soybeans

		Period					
Climate	Winter Precip.	5	6	7	8	9	10
Good	106.0	1.59429	1.65170	1.64265	1.02253	0.65731	0.53835
Average	267.5	0.94444	1.52804	1.55376	0.91069	0.54697	0.44830
Poor	405.5	0.68318	1.32939	1.18994	0.63184	0.26812	0.17989

Table 6.23 Categorical Values of Perfect-3L Available Field Days. Champ. Co.

	Period				
Climate	2	3	4	5	6
Good	16.00	12.13	8.88	9.25	11.75
Average	4.75	7.00	6.34	6.20	7.82
Poor	0.38	2.88	1.75	2.50	3.88

Table 6.24 Categorical Values, of Perfect-3L Available Field Davs. Storv Co.

	Period				
Climate	2	3	4	5	6
Good	13.35	13.61	9.31	8.96	12.29
Average	7.91	8.87	6.80	7.27	9.22
Poor	0.84	4.27	3.46	1.39	5.94

Table 6.25 Perfect-3L Climate Index Categories. Champaign County Corn

	Period							
Year	3	4	5	6	7	8	9	10
1971	2[a]	2	2	2	2	2	3	2
1972	3	2	2	2	2	2	1	2
1973	2	2	2	2	2	2	3	2
1974	2	2	2	3	2	1	1	2
1975	2	2	1	2	2	3	2	1
1976	2	2	3	2	2	2	2	1
1977	1	2	1	2	3	2	2	3
1978	3	3	2	1	2	3	2	2
1979	2	2	2	2	2	2	2	2
1980	2	2	2	2	2	2	2	2
1981	2	3	2	1	2	1	2	2
1982	2	1	2	2	2	2	2	2
1983	2	2	3	3	1	2	2	2
1984	2	2	2	2	1	2	2	2
1985	1	1	2	2	3	2	2	3

Table 6.26 Perfect-3L Winter Precipitation and Climate Index Categoreies, Champaign County Soybeans

		Period					
Year	Winter Precip.	5	6	7	8	9	10
1971	1	2	2	2	2	2	3
1972	2	2	2	3	1	2	2
1973	2	2	2	2	2	3	2
1974	3	1	2	2	1	1	1
1975	2	1	2	2	2	2	2
1976	2	2	2	2	2	2	2
1977	2	2	3	3	2	2	3
1978	2	2	1	2	3	2	1
1979	2	2	2	2	3	2	2
1980	2	2	2	2	2	2	2
1981	1	3	1	2	2	3	2
1982	2	2	3	2	2	2	2
1983	2	2	2	1	2	2	2
1984	2	2	2	1	2	2	2
1985	3	3	2	2	2	1	2

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[a] 1 = Good, 2 = Average, 3 = Poor.

Table 6.27 Perfect-3L Climate Index Categories. Story County Corn

	Period						
Year	4	5	6	7	8	9	10
1971	2[a]	2	2	1	3	3	2
1972	3	2	1	2	2	2	2
1973	2	2	2	2	2	2	2
1974	3	2	2	2	1	2	2
1975	2	1	2	2	2	2	2
1976	2	3	2	2	2	1	1
1977	1	1	2	3	3	3	3
1978	2	2	2	2	2	2	2
1979	2	2	2	2	2	2	2
1980	2	2	2	2	2	2	2
1981	2	2	1	2	2	2	2
1982	2	2	3	2	1	1	2
1983	2	3	3	1	2	2	2
1984	2	2	2	2	2	2	1
1985	1	2	2	3	2	2	3

Table 6.28 Perfect-3L Winter Precipitation and Climate Index Categoreies, Story County Soybeans

		Period					
Year	Winter Precip.	5	6	7	8	9	10
1971	2	2	2	1	2	2	3
1972	2	1	2	2	2	2	2
1973	3	2	2	2	2	2	2
1974	2	2	2	2	2	1	2
1975	2	2	3	2	2	2	2
1976	2	2	2	2	2	2	2
1977	1	1	3	3	3	3	1
1978	2	2	1	2	2	2	2
1979	2	2	2	2	2	2	2
1980	2	2	1	2	2	2	2
1981	1	3	2	2	2	3	2
1982	2	2	2	2	1	1	1
1983	3	3	2	1	1	2	2
1984	2	2	2	2	2	2	2
1985	2	3	2	3	3	2	3

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[a] 1 = Good, 2 = Average, 3 = Poor.

Table 6.29 Perfect-3L Available Field Davs Categories. Champaign County

	Period				
Year	2	3	4	5	6
1971	1[a]	1	2	2	2
1972	3	2	2	1	2
1973	2	3	2	2	2
1974	2	2	2	3	3
1975	2	2	1	2	2
1976	1	2	2	2	2
1977	2	2	2	1	1
1978	3	2	3	2	2
1979	2	3	2	1	1
1980	2	2	2	2	2
1981	2	3	3	3	2
1982	2	2	1	2	3
1983	3	2	2	2	2
1984	2	2	1	2	2
1985	2	1	2	2	2

Table 6.30 Perfect-3L Available Field Davs Categoreies. Story County

	Period				
Year	2	3	4	5	6
1971	2	2	2	2	2
1972	2	2	2	2	2
1973	3	2	2	1	2
1974	2	2	3	3	3
1975	3	2	2	2	2
1976	1	2	2	2	2
1977	2	2	1	2	2
1978	2	2	2	2	2
1979	2	3	2	2	1
1980	2	1	1	2	2
1981	2	1	2	1	2
1982	2	2	3	3	3
1983	2	2	2	2	2
1984	2	3	2	2	2
1985	1	2	2	2	1

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[a] 1 = Good, 2 = Average, 3 = Poor.

Table 6.31 Champaign County Corn Decision and Returns - Perfect 3L-Forecast

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	150	150	5/15	2	0	5/15	2	0	0	0	67,883
1972	0	0	5/15	2	200	5/15	2	200	0	0	59,853
1973c	0	0	5/15	2	150	5/25	4	150	0	0	64,223
1974	0	0	5/15	2	150	5/15	2	150	0	0	36,477
1975	0	0	5/15	2	150	5/15	2	150	0	0	67,013
1976	0	0	5/15	2	200	5/15	2	200	0	0	52,652
1977	0	0	5/15	2	100	5/15	2	100	0	0	58,924
1978c	0	0	5/25	4	150	5/15	2	150	0	0	58,053
1979	0	0	5/15	2	150	5/15	2	150	0	0	51,151
1980	0	0	5/15	2	150	5/15	2	150	0	0	56,341
1981c	200	200	5/25	4	0	5/15	2	0	0	0	62,250
1982	0	0	5/15	2	150	5/15	2	150	0	0	58,032
1983c	0	0	5/15	2	150	5/25	4	150	0	0	38,577
1984	0	0	5/15	2	200	5/15	2	200	0	0	50,543
1985	0	0	5/15	2	100	5/15	2	100	0	0	45,197

Table 6.32 Storv County Corn Decision and Returns - Perfect 3L Forecast

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	100	100	5/15	2	0	5/15	2	0	0	0	44,446
1972	100	100	5/15	2	0	5/15	2	0	0	0	43,986
1973	0	0	5/15	2	100	5/15	2	100	0	0	46,683
1974	100	100	5/15	2	0	5/15	2	0	0	0	37,507
1975	100	100	5/15	2	0	5/15	2	0	0	0	43,046
1976	150	150	5/25	6	0	5/25	6	0	0	0	37,934
1977	100	100	5/15	2	0	5/05	2	0	0	0	34,755
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	150	150	5/15	2	0	5/15	2	0	0	0	44,786
1981	100	100	5/15	2	0	5/15	2	0	0	0	40,331
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	0	0	5/25	6	150	5/25	6	150	0	0	27,780
1984	150	150	5/15	2	0	5/15	2	0	0	0	52,312
1985	100	100	5/15	2	0	5/05	2	0	0	0	26,421

Table 6.33 Champaign Soybean Decision and Returns- Perfect-3L Forecast

	Field 1			Field 2			
Year	Plant Date	Density	Hybrid	Plant Date	Density	Hybrid	Returns
1971	5/15	low	III	5/15	low	III	38,660
1972c	5/25	low	III	5/25	low	III	52,727
1973c	6/07	low	III	6/07	low	III	38,408
1974c	5/25	low	III	6/07	low	III	52,826
1975	5/15	low	III	5/15	low	III	39,028
1976	5/15	low	III	5/15	low	III	42,211
1977	6/07	low	III	6/07	low	III	37,749
1978c	6/07	low	III	6/07	low	III	35,703
1979b	6/07	low	III	6/07	low	III	38,408
1980	5/15	low	III	5/15	low	III	39,095
1981c	6/07	low	III	6/07	low	III	37,831
1982	5/15	low	III	5/15	low	III	39,329
1983c	6/07	low	III	6/07	low	III	38,466
1984b	6/07	low	III	6/07	low	III	38,408
1985	5/25	low	III	5/25	low	III	39,832

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

Table 6.34 Story County Soybean Decision and Returns - Perfect-3L Forecast

	Field 1			Field 2			
Year	Plant Date	Density	Hybrid	Plant Date	Density	Hybrid	Returns
1971	6/07	low	III	6/07	low	III	51,869
1971	5/15	low	III	5/15	low	III	51,851
1972	5/15	low	III	5/15	low	III	51,779
1973b	6/07	low	III	6/07	low	III	48,517
1974c	5/05	low	III	5/25	low	III	53,991
1975b	6/07	low	III	6/07	low	III	52,484
1976	5/15	low	III	5/15	low	III	51,291
1977	5/15	low	III	5/15	low	III	24,505
1978	5/15	low	III	5/15	low	III	51,583
1979c	6/07	low	III	5/25	low	III	52,420
1980	5/15	low	III	5/15	low	III	51,345
1981	5/15	low	III	5/15	low	III	39,104
1982	5/05	low	III	5/15	low	III	53,894
1983c	5/25	low	III	6/07	low	III	49,573
1984c	6/07	low	III	5/15	low	III	51,461
1985	5/15	low	III	5/15	low	III	24,377

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

Table 6.35 Value of Perfect-3L Predictions and Predictors

	Champaign County		Story County	
Year	Corn	Soybeans	Corn	Soybeans
1971	2,210	0	-2,447	0
1972	898	0	-1,199	0
1973	0	0	- 311	127
1974	0	0	- 787	1
1975	0	0	-1,509	127
1976	648	0	- 498	0
1977	-2,466	206	-2,103	0
1978	0	0	0	0
1979	0	127	0	0
1980	0	0	0	0
1981	3,574	0	-1,402	0
1982	0	0	0	0
1983	0	0	- 188	-1
1984	576	64	0	0
1985	-1,821	507	-1,131	0
Mean	241	60	- 770	17
Mean/acre	0.75	0.19	- 2.41	0.05

climate. Thus the perfect-3L predictor adds very little useful knowledge to the fifteen year prior.

Accuracy

As discussed earlier in this chapter, the accuracy of forecasts is of interest to identify changes in forecast values as accuracy varies. As with specificity, there are an infinite number of accuracies that could be tested. Four are selected for this study. Each of these uses the specificity of the NOAA or perfect-3 predictor. This specificity is selected because of its current application as noted earlier.

Table 6.36 describes the forecast accuracies. It lists the probability of each outcome given a forecast for a category. Forecast A represents a

Table 6.36 Distributional Assumptions of Selected Forecast Accuracies.

Forecast A.

	Outcome		
Forecast	Good	Fair	Poor
Good	.40	.30	.30
Fair	.30	.40	.30
Poor	.30	.30	.40

Forecast B.

	Outcome		
Forecast	Good	Fair	Poor
Good	.70	.15	.15
Fair	.15	.70	.15
Poor	.15	.15	.70

Forecast C.

	Outcome		
Forecast	Good	Fair	Poor
Good	.67	.33	.00
Fair	.00	.67	.33
Poor	.00	.00	1.0

Forecast D.

	Outcome		
Forecast	Good	Fair	Poor
Good	1.0	.00	.00
Fair	.33	.67	.00
Poor	.00	.33	.67

scheme in which the correct outcome is predicted 40 percent of the time while each of the other two outcomes has a 30 percent probability. Forecast B is designed to be more accurate than forecast A. It has a .70 probability of cor-.ectly predicting the outcome while the other two categories each has a 15 percent chance of occurring.

Forecasts C and D are designed differently. In forecast C the outcome is never better than the forecast. The correct outcome is predicted with .67 probability. The other one-third probability is to obtain the next lower category. The exception, of course, is a forecast for poor climate which is the lowest category and is correctly predicted with 100 percent accuracy. Forecast D has the opposite design in that the outcome is never worse than the prediction and there is a one-third chance of obtaining the next higher category. Again the exception is a forecast of good climate which has no higher category.

Tables 6.37 through 6.40 contain the optimal decisions and returns from forecasts A through D, respectively, for the Champaign County corn model. In forecast A, it is interesting that in 1973 the field constraint is avoided with fall fertilization, likely due to the 30 percent chance for favorable winter precipitation. In a few other instances fertilization rates are less than for the perfect-3 predictor (Table 6.14). The higher accuracy of forecast B (Table 6.38) leads to decisions more consistent with the perfect-5 predictor.

In Table 6.39 the probability of lower climate outcomes from forecast C reduces fertilization levels in a number of instances. In contrast, the upside potential of forecast D induces quite a few higher fertilization rates. It also causes fall nitrogen application in all years when at least

Table 6.37 Champaign County Corn Decisions and Returns - Forecast A.

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	200	200	5/15	2	0	5/15	2	0	0	0	69,472
1972	0	0	5/15	2	150	5/15	2	150	0	0	58,955
1973b	200	0	5/15	2	0	5/15	2	150	0	0	60,597
1974	0	0	5/15	2	150	5/15	2	150	0	0	36,477
1975	0	0	5/15	2	150	5/15	2	150	0	0	67,013
1976	0	0	5/15	2	150	5/15	2	150	0	0	52,004
1977	150	150	5/15	2	0	5/15	2	0	0	0	63,582
1978c	0	0	5/25	4	150	5/05	2	150	0	0	51,013
1979	200	0	5/15	2	0	5/15	2	150	0	0	50,260
1980	200	200	5/15	2	0	5/15	2	0	0	0	59,800
1981c	200	200	5/15	2	0	5/25	4	0	0	0	62,250
1982	0	0	5/15	2	150	5/15	2	150	0	0	58,032
1983c	0	0	5/25	4	150	5/15	2	200	0	0	38,711
1984	0	0	5/15	2	150	5/15	2	150	0	0	49,967
1985	0	0	5/15	2	150	5/15	2	150	0	0	47,018

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

Table 6.38 Champaign County Corn Decisions and Returns - Forecast B.

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	200	200	5/15	2	0	5/15	2	0	0	0	69,472
1972	0	0	5/15	2	150	5/15	2	150	0	0	58,955
1973b	0	0	5/15	2	0	5/15	2	150	150	0	66,553
1974	0	0	5/15	2	150	5/15	2	150	0	0	36,477
1975	0	0	5/15	2	150	5/15	2	150	0	0	67,013
1976	0	0	5/15	2	200	5/15	2	200	0	0	52,652
1977	150	150	5/15	2	0	5/15	2	0	0	0	63,582
1978c	0	0	5/25	4	200	5/15	2	150	0	0	58,459
1979	200	0	5/15	2	0	5/15	2	150	0	0	50,260
1980	200	200	5/15	2	0	5/15	2	0	0	0	59,800
1981c	200	200	5/25	4	0	5/15	2	0	0	0	62,250
1982	0	0	5/15	2	150	5/15	2	150	0	0	58,032
1983c	0	0	5/25	4	150	5/15	2	200	0	0	38,711
1984	0	0	5/15	2	200	5/15	2	200	0	0	50,543
1985	0	0	5/15	2	150	5/15	2	150	0	0	47,018

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

Table 6.39 Champaign County Corn Decisions and Returns - Forecast C.

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	200	200	5/15	2	0	5/15	2	0	0	0	69,472
1972	0	0	5/15	2	100	5/15	2	100	0	0	56,617
1973b	0	0	5/15	2	0	5/15	2	150	100	0	65,936
1974	0	0	5/15	2	150	5/15	2	150	0	0	36,477
1975	0	0	5/15	2	150	5/15	2	150	0	0	67,013
1976	0	0	5/15	2	200	5/15	2	200	0	0	52,652
1977	100	100	5/15	2	0	5/15	2	0	0	0	60,581
1978c	0	0	5/25	4	150	5/15	2	150	0	0	58,053
1979	0	0	5/15	2	150	5/05	2	150	0	0	49,349
1980	150	150	5/15	2	0	5/15	2	0	0	0	58,487
1981c	150	150	5/25	4	0	5/15	2	0	0	0	60,833
1982	0	0	5/15	2	150	5/15	2	150	0	0	58,032
1983c	0	0	5/25	4	150	5/15	2	150	0	0	38,577
1984	0	0	5/15	2	200	5/15	2	200	0	0	50,543
1985	0	0	5/15	2	150	5/15	2	150	0	0	47,018

b Field time constraint not active but active in base policy in these years,
c Field time constraint prevents earlier planting in these years.

Table 6.40 Champaign County Corn Decisions and Returns - Forecast D.

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	200	200	5/15	2	0	5/15	2	0	0	0	69,472
1972	150	150	5/15	2	0	5/15	2	0	0	0	61,126
1973c	0	0	5/15	2	150	5/25	4	200	0	0	65,078
1974	0	0	5/15	2	150	5/15	2	150	0	0	36,477
1975	250	250	5/15	2	0	5/15	2	0	0	0	65,677
1976	200	200	5/15	2	0	5/15	2	0	0	0	50,217
1977	150	150	5/05	2	0	5/05	2	0	0	0	59,868
1978c	200	250	5/25	4	0	5/15	2	0	0	0	56,418
1979	200	200	5/15	2	0	5/05	2	0	0	0	47,590
1980	200	200	5/15	2	0	5/15	2	0	0	0	59,800
1981c	200	200	5/25	4	0	5/15	2	0	0	0	62,250
1982	200	200	5/05	2	0	5/05	2	0	0	0	55,173
1983b	200	200	5/15	2	0	5/15	2	0	0	0	38,280
1984	0	0	5/15	2	200	5/15	2	200	0	0	50,543
1985	0	0	5/15	2	150	5/05	2	150	0	0	46,453

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

average winter precipitation is forecast, with at least a one-third chance of better nitrogen carryover.

The affect of these accuracies on Story County corn decisions and returns is detailed in Tables 6.41 through 6.44. Note that forecast A does not change any decisions from those of the fifteen year prior. Decisions based on the 70 percent accuracy of forecast B are nearly identical to those of the perfect-3 predictor (Table 6.15) with the exception of the nitrogen application rate in 1973. Forecasts C and D are also little changed from the perfect-3 predictor, with the exception of nitrogen application being postponed until spring for a few years under forecast C.

Table 6.45 shows the value of each forecast accuracy for each location. It is interesting that forecast B for Champaign County is valued at roughly $82 more than the perfect-3 predictor when the only difference is a 30 percent chance of obtaining another outcome, evenly divided. Due to the large intervals in the discrete decision set this $82 difference is viewed as a result of the modeling process and not a material finding.

In marked contrast, forecast accuracy A induces some improved decisions and some unfortunate decisions compared to those of the fifteen year prior. The same is true of forecast accuracy C. On the other hand, forecast D entices fall fertilization so often as to be rendered valueless. Thus, the 70 percent perfect forecasts (B) of Champaign County corn climate has value roughly equal to the perfect forecast from which it is derived. The other three forecast accuracies cause a greater fluctuation in expected returns.

In Story County, forecast A has no value as no changes from the fifteen year prior are induced. Accuracies B, C and D are each expected to cause lower expected returns than the fifteen year prior, mostly due to sub-

Table 6.41 Story County Corn Decisions and Returns - Forecast A.

	Fall Nit.		Planting						Side. Nit.		Net
			Field 1			Field 2					
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	150	150	5/15	2	0	5/15	2	0	0	0	46,893
1972	150	150	5/15	2	0	5/15	2	0	0	0	45,163
1973	150	150	5/15	2	0	5/15	2	0	0	0	46,994
1974	150	150	5/15	2	0	5/15	2	0	0	0	38,294
1975	150	150	5/15	2	0	5/15	2	0	0	0	44,555
1976	150	150	5/15	2	0	5/15	2	0	0	0	38,432
1977	150	150	5/15	2	0	5/15	2	0	0	0	36,858
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	150	150	5/15	2	0	5/15	2	0	0	0	44,786
1981	150	150	5/15	2	0	5/15	2	0	0	0	41,733
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	150	150	5/15	2	0	5/15	2	0	0	0	27,969
1984	150	150	5/15	2	0	5/15	2	0	0	0	52,312
1985	150	150	5/15	2	0	5/15	2	0	0	0	27,553

Table 6.42 Story County Corn Decisions and Returns - Forecast B.

	Fall	Nit.	Planting						Side. Nit.		Net
			Field 1			Field 2					
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	150	150	5/15	2	0	5/15	2	0	0	0	46,893
1972	100	100	5/15	2	0	5/15	2	0	0	0	43,986
1973	150	150	5/15	2	0	5/15	2	0	0	0	46,994
1974	150	150	5/15	2	0	5/15	2	0	0	0	38,294
1975	150	150	5/15	2	0	5/15	2	0	0	0	44,555
1976	150	150	5/15	2	0	5/15	2	0	0	0	38,432
1977	100	100	5/15	2	0	5/15	2	0	0	0	35,893
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	150	150	5/15	2	0	5/15	2	0	0	0	44,786
1981	100	100	5/15	2	0	5/15	2	0	0	0	40,331
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	150	150	5/15	2	0	5/15	2	0	0	0	27,969
1984	150	150	5/15	2	0	5/15	2	0	0	0	52,312
1985	100	100	5/15	2	0	5/15	2	0	0	0	27,563

Table 6.43 Story County Corn Decisions and Returns-- Forecast C.

	Fall Nit.		Planting Field 1			Planting Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	0	0	5/15	2	150	5/15	2	150	0	0	44,800
1972	150	150	5/15	2	0	5/15	2	0	0	0	45,163
1973	0	0	5/15	2	150	5/15	2	150	0	0	47,905
1974	150	150	5/15	2	0	5/15	2	0	0	0	38,294
1975	150	150	5/15	2	0	5/15	2	0	0	0	44,555
1976	150	150	5/15	2	0	5/15	2	0	0	0	38,432
1977	100	100	5/15	2	0	5/15	2	0	0	0	35,893
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	150	150	5/15	2	0	5/15	2	0	0	0	44,786
1981	100	100	5/15	2	0	5/15	2	0	0	0	40,331
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	0	0	5/15	2	150	5/15	2	150	0	0	28,419
1984	0	0	5/15	2	150	5/15	2	150	0	0	50,295
1985	150	150	5/15	2	0	5/15	2	0	0	0	27,553

Table 6.44 Story County Corn Decisions and Returns - Forecast D.

	Fall Nit.		Planting Field 1			Planting Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1971	100	100	5/15	2	0	5/15	2	0	0	0	44,446
1972	100	100	5/15	2	0	5/15	2	0	0	0	43,986
1973	100	100	5/15	2	0	5/15	2	0	0	0	45,277
1974	150	150	5/15	2	0	5/15	2	0	0	0	38,294
1975	150	150	5/15	2	0	5/15	2	0	0	0	44,555
1976	150	150	5/15	2	0	5/15	2	0	0	0	38,432
1977	100	100	5/15	2	0	5/15	2	0	0	0	35,893
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	150	150	5/15	2	0	5/15	2	0	0	0	44,786
1981	100	100	5/15	2	0	5/15	2	0	0	0	40,331
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	150	150	5/15	2	0	5/15	2	0	0	0	27,969
1984	150	150	5/15	2	0	5/15	2	0	0	0	52,312
1985	100	100	5/15	2	0	5/15	2	0	0	0	27,563

Table 6.45 Value of Imperfect Predictions and Predictors of Corn Climate

	Champaign				Story			
Year	Acc'cy A	Acc'cy B	Acc'cy C	Acc'cy D	Acc'cy A	Acc'cy B	Acc'cy C	Acc'cy D
1971	3,799	3,799	3,799	3,799	0	0	-2.093	-2,447
1972	0	0	-2,338	2,171	0	-1,177	0	-1,177
1973	-3,626	2,330	1,713	855	0	0	911	-1,718
1974	0	0	0	0	0	0	0	0
1975	0	0	0	-1,336	0	0	0	0
1976	0	648	648	-1,787	0	0	0	0
1977	2,192	2,192	- 809	-1,522	0	- 965	- 965	- 965
1978	-7,040	405	0	-1,635	0	0	0	0
1979	- 891	- 891	-1,802	-3,561	0	0	0	0
1980	3,459	3,459	2,146	3,459	0	0	0	0
1981	3,574	3,574	2,156	3,574	0	-1,402	-1,402	-1,402
1982	0	0	0	-2,859	0	0	0	0
1983	134	134	0	- 297	0	0	450	0
1984	0	576	576	576	0	0	-2,017	0
1985	0	0	0	-565	0	10	0	10
mean	107	1,081	406	58	0	- 235	- 341	- 513
mean/ac.	0.33	3.38	1.27	0.18	0	- 0.74	-1.07	-1.60

optimal fertilization levels in some years. Although not all potential forecast accuracies are tested here, it is likely that imperfect corn climate forecasts in Story County have little to no value compared to the fifteen year prior, especially given the very low value of the perfect-5 predictor.

Effect of Different Prior on Climate Information Value

The preceding investigation of climate forecast values assumed the decision maker has perfect knowledge of the actual climate distribution, defined as that of the past fifteen years. Studies referenced in Chapter II indicate that decision makers may formulate expectations of stochastic events based on more recent outcomes, discounting outcomes of the past.

Ambiguity theory suggests that decision makers may only rule out certain probability distributions rather than selecting one on which to operate. This section investigates the value of climate forecasts given different priors.

The analyses thus far have assumed one risk position. With the fifteen year prior the decision maker has complete, accurate knowledge of the probability distribution of climate outcomes. Recognizing the sizeable potential impact of the priors on the value of Champaign County corn climate forecasts, this section investigates ambiguity and its effect on priors. Furthermore, alternate priors are developed to determine their effect on the value of climate forecasts.

Three Year Historical Prior

In a simple test to value climate information when prior expectations are based only on recent events, a three year historical prior is constructed. This prior is the average of the three most recent climate events (climate indices, winter precipitation and available field days), using the data in Tables 5.1 through 5.12. The optimal decisions and returns from the three year prior expectations for Champaign County and Story County corn are given in Tables 6.46 and 6.47 respectively. It is apparent that the amount and timing of nitrogen application based on this prior in Champaign County is quite different from that of either the fifteen year prior or any of the perfect predictors. There is, again, little change from the fifteen year prior in Story County.

Tables 6.48 and 6.49 show the value of the various corn climate predictors and accuracies studied thus far when compared to the returns from

Table 6.46 Champaign County Corn Decisions and Returns - 3 Year Prior.

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1974	150	150	5/15	2	0	5/15	2	0	0	0	21,427
1975	0	0	5/15	2	150	5/15	2	150	0	0	67,013
1976	0	0	5/15	2	200	5/15	2	200	0	0	52,652
1977	0	0	5/15	2	200	5/15	2	200	0	0	62,374
1978c	150	150	5/15	2	0	5/25	4	0	0	0	54,945
1979	150	150	5/15	2	0	5/15	2	0	0	0	48,397
1980	150	150	5/15	2	0	5/15	2	0	0	0	58,487
1981c	200	200	5/15	2	0	5/25	4	0	0	0	62,250
1982	200	200	5/15	2	0	5/15	2	0	0	0	56,145
1983b	200	200	5/15	2	0	5/15	2	0	0	0	38,280
1984	200	200	5/15	2	0	5/15	2	0	0	0	37,735
1985	0	0	5/15	2	150	5/15	2	150	0	0	47,018

b Field time constraint not active but active in base policy in these years.
c Field time constraint prevents earlier planting in these years.

Table 6.47 Story County Corn Decisions and Returns - 3 Year Prior.

			Planting								
	Fall Nit.		Field 1			Field 2			Side. Nit.		Net
Year	Fld 1	Fld 2	Date	Dec.	Nit.	Date	Dec.	Nit.	Fld 1	Fld 2	Returns
1974	100	100	5/15	2	0	5/15	2	0	0	0	37,507
1975	150	150	5/15	2	0	5/15	2	0	0	0	44,555
1976	150	150	5/15	2	0	5/15	2	0	0	0	38,432
1977	150	150	5/15	2	0	5/15	2	0	0	0	36,858
1978	150	150	5/15	2	0	5/15	2	0	0	0	43,525
1979	150	150	5/15	2	0	5/15	2	0	0	0	41,255
1980	100	100	5/15	2	0	5/15	2	0	0	0	43,434
1981	150	150	5/15	2	0	5/15	2	0	0	0	41,733
1982	150	150	5/15	2	0	5/15	2	0	0	0	27,166
1983	150	150	5/15	2	0	5/15	2	0	0	0	27,969
1984	150	150	5/15	2	0	5/15	2	0	0	0	52,312
1985	150	150	5/15	2	0	5/15	2	0	0	0	27,553

Table 6.48 Value of Predictions and Predictors vs. 3 Yr. Prior, Champaign County Corn

Year	Perf. 5	Perf. 3	Perf. 3L	Acc'cy A	Acc'cy B	Acc'cy C	Acc'cy D
1974	15,050	15,050	15,050	15,050	15,050	15,050	15,050
1975	0	0	0	0	0	0	-1,336
1976	0	0	0	- 648	0	0	-2,435
1977	1,208	1,208	-3,449	1,208	1,208	-1,793	-2,506
1978	3,513	1,687	3,108	-3,932	3,513	3,108	1,473
1979	2,754	2,754	2,754	1,863	1,863	952	- 807
1980	1,312	1,312	-2,146	1,312	1,312	0	1,312
1981	0	0	0	0	0	-1,418	0
1982	1,887	1,887	1,887	1,887	1,887	1,887	- 972
1983	432	297	297	432	432	297	0
1984	12,809	12,809	12,809	12,233	12,809	12,809	12,809
1985	0	0	-1,821	0	0	0	- 565
mean	3,247	3,084	2,374	1,960	3,173	2,574	1,835
mean/ac.	10.15	9.64	7.42	6.13	9.92	8.04	5.74

Table 6.49 Value of Predictions and Predictors vs. 3 Yr. Prior, Story County Corn

Year	Perf. 5	Perf. 3	Perf. 3L	Acc'cy A	Acc'cy B	Acc'cy C	Acc'cy D
1974	787	787	0	787	787	787	787
1975	0	0	-1,509	0	0	0	0
1976	0	0	- 498	0	0	0	0
1977	0	- 965	-2,103	0	- 965	- 965	- 965
1978	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0
1980	1,352	1,352	1,352	1,352	1,352	1,352	1,352
1981	0	-1,402	-1,402	0	-1,402	-1,402	-1,402
1982	0	0	0	0	0	0	0
1983	450	0	- 188	0	0	450	0
1984	0	0	0	0	0	-2,017	0
1985	10	10	-1,131	0	10	0	10
mean	217	- 18	- 457	178	- 18	- 150	- 18
mean/ac.	0.68	- 0.06	- 1.43	0.56	-0.06	-0.47	-0.06

the three year prior in each county. It is clear that in Champaign County (Table 6.48) the values of the predictions over the twelve years increase dramatically from the fifteen year prior, especially to contradict inaccurate expectations of favorable winter nitrogen carryover. Interestingly, even forecast accuracy A shows value compared to the three year prior.

However, in Story County the corn climate predictors still demonstrate little value (Table 6.49). The lower variability of the Story County climate mentioned earlier causes less radical changes in the three year prior decisions than in Champaign County. Again, the predictions whose value is consistently positive prevent suboptimal nitrogen application (1974 and 1980).

Perceptions That May Cause Traditions

It is plausible to envision midwestern grain producers who know how climate affects corn production but are not completely aware of the historical climate probability distribution. Under such circumstances and without climate forecasts, these decision makers must still make production decisions. Wise and Yotopoulos (and Yotopoulos and Wise) discussed the issue of economic rationality versus tradition in making production decisions. They addressed whether production input decisions based on tradition could be explained by the postulate of profit maximization. At issue here is discovering alternate priors on climate distribution which may lead to traditional behavior to evaluate the differences in climate forecast valuations.

The fifteen year prior nitrogen application rate in Champaign County is

150 pounds per acre. This rate, whether based on the historical climate distribution or an ambiguous notion thereof, is supported by the 1976 to 1985 Illinois average nitrogen application rate of 147 pounds per acre (Illinois Agricultural Statistics Service, 1986). However, it is plausible to envision corn growers developing prior (or traditional) nitrogen application rates of 100 or 200 pounds per acre, the decision alternatives neighboring the 150 pound decision in the corn DP model.

The purpose of the ambiguity model developed in Chapter II is to determine whether or not combinations of subjective probabilities, S(p), on the five-category climate outcomes might give rise to such base decisions or traditions. An infinite number of combinations of probabilities on climate index in each period exist. To narrow the scope of the investigation, these climate perceptions are divided into three groups. The first changes the probabilities on winter precipitation levels. The next changes the climatp probabilities in stage 7, the period of nitrogen-climate interaction in the Champaign County corn OP model. The third is to change climate probabilities in all periods except stage 7, indicating a perception of a generally favorable or unfavorable growing season but without the nitrogen-climate interaction.

An example of a traditional input decision is fall nitrogen application. Recalling equation 4.16, winter nitrogen carryover is expected to be favorable if precipitation is less than or equal to 380 mm. Table 6.50 depicts sample subjective probabilities of each category of stage 1 climate which could cause the decision maker to operate on expected winter precipitation of 380 mm or less without climate forecasts. The sample probability perceptions in Table 6.50 indicate that a prior for favorable

Table 6.50 Example Winter Precipitation Probability Distributions

		Probability Distributions a-f					
Category	Precip.	a	b	c	d	e	f
Excellent	254.0	0.220	0.000	0.200	0.250	0.200	0.150
Good	314.5	0.180	0.450	0.300	0.150	0.200	0.275
Average	415.1	0.350	0.400	0.350	0.400	0.400	0.375
Fair	487.0	0.250	0.150	0.150	0.125	0.125	0.125
Poor	521.0	0.000	0.000	0.000	0.075	0.075	0.075
Expected Value:		379.53	380.62	363.49	376.67	379.69	380.20

winter nitrogen carryover is plausible under ambiguity.

The expected value of climate in period 7 was varied from extremes of poor through excellent, and beyond these limits, holding climate in all other periods constant at their expected values. In no instance did the preferred base nitrogen level change.

Next, the climate in periods 5, 6, 8, 9 and 10 were varied. The fifteen year expected value of each of these, when inserted into the production function of Chapter IV, contributes the amount 0.4532 toward the exponent in Y - exp(CP). This same sum calculated at climate index values of fair (Table 5.1) is 0.06911. If this sum falls below 0.2939 the base nitrogen level becomes 100 pounds per acre. Given the relationship among these three sums ($0.06911<0.2939<0.4532$) it is easy to envision that there exist a multitude of θ's and β's which could cause heavier weighting of the probabilities for lower than average climate conditions. Specific calculations for differential weights in each period were not performed due to the extensive joint probabilities. Obtaining a base nitrogen level of 200 pounds per acre is not plausible under different simulated weights across all climate categories.

Forecast Valuations Under Traditional Priors

Earlier in this chapter it was noted that the value of climate information depends heavily on the prior. Further evidence of this fact is presented in Table 6.51, which contains the value of the perfect-5 and perfect-3 Champaign County corn predictions and predictors compared to the priors of a) 100 pounds of nitrogen applied in the spring, and b) 150 pounds of nitrogen applied in the fall. These analyses are performed at the original price relationships.

The values of the perfect-5 and perfect-3 predictors (mean) under the prior of 100 pounds per acre of spring applied nitrogen are quite similar to

Table 6.51 Value of Perfect-5 Predictions and Predictors vs. Ambiguous Priors. Champaign County Corn

Prior:	100 lbs. Spring Nit.			150 lbs. Fall Nit.		
Year	Net Returns	Perf. 5	Perf. 3	Net Returns	Perf. 5	Perf. 3
1971	63,109	6,363	6,363	67,883	1,589	1,589
1972	56,617	5,925	4,509	61,126	1,416	0
1973	61,647	4,906	2,576	52,390	14,163	11,833
1974	35,179	1,298	1,298	21,427	15,050	15,050
1975	64,364	2,649	2,649	63,583	3,430	3,430
1976	50,040	2,612	2,612	49,235	3,417	3,417
1977	58,924	4,658	4,658	63,582	0	0
1978	55,750	2,709	882	54,945	3,514	1,687
1979	49,204	1,947	1,947	48,397	2,754	2,754
1980	54,164	5,636	5,636	58,487	1,313	1,313
1981	56,346	5,904	5,904	60,832	1,418	1,418
1982	55,735	2,297	2,297	54,942	3,090	3,090
1983	37,171	1,540	1,406	36,335	2,376	2,242
1984	48,113	2,430	2,430	37,289	13,254	13,254
1985	45,197	1,821	1,821	29,539	17,479	17,479
Mean		3,513	3,133		5,618	5,237
Mean/ac.		10.98	9.79		17.56	16.37

their values under the three year prior (Table 6.48). However, rather than compensate for wide swings in the decisions based on the three year prior, the value of the predictions is modestly high in each year. This is likely due to the climate forecasts generally coaxing a more aggressive fertilization rate from the producer.

Under the prior of fall nitrogen application, the values of the predictors are further increased by roughly $2,000. In contrast to the 100 pound prior, the value of predictions varies widely depending upon the value of preventing fall fertilization and the value of increasing the fertilization rate above 150 pounds per acre.

Thus, the value of the Champaign County perfect-5 corn predictions and predictors are again shown to vary tremendously based upon the prior, ranging from $1,380 against the fifteen year prior to $5,618 against a prior for fall nitrogen application of the same fertilization rate. Although price relationships, accuracy and specificity may impact the value of climate forecasts to midwestern grain producers, clearly the most important determinant of information value discussed here is the prior. It is important to note that this study does not purport to identify the method by which grain producers formulate priors. Clearly this is an area for future research.

Summary

The specificity and accuracy of the perfect-5 climate forecasts were changed to discover their impact on the value of the climate predictions and predictors. Soybean climate forecasts continued to be of little value in producer decision making. Less specific or imperfect Story County corn climate forecasts induced costly decisions compared to the fifteen year prior.

In the Champaign County corn model, the perfect-3 predictor was found to have an expected value of $1,000 compared to $1,380 of the perfect-5 predictor. Aggregating the central 70 percent of the distribution to be more precise in the extreme values by means of the perfect-3L predictor caused the expected value of the predictor to drop to $241. An accuracy of 70 percent on the perfect-3 predictor was found to not impair the value of the predictor. However, accuracies less than that or which favor one end of the distribution are found to cause severe decreases in the expected value of the perfect-3 forecasts.

The value of the Champaign County corn climate forecasts was found to be affected by the assumption of the prior formed by the decision maker. Compared to the three year prior, the values of the perfect-5 and perfect-3 forecasts rose above $3,000, as did the value of the imperfect, three-category forecast with 70 percent accuracy. The formation of additional priors under the theory of ambiguity allowed further insight into the impact of the prior on the value of the forecasts. It is concluded that an empirical investigation into the formation of priors based on the use of climate information by grain producers is necessary to more firmly identify the value of climate forecasts.

Notes

1. Despite concerns regarding the validity of the Story County soybean model raised in the previous two chapters, analyses of effects from changing forecast specificity are included here. Comparisons within the Story County soybean model are thought to be less susceptible to misspecification than comparisons between it and other models. Nonetheless, these results should be interpreted with appropriate caution.

2. A base nitrogen level of 100 pounds per acre can be obtained when the period 7 climate index extends far outside the range of the data. This result is viewed as uninteresting due to the curvature imposed on the estimation of the production function in Chapter IV.

CHAPTER VII

SUMMARY AND IMPLICATIONS

Introduction

The purpose of this study is to further investigate the value of climate forecasts for midwestem grain producers. The study focuses on developing a realistic model of two corn and soybean growers, one each in Illinois and Iowa. The motivation for this work is derived from the limitations of other such models in detecting sources of climate forecast value other than for a selection of one or two inputs.

Three topics are discussed in this chapter. These are 1) the development of the models and their use, 2) the climate forecast schemes addressed in this study and their value to midwestern agriculture, and 3) the impact and implications of alternate priors reasonably formed by the decision maker using the climate forecasts.

Modeling Considerations

As in Mjelde's work, this study employed growth simulation models to generate data, econometric models to estimate production functions, dynamic programming models to ascertain optimal policies, and management simulation models to arrive at comparable net returns. The use of growth simulation models in agricultural economics research is likely to increase in the future. Their usefulness in generating large "experimental" data sets is well documented. As noted earlier, the growth models used in this study may have shortcomings which detract from their ability to capture all climate effects on crop production. These include the incorporation of only one nitrogen level in the corn growth model and the potential inability of this model to accurately describe the effects of competition between neighboring plants. If the research use of the corn growth simulation model is to increase, it is recommended that these items be addressed in future revisions.

Dynamic programming was used to discover optimal solutions consisting of a sequence of decisions through time. This technique proved to be valuable despite certain limitations. The fineness of the DP models' state and decision variable grids was constrained by the size of the decision set. It is believed that further refinements in the results of this study could be obtained by eliminating certain management decisions, particularly seed variety and plant population. In so doing the dimension of the state variables could be increased, resulting in even less of an approximation of the value of the recursive equations in the DP search for an optimal policy. Although the DP method has its shortcomings, it remains an appropriate optimization technique in studies such as this.

The management simulation models are a simple reconstruction of the DP algorithm without an optimization routine. Their use in evaluating alternate decision sets along a continuum remains preferred to the use of the optimum value of the DP recursive equation, which is a discrete approximation.

The information valuation equations used in this study provide for the possibility of a mathematical outcome less than zero. Information had been thought to have no value if its use provides returns less than the use of the prior. This study allowed the value of a prediction to be less than zero because the decision maker using the information source would not know when its use is not optimal. However, it remains intuitive that if the decision maker's expected value of using the predictions, that is the value of the predictor, is less than zero, then a decision maker would not use the information source and its value would be zero.

The details of the farms modeled in this study provided insight into the frequency with which field time constraints may be encountered, effectively reducing the size of the decision set. The use of this detail in future research is encouraged. The assumptions of multiple fields and multiple crops were fruitfully incorporated into the decision set to find additional uses of climate information.

That the inclusion of multiple soil types provided inconsequential detail in this study is not an indication that this structure should not be continued in future research. Alternate locations, and perhaps growth simulation models of other crops, may show larger differences in soil types or response to soil types. The inclusion of multiple fields and soil types, multiple crops, and a well described constraint may be more efficiently modeled over a few acres rather than an entire farm.

Value of Climate Forecasts

The value of climate forecasts in making soybean production decisions was found to be essentially nil. Although not expected at first, the lack of any management-climate interactions detected in the estimates of the soybean production functions dictated this result. Incorporating a decision alternative on soybean row spacing may have generated different results.

The Story County corn climate index was found to have lower variability than that of Champaign County. Thus, the perfect forecasts, both five- and three-category, caused little change in decisions based on the fifteen year historical prior.

In contrast, the perfect forecasts of Champaign County corn climate were shown to have an expected value of $4.31 per acre for the five-category forecast and $3.12 per acre for the three-category forecast. This range is somewhat consistent with the findings of both Sonka et al and Tice and Clouser, considering the different price relationships used in these studies. The aggregation of the central 70 percent of cumulative probability into one category in the perfect-3L forecasts reduced the predictor value to $.75 per acre.

More than half of the Champaign County corn climate predictor value is derived from taking advantage of low winter precipitation for beneficial fall fertilization. With increasing public concern about ground water quality and contamination from nitrate leaching, there is a possibility that this portion of the climate forecast value may disappear due to regulation.

The value of the perfect-5 forecasts was found to increase as the ratio between corn price and nitrogen price increased. The construction of the models resulted in an increased base fertilization rate at a price ratio of 15. This caused a downward shift in the forecast valuation at that price ratio, followed by a continued positive relationship between an increasing price ratio and increasing predictor value.

The upper limit of the value of climate forecasts in switching 320 acres of corn to soybeans and vice versa was examined at various soybean/corn price ratios. Within a price ratio range of 2.9 to 3.4, the perfect-5 Champaign County corn climate predictor was found to be able to increase net revenues between $2,168 and $4,592 by initiating a change in crop. The upper limit of the value of climate information for this purpose is nearly $14.35 per acre. However, this valuation does not consider general equilibrium effects on output price if many producers respond to climate forecasts in this manner.

Various accuracies associated with the NOAA forecast scheme were examined. At 70 percent accuracy the value of the Champaign County corn predictor is nearly identical to the value of the perfect-3 predictor. Other forecast accuracies sampled were found to have much lower value, if any.

Impact of Alternate Priors

The assumption that the decision maker formed prior expectations on climate from a fifteen year data set was relaxed to investigate the impact of alternate priors on climate forecast value. Based on the theory of ambiguity a number of different priors were developed and tested.

The value of the perfect-5, perfect-3 and perfect-3L Champaign County corn predictors increased approximately $2,000 each when valued against a prior based on the most recent three years of climate outcomes. These values of $7.42 to $10.15 per acre are substantially derived from fall fertilization decisions. Again, the 70 percent accurate 3-category predictor was found to have value similar to its perfect counterpart.

Two base decision sets derived from a range of other priors were also examined. When compared to a lower base fertilization rate, the values of the perfect predictors were again roughly $2,000 higher than the values derived from the fifteen year historical prior. Furthermore, when compared to a base decision of fall nitrogen application, the values of the perfect predictors increased by approximately $4,000, or about $12.50 per acre.

These increases in the value of the predictors are derived from alternate priors that are thought to be quite reasonable. The differences are large enough that a more accurate determination of the value of climate forecasts in midwestern agriculture requires an investigation into both agricultural decision makers' formation of climate expectations and the method by which climate information is actually incorporated into decisions. Experimental design and choice of human subjects are likely to have significant effects on the results of such studies. These studies are seen as quite useful and necessary in further investigating climate forecast issues in agriculture as well as the general application of ambiguity theory as an alternative to risk theory in economics.

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