Estimating the Value of Sequential Updating Solutions for Intrayear Crop Management

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Results of comparing updating versus nonupdating modeling assumptions call into question the use of models based on nonupdating strategies as valid representations of actual farmer actions. If farmers are sequential updaters, the results indicate that models assuming no updating are inaccurate. The degree of this inaccuracy ranges between 4% and 10% of profits for the study area. Further, the results indicate that updating appears to be important for both descriptive and prescriptive studies of farmer behavior.

Key words: sequential updating, dynamic models, certainty equivalence.

The agricultural economics profession has a strong tradition of empirical research applied to both firm level and public policy questions (Leontief). Empirical investigations focused on economic problems of the farm firm have contributed greatly to the profession's earned reputation in this regard (Jensen). These efforts have included studies to prescribe means to improve management practices (Swanson) as well as policy-oriented analyses based on predicted responses of individual producers (Quiggin).

Although agricultural economists have been creative in interjecting realism into their modeling efforts (Heady and Chandler), the role of time and the attendant possibility for the decision maker to gather information as the production horizon unfolds generally have not been depicted realistically. The frequent practice is to assume that all input decisions (implying both timing and intensity) are made at the beginning of the planning cycle, even though some of the decisions will not be implemented until well into the cycle. (See, for example, Skees and Reed; Nelson and Loehman; Richardson and Nixon.) Irrigation scheduling has been one exception to the above practice (e.g., Burt and Stauber).

Antle (1983b), however, has argued persuasively that crop production is a dynamic process and that farm decision making should be depicted as a sequential updating process. That is, inputs are applied at several points in time within a single crop year's production cycle. Moreover, the rates and timing of input applications are dependent on the levels of controllable and uncontrollable inputs realized prior to the current decision point as well as current expectations of future events. For example, the occurrence of excessive rainfall has a decided impact on the timing of field operations in row crop production. Such dependence arises because farmers are addressing a stochastic intertemporal optimization problem. In such cases, past events almost always influence the best course of action for the remainder of the production horizon. If producers do alter input decisions as information becomes available, production function parameters estimated under the assumption that updating does not occur usually are biased and inconsistent (Antle 1983b; Antle and Hatchett).

There are significant a priori reasons, therefore, for modeling the decision process for crops as a sequential process where updating is pos-

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This research was partially supported by the Texas Agricultural Experiment Station Project 6507 and NSF Grant ATM 84-13043. Texas Agricultural Experiment Station Technical Article No. 24368.

The authors acknowledge the helpful comments of Mark Cochran, Peter Lamb, Steven Hollinger, and the anonymous reviewers.

sible. Historically, computational constraints and lack of data were major impediments precluding the development of models incorporating these characteristics (Johnson). Recently, however, advances in computing technologies have greatly expanded computational possibilities available to the researcher. Concurrently, use of more sophisticated modeling techniques by agronomic scientists has made data available in forms that traditionally were not possible.

Advances in computing technologies and the availability of compatible data sources provide the opportunity for modeling crop production as a sequential process. The additional efforts needed to more realistically model the sequential process are not costless, however. Creating the extensive data bases required generally is costly in terms of time and financial resources. Therefore, it is important to evaluate the type and magnitude of gains that are obtainable from modeling a decision situation as a sequence of decisions where updating occurs. This paper specifically addresses that issue by comparing results that are obtained from a model that allows updating to occur with results for the identical situation where the modeling approach used does not utilize updating.

In this analysis, a model of corn production in east-central Illinois is used to estimate the value of updating. The model is first optimized with respect to the included decision variables assuming certainty. Then an optimal, intertemporal solution is obtained with uncertainty explicitly acknowledged in the optimization process. This latter solution uses sequential updating based on climate conditions during the production cycle, whereas the former does not. The two solutions are applied to the actual climate conditions for the 14 years 1970–83 to compare the differences in returns that would have been realized. These differences provide an estimate of the benefit of modeling the system as a sequential updating process relative to depicting the situation as a nonupdating process.

Methodology

The underlying production function for the corn production process is estimated using data synthesized from a corn-growth simulation model (Reetz) as opposed to data based on the actions of commercial producers. Using synthesized data permits consistent estimation using single equation methods thus alleviating one of Antle's concerns. Consistent estimates are obtained because within the experimental design to generate the synthetic data, information about earlier stages' production is not used to alter the current stage's input decisions. Validation of the corn-growth model for east-central Illinois is presented in Hollinger. (In general, the model generates yields closely replicating corn-yield data from Champaign County, Illinois.) Few data bases exist which are sufficiently detailed to estimate a model incorporating the timing aspects of crop production as well as several of the important decisions that must be made in growing a crop. Lack of readily available production data appropriate for use in a model that allows sequential updating probably explains why such models have not been estimated before for row crop production.[1] For the foreseeable future, estimation using synthetic data is likely the only method that will be feasible for detailed intrayear dynamic models of crop production.

It is assumed that the objective of the farmer is to maximize returns net of variable costs for one acre of corn over a single crop year.[2] This simplified problem is utilized because of the computational problems that would occur if additional crops were considered. The nonupdating (NU) solution is computed by viewing the profit maximizing problem in a certainty equivalent, open-loop (Antle 1983b) framework. That is, the certainty equivalent approach (Malinvaud) is utilized by setting all random variables equal to their means and solving the problem under deterministic assumptions.[3] It is an open-loop solution in the sense that once the level of the various inputs are determined at the beginning of the planning horizon, they are not altered regardless of what transpires before the actual application of that input. These are inflexible strategies.

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[1] See Chavas, Kliebenstein, and Crenshaw; and Rodriguez and Taylor for updating approaches to livestock management.

[2] Other criteria such as expected utility could be used to measure the benefit of updating, but the analysis is limited to net returns for simplicity.

[3] It should be noted that the concept labeled "certainty equivalence" by Malinvaud for optimizing the expected value of stochastic problems is very different from the concept of certainty equivalence in finance problems. In this latter situation, a certainty equivalent is the amount a risk-averse decision maker would accept in lieu of the return of a risky prospect (Copeland and Westin). In this study, certainty equivalence is used as Malinvaud defined it.

For example, if the decision is made to plant in early spring, then that activity is undertaken regardless of the prior climatic events. Deterministic dynamic programming (Bellman) is used to obtain the NU solution because of discontinuities in some of the decision variables. (e.g., seed type).

The above method is essentially that taken in most NU approaches to farm production. For example, the studies by Zacharias and Grube; Lazarus and Dixon; and Burt assume that a set of deterministic rules for raising crops will result in a precise yield regardless of the intrayear conditions that actually occur. Note that the NU approach is not labeled static nor is the updating (U) approach labeled dynamic. Crop production is intrinsically dynamic in the sense that there is a time lapse between input application and the realization of the final product.

For the U solution, stochastic dynamic programming (DP) is utilized to maximize expected profits over historical climate probabilities. The resulting solution gives the optimal action to take in each period as a function of the particular state of the system at the time a decision has to be made. For instance, if the decision is to be made in early spring and heavy rainfall has been experienced prior to that time, the decision may be to fertilize, whereas if there had been light rainfall the decision might be not to fertilize. In contrast, the NU solution would be based on a rule to fertilize or not regardless of the past climatic events.[4] Using Antle's (1983b) classification, the U solution is open loop with feedback, because all decisions are functions of prior decisions and the current state of the system. Further, the optimal decisions are computed under the assumption that the state of the system will be known when the decision is made.

Corn Production Model

The single-acre corn production model is explained in detail elsewhere (Mjelde; Mjelde et al. 1987; Mjelde et al. 1988); therefore, the model is only briefly described here. The price of corn is the expected price at harvest and is assumed fixed over the crop year. Further, the producer knows the input costs at each stage (costs vary by stage) at the beginning of the crop year. With these two assumptions, the value of updating is a function solely of climatic variability. Using Antle's (1983a) terminology, the value of updating examined is the value of sequentially updating information when the underlying production function is multistage and exhibits output dynamics only.

Eight stages are defined in the production cycle. These are: fall preceding planting, early spring, late spring, early summer, midsummer, late summer, early harvest, and late harvest. Relevant decision alternatives within the model are stage dependent. Decision alternatives within the model pertain to the amount and timing of nitrogen application, stage in which planting occurs, planting density, hybrid planted, and time of harvest. In each stage the decision maker can choose to do nothing. Six nitrogen application levels (0, 50, 150, 200, 225, and 267 pounds per acre) are available in every stage that permits a nitrogen application. Nitrogen can be applied either prior to planting or as sidedressing. Because of agronomic and physical considerations, sidedressing can only occur in the stage immediately after planting. In the two possible planting stages, early spring and late spring, the producer can choose between three hybrids (short, medium, and full season) and three planting densities (20,000, 24,000, and 32,000 plants per acre). The producer can harvest at early harvest and pay higher artificial drying costs but incur smaller field losses, or the producer can delay harvest to the late harvest stage. Between early and late harvest there is a potential for field drying to occur, but larger field losses may occur as well depending on climatic conditions.

Seven state variables are included in the model. At any one stage of the model, however, no more than four of the state variables can take on more than one value. Six state variables associated with determining corn yield are: (*a*) a variable which incorporates the effect of planting date, density, and hybrid; (*b*) the amount of nitrogen in pounds per acre; (*c*) a variable indicating the cumulative effect of climatic conditions on corn yield; (*d*) a combined nitrogen and climate state variable; (*e*) the corn kernel percent moisture; and (*f*) October climatic conditions which affect corn field

[4] It should be pointed out here that the certainty equivalence (CE) principle can be applied to either U or NU solutions. For example, Rodriguez and Taylor use CE to derive an updating rule and compare it with the responses for the model when solved using DP and recognizing the uncertainty explicitly. Thus, the term CE does not indicate whether or not updating is being used.

losses at late harvest. The seventh state variable indicates if the number of field operations the producer can perform during early spring, late spring, and/or early summer is restricted. These restrictions are based on unfavorable climatic conditions. If rainfall is high during early spring, field operations are limited to either planting or nitrogen application but not both. Late spring field restrictions are a function of early spring planting. If the acre was planted in early spring and high late spring rainfall occurs, no field operations can occur in late spring. For fields not planted in early spring and high late spring rainfall occurs, the field can be planted but no nitrogen can be applied. No field operations are permitted if high rainfall occurs during early summer.

Three climatic conditions, good, fair, and poor, are defined for the intervals between each decision point. Between fall and early spring the relevant climatic condition is precipitation, whereas between the remaining stages a climatic index is used (Mjelde and Hollinger). The climate index is a function of temperature, rainfall, solar radiation, and evaporation. In computing the U solution, the probability of being in a particular climatic condition is equal to the relative frequency that the climate was of a particular condition during the 1970–83 interval.

Results

The above model is used to obtain both the NU and U decision rules. To obtain the NU rule, the model is solved as described earlier assuming only fair climatic conditions can occur. Thus, the certainty equivalence decision rule provides one set of management actions for each stage. The U decision rule uses the historical probabilities of climatic conditions based on the climate observed from 1970 to 1983. The U rule gives a set of decisions corresponding to each possible state within a stage. Based on historical probabilities, this decision rule provides the producer with the ability to update and revise input intensities as different climatic conditions are experienced. Both the NU and U decision rules are then simulated using the Markov relationships in the DP model to obtain the expected net returns associated with the actual climatic conditions occurring in the years 1970–83.

Three economic scenarios are used to estimate the value of updating. These three scenarios are: a low-profit margin, a medium-profit margin, and a high-profit margin. The medium-profit margin has a corn price of $2.12 per bushel and base input costs representative of the years 1981 through 1983 (Mjelde). The low-profit margin uses a corn price of $1.50 per bushel and input costs are increased by 50% from the base level. A corn price of $2.74 per bushel and base costs decreased by 50% characterize the high-profit margin scenario. In all three scenarios, an interest rate of 10.5% for operating captial is used.

For all economic and climate scenarios, the optimal planting decisions for both the NU and U decision rules are to plant a full-season hybrid at 32,000 plants per acre during early spring. Because of agronomic and physical consideration (discussed earlier) and the early planting date, sidedressing can occur only in late spring for either the U or NU decision rules. Table 1 lists a comparison of the net returns based on the 14 years of actual weather data under both the NU and U solutions. This table also lists the management actions chosen under each profit margin scenario based on the NU and U decision rules. Because of the robustness of the planting decisions, changes in the timing and amount of applied nitrogen along with varying the harvesting stage (based on kernel percent moisture) generate the value of updating.

Besides the previously mentioned planting decisions, the NU decisions for applied nitrogen under the low-, medium-, and high-profit margins are: (*a*) for fall 0, 150, and 150 pounds per acre; (*b*) for early spring 150, 0, and 0 pounds per acre; and (*c*) for late spring 50, 50, and 50 pounds per acre. The NU harvest decisions are to harvest during the late harvest stage for the low- and medium-profit margins and harvest early under the high-profit margin scenario. As table 1 indicates, there is considerable variation between U and NU input intensities and timing for the same economic scenario.

Because of the field operation restrictions, modifications had to be made in the implementation of the NU rule for some years. Recall that if rainfall is high during early spring, only one pass (either plant or apply nitrogen) can be made through the field in this stage. This restriction is binding in the years 1973, 1976, 1978, 1981, and 1983 so the NU solution was altered in these years to do no fertilizing in the early spring for the low-profit sce-

Table 1. Comparison of the Nonupdating Solution to the Updating Solution

			Decision Rule							
	Net Returns[a] ($/acre)		Fall Nitrogen (lbs./ac)		ESp[b] Nitrogen (lbs./ac)		LSp[c] Nitrogen (lbs./ac)		Harvest stage[d]	
Year	NU	U	NU	U	NU	U	NU	U	NU	U
			Low-Profit Margin							
1970	70.96	70.17	0	0	150	150	50	0	LH	EH
1971	70.96	70.96	0	0	150	150	50	50	LH	LH
1972	70.96	85.31	0	0	150	150	50	0	LH	LH
1973	69.44	70.90	0	0	0	0	50	50	LH	EH
1974	33.35	33.35	0	0	150	150	0	0	LH	LH
1975	54.22	68.57	0	0	150	150	50	0	LH	LH
1976	84.84	84.84	0	0	0	0	50	50	LH	LH
1977	47.77	70.17	0	0	150	150	50	0	LH	EH
1978	55.27	55.27	0	0	0	0	50	50	LH	LH
1979	89.16	89.16	0	0	150	150	50	50	LH	LH
1980	54.22	70.16	0	0	150	150	50	0	LH	EH
1981	69.44	69.44	0	0	0	0	50	50	LH	LH
1982	70.96	85.31	0	0	150	150	50	0	LH	LH
1983	−24.90	−15.79	0	0	0	0	0	0	LH	EH
			Medium-Profit Margin							
1970	165.49	159.87	150	50	0	0	50	200	LH	EH
1971	165.49	163.57	150	50	0	0	50	150	LH	EH
1972	165.49	157.35	150	50	0	0	50	200	LH	LH
1973	141.71	185.94	150	50	0	0	50	200	LH	EH
1974	80.04	137.08	150	50	0	225	0	0	LH	LH
1975	141.71	131.91	150	50	0	0	50	200	LH	EH
1976	191.34	191.22	150	50	0	0	50	150	LH	LH
1977	132.55	159.87	150	50	0	0	50	200	LH	EH
1978	141.71	134.21	150	50	0	0	50	50	LH	EH
1979	191.34	189.28	150	50	0	0	50	150	LH	EH
1980	141.71	135.88	150	50	0	0	50	200	LH	EH
1981	165.49	181.41	150	50	0	0	50	50	LH	EH
1982	165.49	157.35	150	50	0	0	50	200	LH	EH
1983	52.91	76.20	150	50	0	0	0	0	LH	EH
			High-Profit Margin							
1970	291.30	287.13	150	50	0	200	50	0	EH	EH
1971	299.99	328.36	150	50	0	225	50	0	EH	EH
1972	299.07	292.88	150	50	0	225	50	0	EH	EH
1973	260.20	321.03	150	50	0	0	50	200	EH	EH
1974	183.88	289.91	150	50	0	225	0	0	EH	LH
1975	268.20	264.03	150	50	0	200	50	0	EH	EH
1976	333.54	333.49	150	50	0	0	50	150	EH	EH
1977	291.30	287.13	150	50	0	200	50	0	EH	EH
1978	268.20	293.92	150	50	0	0	50	225	EH	EH
1979	334.55	328.36	150	50	0	225	50	0	EH	EH
1980	260.20	254.02	150	50	0	225	50	0	EH	EH
1981	299.07	293.00	150	50	0	0	50	225	EH	EH
1982	299.45	295.28	150	50	0	200	50	0	EH	EH
1983	163.96	151.44	150	50	0	0	0	0	EH	EH

[a] The expected net returns in dollars/acre only deduct costs directly affected by the decision variables endogenous to the dynamic programming model. Therefore, the expected net returns are substantially higher than accounting measures of net profits.
[b] Amount of early spring applied nitrogen.
[c] Amount of late spring applied nitrogen.
[d] Stage harvested, either EH for early harvest or LH for late harvest.

nario.[5] As noted earlier, both NU and U rules always choose to plant in early spring. Given that planting occurred at early spring, no side-dressing could occur during late spring in 1974 and 1983 because of high rainfall. These restrictions mean that even though the NU decision is to apply 50 pounds of nitrogen during late spring, the NU simulation for 1974 and

[5] The planting option is selected instead of fertilization, because it would be a rare midwestern farmer who would choose to fertilize instead of plant in this situation.

Table 2. Expected Value of Decision Making Based on Updating over Nonupdating in Dollars per Acre per Year

	Profit Margin		
	Low	Medium	High
Mean U	64.85	154.37	287.14
St. Dev. U	27.19	30.55	45.51
Mean NU	58.33	145.89	275.21
St. Dev. NU	28.07	38.51	48.87
Value of Updating[a]	6.52	8.48	11.93
Percent of U[b]	10.05	5.49	4.15
P-value[c]	0.005	0.085	0.105
Stochastic Dominance[d]	FSD	SSD	None

[a] Value in $/acre/year, calculated by subtracting mean NU from mean U. The mean and standard deviations (St. Dev.) are calculated from the expected returns provided in table 1.
[b] Value of updating as a percent of the U mean net return.
[c] Marginal level of significance (*P*-value) for a one-sided paired *t*-test.
[d] Dominance of the U decision rule over the NU decision, FSD—first-order stochastic dominant, SSD—second-order stochastic dominant, and None—neither distribution dominates.

1983 did not apply sidedressing. The early spring restrictions only affect the low-profit margin scenario, whereas the late spring restrictions affect all three profit scenarios. These same field restrictions also are placed on the U decision rules. The decision rules presented in table 1 reflect these restrictions.

Table 2 presents the value of updating based on climatic conditions. This value is calculated as the difference between the expected net returns using the U decision rules and the expected net returns using the NU decisions. The expected gain in allowing updating ranges between $6.52 to $11.93 per acre per year over the various economic scenarios. Placing the expected gain from updating in percentage terms, the gain ranges between 4% and 10% (table 2). It is interesting to note that the largest dollar gain is associated with the high-profit margin scenario, but in percentage terms, the largest gain is associated with the low-profit margin scenario. Paired *t*-tests for the differences in expected net returns between the U and NU rules indicate that at an alpha level of .105 or less, the differences are significantly different from zero for a one-sided test. The greatest level of significance (*P*-value of .005) is associated with the low-profit margin.

In all economic scenarios, the standard deviation of expected returns for the U decision rule is less than the standard deviation associated with the NU decision rule (table 2), although these differences are not tested statistically.[6] Stochastic dominance procedures show that the U decision rule dominates the NU decision rule by first-order stochastic dominance under the low-profit margin scenario. The updating rule dominates the NU rule by second-order stochastic dominance under the medium-profit margin. No dominance occurs under the high-profit margin scenario. This lack of dominance can be attributed to the left-hand tail problem (Anderson). That is, the lowest expected net returns from the U rule are less than the lowest net returns from using the NU rule. If 1983 is eliminated from the set of outcomes, the U rule dominates the NU rule by second-order stochastic dominance under the high-profit margin scenario.

Implications and Conclusions

Our initial hypothesis, properly stated, is that there is no difference in net returns between sequential updating solutions (open-loop with feedback) and nonupdating (open-loop) solutions. For a low-profit margin, the results indicate that, at a marginal significance level of .005, updating is better. For the other two profit margins, the differences are less significant statistically but indicate the superiority of updating procedures. In percentage terms, the gains to updating would likely be considered important by most producers. Clearly, economic (price) conditions influence the value of updating.

The results also are important in terms of supporting two of Antle's hypotheses. First, within a multistage production process risk-neutral as well as risk-averse producers would prefer updating since updating both increases mean returns and appears to lower variability. Thus, output variability resulting from stochastic weather patterns matters even to risk-neutral producers. Second, the results show that decisions made subsequent to the intitial period by profit maximizing farmers are endogenous. Thus, consistent estimates of econometric models of production functions and derived demands on behavioral data must generally use simultaneous systems estimators. Therefore, updating appears to be important

[6] The usual *F* statistic for testing the difference of two variances is not applicable here, since the implied two samples are not random with respect to each other.

for both descriptive and prescriptive studies of farmer behavior.

The results call into question the use of models based on nonupdating strategies as valid representations of actual farmer actions. If farmers are sequential updaters, then the results presented here indicate that models assuming no updating are inaccurate. The degree of such inaccuracy for this application ranges between 4% and 10% of profits. There is also considerable variation in predicted nitrogen use among the models. These results call into question the validity of policy implications based on the nonupdating assumptions.

The generality of these results is bounded by the nature of the application. With a single crop and acre model, considerations such as abandoning acreage under extreme conditions or switching between crops under different weather conditions is not possible. Further, the results are short run assuming both input and output price certainty. Thus, the results ignore interactions between stochastic prices and stochastic yields obtained throughout the crop year. The use of a whole farm model with financial and capital acquisition activities would be a more robust test. Nonetheless, the results of this study are suggestive that efforts to model farmer behavior as a sequential updating process would be worthwhile.

[*Received September 1988; final revision received January 1989.*]

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