THE VALUE OF SOIL WATER AND WEATHER INFORMATION IN INCREASING IRRIGATION EFFICIENCY

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Introduction

Irrigation is becoming more important in Minnesota as indicated by its large share of total statewide consumption. The Water Planning Board estimated water consumption for irrigation to be about 26% of the total in 1976 and projected that the proportion would increase to 46% by 1990 (Water Resources Research Center). Increased irrigation efficiency could free additional water for other uses and/or enable greater production from irrigated agriculture. Potentially large benefits from increased irrigation efficiency could accrue to consumers as well as irrigators in the state.

Problem Statement

Irrigators plan to achieve one or more objectives with their irrigated enterprises. These include increasing expected returns and reducing the variability of returns. Irrigators are usually uncertain about the optimal timing and amount of irrigation water to apply to attain their objectives. Better information about soil water levels and future weather events could potentially reduce this uncertainty and improve the distributions of net returns from irrigated enterprises. The question asked in this study is, "How much could irrigators with possibly nonneutral risk preferences afford to pay for these kinds of information?"

Review of Previous Work

Much previous research has dealt with the question of the optimal allocation of water to irrigated enterprises. Generally this research has recognized that the timing of water applications may be as important as how much water is applied. A goal of many of these studies is to estimate an economically optimal rule for scheduling irrigation (Dudek et al.; Swaney et al., 1983a). Stochastic dynamic programming (Bras and Cordova; Burt and Stauber; Zavaleta et al.) has been used to find an optimal decision rule for water application. Advantages of this method are: 1) it is a formal optimization procedure; 2) it explicitly recognizes the role of time in the production process; and, 3) it utilizes information revealed as the season progresses. A disadvantage of the procedure is that it is computationally cumbersome, requiring that the number of state and control variables analyzed be kept small. Also, the approach requires that a utility function be specified. A

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linear utility function is usually assumed.

Researchers have used diverse methods to analyze how irrigation scheduling decisions affect the net returns distribution and the optimal choices of irrigators with nonneutral risk preferences. Palmer et al. compared several irrigation application schedules in terms of the level of net cash returns which could be reached with a given level of probability. Harris et al. used first and second degree stochastic dominance while Nielson used stochastic dominance with respect to a function to compare several possible irrigation strategies with a conventional strategy. Boggess derived a set of efficient irrigation strategies in E-V space. He also analyzed the contributions to net returns variance due to variability of output prices, yields, irrigation water prices, and irrigation water application amounts.

Several studies have analyzed the effect of better soil water (Dudek et al.; Nielson) or weather (Swaney et al., 1983b; Zavaleta et al.) information on the distribution of net returns from irrigated agriculture. However, none of these studies have estimated the value of soil water and weather information to the operator of a representative farm when the operator has nonneutral risk preferences. Such an analysis must evaluate the effect of information on net returns to the total business compared to a low information benchmark irrigation strategy.

Measuring the Value of Information

Lavalle was one of the first information theorists to devise a measure of the value of information which takes into account nonneutral risk preferences as well as the costs of information acquisition. He showed that the net value of information is the difference between the minimum the producer would accept to give up the opportunity to make the decision without information and the maximum the individual would pay to buy back the right to make the decision when the information is revealed. Byerlee and Anderson define the value of a predictor which is subject to error as an amount V_z which satisfies the following equality:[1]

$$\int\int U(\pi(\Theta,X^*(k)) - V_z)g(\Theta|k)f(k)d\Theta dk - \int\int U(\pi(\Theta,X_0^*))g(\Theta|k)f(k)d\Theta dk = 0 \quad (1)$$

where U is a von Neumann Morgenstern utility function; π, profit; Θ, a random disturbance; X, a choice variable of production; $g(\Theta|k)$, the probability of observing the random variable given the prediction k; f(k), the probability of generating the prediction k; and X_0^*, the level of the choice variable which maximizes expected utility under the prior distribution. This is subject to the constraint that expected utility be maximized for every k for which f(k) > 0 as shown in (2):

$$\partial(\int U(\pi(\Theta,X) - V_z)g(\Theta|k)d\Theta)/\partial X = 0 \quad (2)$$

If the predictor is assumed to be perfect, i.e. Θ is known for given k, the value of the predictor is the amount V_z which satisfies (3):

$$\int U(\pi(\Theta,X) - V_z')d\Theta - \int U(\pi(\Theta,X_0^*))d\Theta = 0 \quad (3)$$

subject to the constraint:

$$\partial\pi(\Theta,X)/\partial X = 0 \qquad (4)$$

for every possible Θ. These measures form a basis for estimating the value of information to irrigators.

A Conceptual Model for Estimating the Value of Information

The focus of the study is a representative crop farmer whose goal is maximization of expected utility. Utility is a function of the random variable, after-tax net income (ATNI), calculated as follows:

$$ATNI = (DY + IY)P + OFI - OC - PC - IC - YC - T \qquad (5)$$

where the variables represent dryland yields (DY), irrigated yields (IY), output prices (P), off-farm income (OFI), overhead costs (OC), production costs (PC), irrigation variable costs (IC), yield-related costs (YC), and state, federal, and social security taxes (T). OFI, OC and PC are assumed to be fixed regardless of weather or irrigation decisions; the remaining variables are random.

In this setting information about soil water or weather allows the manager to improve the timing and/or amount of water applied, thus lowering IC and/or raising IY and generating a more desirable distribution of ATNI given his risk preferences. For a given level of information, a series of irrigation strategies (choices about the timing and amount of water to apply) could be followed. A search is made of several possible strategies and that strategy chosen which maximizes the value of that level of information for a given set of risk preferences. The value of information is defined to be the amount which can be deducted from each element of an ATNI distribution corresponding to information before its expected utility no longer exceeds the expected utility from an ATNI distribution generated without information. This definition follows from that given by Byerlee and Anderson and holds for both perfect and imperfect predictors.

The value of information is quantified using stochastic dominance with respect to a function (Meyer). This approach permits comparison of ATNI distributions for a group of agents whose coefficients of absolute risk aversion lie within specified bounds over the range of outcomes evaluated. The advantage of the approach is that a specific utility function need not be assumed; rather, the analysis can be applied to as large (small) a group as desired by expanding (reducing) the absolute risk aversion interval.

Meyer's methodology is extended to provide a lower bound on the estimate of the value of information; information may be worth more than this to some but not all decisionmakers characterized by absolute risk aversion coefficients in the specified interval. The lower bound on the value of information is that amount by which each element of an ATNI distribution generated with information can be lowered before it no longer dominates an ATNI distribution generated without information. The first step in calculating the value is to select a decision rule i for scheduling irrigation and to calculate the value of information V_i using this rule. This is done by finding an amount V_i such that inequalities 6 and 7 are simultaneously satisfied.

$$\int_0^1 (G(X) - F_i(X - V_i))U'(X)dX > 0 \qquad (6)$$

$$\int_0^1 (G(X) - F_i(X - V_i - Y))U'(X)dX \leq 0 \qquad (7)$$

F_i and G are cumulative ATNI distributions generated with and without information, respectively; X represents ATNI; U is a von Neumann Morgenstern utility function; V_i is the value of information which generates F_i using decision rule i; and Y is a small positive amount. The restriction is imposed that agent's absolute risk aversion coefficients lie between specified upper and lower boundaries as shown in (8):

$$r_2(X) \geq - U''(X)/U'(X) \geq r_1(X) \qquad (8)$$

Initially V_i is set equal to zero to determine if $F_i(X)$ dominates G(X). If so, V_i is augmented by Y until inequalities 6 and 7 are satisfied. Finally a search is made of a series of possible irrigation strategies and that strategy selected which maximizes the value of information as shown in (9):

$$V_i^* = \max (V_i: i = 1, \ldots . n) \qquad (9)$$

where n is the number of strategies evaluated for a given level of information. V_i^* is a lower bound on the value of information for agents whose absolute risk aversion functions over the range of income considered lie within the specified interval. The value may be higher than this for some but not all agents in that interval.

Empirical Methodology

A model of a 640-acre representative crop farm producing 260 acres of irrigated corn and soybeans is developed as the setting for evaluating information. Farm costs are divided into variable costs which are presumed to be affected by weather or irrigation decisions (IC, YC, and T) and fixed costs (OC and PC). Variable costs include electricity, lubrication, and repair charges connected with irrigation; crop hauling, drying, and storage costs; and taxes. Taxes are determined by net income in the current year as well as the farm's economic performance in prior years.[2]

Distributions of output prices are generated based on five-year price projections made by the Minnesota Agricultural Extension Service in 1983 as well as historical real price variability observed from 1958 through 1982. The distributions are used to generate random prices for each year of weather data following a procedure developed by King which takes into consideration correlations among crop prices.

A crop growth and yield model developed by Hill and Hanks is used to estimate yields as a function of random weather, irrigation applications, crop variety, and soil characteristics. Parameters of the corn and soybean yield response functions were statistically estimated using weather, irrigation and yield data from several Minnesota sites.[3] Random weather variability for analyzing the irrigation strategies is provided by 11 years of weather data from the Lamberton Experiment Station in southwest Minnesota. Each year is assumed to be an independent, equally likely outcome. Estimates of dryland crop yields for each year of weather are taken from the Lamberton Experiment Station and southwest Minnesota farm data.

Three levels of soil water information are analyzed. They are: 1. soil water information provided by the Checkbook method (Werner); 2. intermediate soil water information (knowledge of actual soil water levels plus or minus a uniformly distributed error not to exceed 10% of plant available soil water holding capacity); and, 3. perfect soil water information. The three levels of weather information compared are: 1. no information on either potential crop transpiration demand[4] (Tp) or rainfall for the future; 2. knowledge of Tp for the next three days; and, 3. perfect weather information, i.e., knowledge of Tp and rainfall for three days. A total of six combinations of soil and weather information are evaluated. They are:

1. Soil water information provided by the Checkbook, no weather information
2. Intermediate soil water, no weather information
3. Perfect soil water, no weather information
4. Intermediate soil water, future Tp information
5. Perfect soil water, future Tp information
6. Perfect soil water, perfect weather information

These information levels are compared with a benchmark strategy which can be used by an irrigator possessing very little soil water or weather information.[5]

Several irrigation strategies are evaluated for each information level. The strategy concerns the soil water depletion level at which to trigger irrigation.[6] Several depletions at five percentage point intervals are searched and the trigger level which maximizes the value of information for a given set of risk preferences determined. The optimal trigger level is generally not the same for corn and soybeans; rather, the expected profit maximizing triggers and other triggers above and below profit maximization are determined independently for each crop.

The value of information is analyzed for six absolute risk aversion intervals. The placement of the intervals is based on a study by Wilson of Minnesota swine producers' risk attitudes. He found that 69% of the producers with identifiable risk attitudes fell within an interval of -.0002 to +.0003. This interval is subdivided into three smaller intervals: -.0002 to -.00005, -.00005 to .0001, and .0001 to .0003. Additionally, a very risk averse interval, .0003 to .0015, a very risk seeking interval, -.001 to -.0002, and risk neutrality are included.

Results

Table 1 shows after-tax per irrigated acre values of different levels of information for varying degrees of risk aversion. The trigger level used to initiate irrigation for corn/soybeans is also given in parentheses. The results are shown for the average acre producing one half corn and one half soybeans. The results show that more information generally has greater value. However, perfect information does not seem to offer a high potential payoff relative to what can be gained with existing information systems. The results for the risk neutral case are discussed first.

Risk Neutrality and the Value of Information

The expected return to perfect soil water and weather information is $5 per acre. The Checkbook information system yields an expected return of $2.78 per acre or about 55% of the return to perfect information. Perfect soil water information alone generates an expected return of $4.14 or 83% of the expected return to perfect information. These results are interesting because they show that a large share of the return to perfect information can be gained by soil water information alone. Soil water information is site specific and, therefore, has the characteristics of a private good. Its economic return is maximized at the point where its expected marginal return to the producer equals its marginal cost. Weather information, by contrast, displays characteristics of a public good (Henderson and Quandt, pp. 298-302) meaning that its use by one producer does not preclude its use by others. Therefore, its marginal social return exceeds its marginal private return and, if left to individual producers, too little of such information would be produced. The finding that soil water information gives a large fraction of the total gain from information implies that, given better information-producing technology, profit maximizing irrigators will have the incentive to exploit the optimal amount of a large part of such information.

The finding that weather information generates a small fraction of potential returns to perfect information does not necessarily imply that research on ways to produce better weather information would have a low rate of return. The return might be high if the per acre cost of producing better weather information were low and it could be applied to many acres.

Risk Preferences and the Value of Information

The results in Table 1 show the value of information to be sensitive to risk preference. For example, the most risk seeking producer could afford to pay $.50 per acre for information provided by the Checkbook. This amount increases to $2.78 per acre for risk neutrality and $24.00 per acre for the most risk averse producer. The other information levels show similarly large increases in value as absolute risk aversion rises.

Table 1. After-Tax Per Irrigated Acre Values[a] of Selected Information Scenarios and Optimal Irrigation Strategies[b] by Degree of Risk Aversion

Information Level	Coefficient of Absolute Risk Aversion Interval: Risk Seeking -.001 to -.0002	-.0002 to -.00005	-.00005 to .0001	Risk Neutral 0.0 to 0.0	.0001 to .0003	Risk Averse .0003 to .0015
Checkbook	0.50 (20/40)	0.60 (20/40)	0.80 (15/35)	2.78 (15/35)	16.70 (10/20)	24.00 (10/20)
Int. Soil no Weath.	1.20 (35/40)	1.40 (30/35)	1.50 (30/35)	3.23 (30/35)	17.80 (15/20)	25.70 (15/20)
Perf. Soil no Weath.	1.80 (30/45)	2.00 (30/45)	2.30 (30/45)	4.14 (30/45)	18.10 (20/35)	25.70 (15/30)
Int. Soil Fut. Tp	2.20 (50/55)	2.40 (50/55)	2.30 (50/55)	4.23 (50/55)	18.20 (35/40)	25.70 (35/40)
Perf. Soil Fut. Tp	2.30 (45/60)	2.50 (45/60)	2.80 (45/60)	4.82 (45/60)	19.00 (40/55)	26.30 (40/55)
Perf. Soil and Weath.	2.60 (45/60)	2.80 (45/60)	3.10 (45/60)	5.00 (45/60)	18.90 (35/50)	26.40 (35/50)

[a] Table entries on upper line refer to values of information (1983 dollars) per irrigated acre for the absolute risk aversion coefficient interval specified above the column. The value of an information level is the amount by which each element of its after-tax net income distribution can be lowered before it no longer dominates the distribution derived with the benchmark strategy.

[b] Figures in parentheses denote the percentage depletion level at which irrigation is initiated for corn/soybeans. Where no weather information is available, the trigger level refers to soil water depletion. Where some future weather information is assumed, the trigger level refers to the depletion level to which soil water levels would fall over the next three days given the available weather information and given that no irrigation occurs.

Higher levels of risk aversion are generally marked by lower depletion levels for triggering irrigation. Thus when risk aversion increases, irrigation tends to be started sooner and more water applied. For example, using Checkbook information the optimal triggers are 20 and 40% for corn and soybeans, respectively, for the most risk seeking interval. The optimal triggers fall to 15 and 35% for risk neutrality and to 10 and 20% for the more risk averse intervals.

The large increases in information value for the most risk averse producers reflect the fact that information has a high payoff in the lowest income year, 1976. In 1976, a very dry year, irrigated corn yields decline substantially when the benchmark strategy is used. Irrigation based on better information is able to prevent these yield losses. When 1976 is eliminated, the value of information to the most risk averse producers is reduced considerably. However, the value of information still increases with risk aversion.

The Effects of Taxes on the Value of Information

The value of information is calculated on a before-tax basis to show the effects of taxes. These results presented in Table 2 show that the before-tax values generally exceed the after-tax values as would be expected. For example, the value of Checkbook information to the risk neutral individual is $3.83 before taxes and $2.78 after taxes; for the most risk averse interval the before and after-tax values are $28.90 and $24.00, respectively. With some exceptions taxes reduce the value of information to risk seekers relatively more (although not necessarily absolutely more) than to risk averters. This follows from the fact that risk seekers place more weight on the best outcomes, which are taxed more heavily than low or median outcomes.

Analysis presented elsewhere (Bosch) shows that the primary effect of lowering the producer's equity position[7] on the value of information is through the tax effects. When the equity position is lowered, tax obligations fall and the differences between before and after-tax values of information decline.

Summary and Conclusions

Increasing irrigation efficiency could benefit producers and consumers by saving water for other uses and/or leading to more output from irrigation water. Irrigation efficiency can be increased by providing the irrigator with better soil water and weather information. Six combinations of soil water and weather information are compared with a benchmark strategy, which is based on little information.

Results show that, while better information has a higher value, the additional payoff to higher levels of information is relatively low. For example, perfect soil water information alone provides 83% of the return to perfect soil water and weather information. Information value rises as risk aversion increases as does the expected amount of water applied. Thus, the return to better information producing technology may be underestimated if risk preferences are disregarded and many irrigators

Table 2. Before-Tax Per Irrigated Acre Values[a] of Selected Information Scenarios and Optimal Irrigation Strategies[b] by Degree of Risk Aversion

	Coefficient of Absolute Risk Aversion Interval					
	Risk Seeking			Risk Neutral		Risk Averse
Information Level	-.001 to -.0002	-.0002 to -.00005	-.00005 to .0001	0.0 to 0.0	.0001 to .0003	.0003 to .0015
Checkbook	0.30 (20/40)	1.10 (20/40)	1.10 (15/35)	3.83 (15/35)	23.40 (10/20)	28.90 (10/20)
Int. Soil no Weath.	1.30 (35/40)	2.40 (30/35)	1.90 (30/35)	4.68 (30/35)	25.00 (15/20)	31.00 (15/20)
Perf. Soil no Weath.	2.80 (30/45)	3.60 (30/45)	3.20 (30/45)	6.05 (30/45)	25.30 (20/35)	31.00 (15/30)
Int. Soil Fut. Tp	3.20 (50/55)	4.30 (50/55)	3.20 (50/55)	6.19 (50/55)	25.50 (35/40)	31.10 (35/40)
Perf. Soil Fut. Tp	3.70 (50/65)	4.50 (45/60)	3.80 (45/60)	7.01 (45/60)	26.40 (40/55)	31.80 (40/55)
Perf. Soil and Weath.	4.20 (50/65)	5.00 (45/60)	4.60 (45/60)	7.35 (45/60)	26.40 (35/50)	31.80 (35/50)

[a] Table entries on upper line refer to values of information (1983 dollars) per irrigated acre for the absolute risk aversion coefficient interval specified above the column. The value of an information level is the amount by which each element of its before-tax net income distribution can be lowered before it no longer dominates the distribution derived with the benchmark strategy.

[b] Figures in parentheses denote the percentage depletion level at which irrigation is initiated for corn/soybeans. Where no weather information is available, the trigger level refers to soil water depletion. Where some future weather information is assumed, the trigger level refers to the depletion level to which soil water levels would fall over the next three days given the available weather information and given that no irrigation occurs.

are risk averse. However, the results are sensitive to inclusion of the lowest income year, a year in which information increases yields and net returns substantially. Taxes tend to reduce the value of information, but the percentage reduction is greater for risk seekers than risk averters.

Additional research is being done on the value of information. The research is being expanded by considering several random output prices for each year of weather data. This may reduce the sensitivity of the information value and the optimal irrigation strategy to deletion of the best or worst outcome.

Footnotes

[1] The notation of Byerlee and Anderson has been altered.

[2] A more detailed description of the methodology including the procedure for randomly generating a series of prior years of tax history for the farm is presented in Bosch.

[3] More details concerning the estimation procedure and the resulting equations can be found in Bosch (1984).

[4] Potential crop transpiration is the amount of water the plant could give off to the atmosphere on any given day if soil water is not limiting.

[5] The benchmark strategy was devised in consultation with extension irrigation engineers and researchers familiar with irrigation practices in Minnesota.

[6] All irrigation applications consisted of .75 of an inch of effective water.

[7] The results presented here are derived assuming the producer's debt-to-asset ratio to be 20% for depreciable assets and 15% for real estate.

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