Risk Management Strategies in Humid Production Regions: A Comparison of Supplemental Irrigation and Crop Insurance

Timothy J. Dalton, Gregory A. Porter, and Noah G. Winslow

Recent federal agricultural programs have accelerated the devolution of enterprise risk management responsibility from the state to individual producers. Using a biophysical simulation model, the risk management benefits of federal crop insurance and supplemental irrigation are derived and compared to uninsured rainfed crop production in an expected utility framework. Federal crop insurance programs are inefficient at reducing producer exposure to weather-related production risk in humid regions, and the risk management benefits from supplemental irrigation are found to be scale and technology dependent. Environmental policies that regulate resource development will increase the investment cost of irrigation alternatives and reduce economic feasibility.

Key Words: insurance, risk, supplemental irrigation

Recent federal agricultural programs have accelerated the devolution of enterprise risk management responsibility from the state to individual producers. This devolution was initiated over 20 years ago after long-standing periods of crop relief in the 1970s where payments were made to producers without declaration of a disaster area. Multiple-peril crop insurance was established in the 1930s, but was used only on a limited basis through the 1970s. Major reforms in the 1990s have dramatically increased participation.

The 1996 Farm Bill initiated the devolution of crop risk management from federal relief programs to greater emphasis on producer risk management. Nonetheless, in 1998 and 1999, emergency market- and crop-loss assistance totaled $15 billion. The Agricultural Risk Protection Act of 2000 further stimulated interest in the integrated management of crop production risk through education, new crop insurance programs, higher premium subsidies, and additional market loss assistance monies.

By contrast, under the Farm Security and Rural Investment Act of 2002, cost-share funding for ground and surface water conservation projects, under the Environmental Quality Incentives Program (EQIP), has accelerated interest in using supplemental irrigation to manage production risk. Many producers are comparing the cost of multiple-peril crop insurance with the investment and annual cost of risk-reducing production strategies. These comparisons are often limited by incomplete information on the costs and benefits of technologies, such as supplemental irrigation, that mitigate downside production risk.

Total irrigated cropland in the United States covers just 16% of the nation's land base, yet it produces over 49% of crop sales [U.S. Department of Agriculture/Economic Research Service (USDA/ERS), 2003b]. Over the past three decades, acreage under irrigation has increased at an average rate of a half million acres per year, and there is increasing

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reliance on irrigation in the humid areas of the Atlantic, North Central, and Delta states (USDA/ERS, 2003a). Twenty-two percent of irrigated cropland is located in the East, accounting for about 5.5% of the total regional cropland base, as opposed to the remaining 78% in the West, or 18% of western cropland[1] (USDA/ERS, 2003a).

Over the period 1987–97, new acreage placed under supplemental irrigation in the humid East increased by 38%, while in the arid West, acreage increased by about 14%. In 1998, irrigation investment in the East amounted to nearly $420 million. At the same time, 2.4 million acres of irrigated land were retired from production. Numerous crops are produced under irrigation; however, irrigated acreage as a share of total acreage is greatest for rice (100%), orchard crops (80%), Irish potatoes (79%), and vegetables (70%) (USDA, 1999).

As the lack of information on revenue, investment, and operating costs can deter producer investment in new production technologies, or the wrong investment decision can increase the probability of insolvency, one objective of this study is to derive the risk management benefits of supplemental irrigation in humid areas using an expected utility framework. Imperfect substitutability between capital and variable production inputs and discontinuous fixed cost functions make analytical derivation of profit-maximizing irrigation technology decisions intractable. An ex ante bioeconomic simulation approach is used to derive the distribution of expected net revenues to alternative irrigation technologies and insurance programs used in humid production conditions. Based upon these results, an expected utility framework is applied to derive certainty equivalents for each decision alternative. These are compared against nonirrigated uninsured and insured production to determine whether supplemental irrigation and multiple-peril crop insurance are effective tools to manage production risk. This approach is generalizable to commodities produced in humid conditions where irrigation investment is under consideration and crop insurance programs exist.

An application is made to eastern potato production where only a fraction of potato acreage is irrigated. According to the *1997 Census of Agriculture*, Maine ranks sixth in the nation in terms of potato acreage, but eleventh in terms of fall potato acreage under irrigation among all major producing states. Less than 12% of acreage is irrigated in Maine as compared to Western states where nearly 100% is irrigated. In the humid production regions of the Midwest, 92% of potato acreage is irrigated in Wisconsin, 75% in Michigan, and 52% in Minnesota. As a result, the value of production per acre in Maine is among the lowest in the nation [USDA/National Agricultural Statistics Service (NASS), 1999].

The remainder of the paper is organized as follows. A review of the irrigation investment literature is provided, followed by a description of the approach and methods used to derive the risk management benefits of supplemental irrigation. Next, the risk management benefits of supplemental irrigation are derived for a risk-averse producer, and these results are compared to nonirrigated uninsured and insured production. Policy simulation scenarios are then examined. The final section presents a summary of the findings and concluding remarks.

Literature Review

Variability in crop yield due to stochastic weather events can impact the profitability and riskiness of agricultural production in humid regions. In humid temperate regions, irrigation investment analysis is conditional upon usage, especially when used to supplement rainfall. In these regions, the range of use for supplemental irrigation can be from "not at all" in wet years, to "frequently" in dry years, resulting in highly variable economic costs and returns from year to year. Epperson, Hook, and Mustafa (1993) found irrigation is needed in many of the humid regions of the United States because uneven rainfall creates uncertain net returns and lower overall profits. Irrigation has also been identified as an important risk management strategy (Vandeveer, Paxton, and Lavergne, 1989; Boggess and Ritchies, 1988). However, much of this research was conducted prior to federal policy reform designed to shift responsibility for crop risk management to producers.

Since demand for irrigation is dependent upon deficient natural rainfall, annual operating costs are conditional upon usage. Caswell and Zilberman (1985) determined that cost savings have a significant impact upon the choice of, and tendency to adopt, new irrigation technologies. While cost savings play an important role in triggering the adoption of more efficient irrigation systems for the

[1] "East" or eastern states include those found in the Northeast, Appalachian, Southeast, North Central, and Delta farm production regions. The "West" or western states include all other states.

grower already versed in technology usage, cost and revenue uncertainty can act as a significant impediment for the uninitiated grower. This source of uncertainty can be a critical factor in delaying a producer's decision to adopt new technology (Purvis et al., 1995; Engel and Hyde, 2003). Boggess and Amerling (1983) simulated irrigation investment decisions in humid areas and found that weather pattern variability had a significant effect upon costs, revenue, and investment viability.

Annual irrigation costs are uncertain due to stochastic weather events and the demand for irrigation water. This source of uncertainty largely determines the annual cost of irrigation. Using an economic-engineering simulation modeling approach, limited information on investment costs and the technical requirements were identified by Uva et al. (2000) as key impediments to producer adoption in the case of zero runoff subirrigation systems. Bernardo (1988) also employed a simulation approach to evaluate the impact of spatial variability of irrigation application. He found that non-uniform water application increased water usage and the cost of irrigation. As noted by Schneekloth et al. (1995), one of the most important problems facing decision makers is the ordering of alternative investment decisions with different risky outcomes to determine which option reduces operator exposure to production risk.

Approach and Methodology

A risk-averse producer's decision to adopt irrigation technology is modeled in an expected utility framework. Assume the crop production process can be described at site i for time period t by a technology set, $v_{it} \in T(z_{it}, w_{it})$, where **v** is a vector of variable inputs, **z** is a vector of fixed inputs, and w is a set of location-specific weather characteristics. Assuming the production function is single-valued and nonjoint in inputs, the stochastic production function can be written as $y_{it} = f(v_{it}, z_{it}, w_{it}, \varepsilon_{it})$, and the expected profit function as $E(\pi_{it}) = E(\pi_{it}(p_t, \mathbf{r}_t, z_{it}, w_{it}, \varepsilon_{it}))$, where p_t is expected output price, $\mathbf{r}_t$ is a vector of expected input prices, and ε_{it} denotes nondeterministic production events.

By comparison, the irrigated crop production technology set, $v_{it}^h \in T(z_{it}, (w_{it} + h_{it}), z_{it}^h)$, is augmented with crop water (h) applied through supplemental irrigation capital (z_{it}^h). When irrigation water is applied only to supplement seasonal moisture deficiencies, the variable technology set expands to include variable irrigation inputs without affecting biochemical crop inputs.[2] The production function, under irrigation, is written as

$$y_{it}^h = f\big(v_{it}^h, z_{it}, (w_{it} + h_{it}), z_{it}^h, \varepsilon_{it}\big),$$

and the profit function as

$$E(\pi_{it}^h) = E\big(\pi_{it}^h\big(p_t, \mathbf{r}_t, z_{it}, (w_{it} + h_{it}), z_{it}^h, \varepsilon_{it}\big)\big).$$

These two alternatives are compared against an unirrigated scenario where yield loss is indemnified by crop insurance, I. In the realized alternative where multiple-peril crop insurance is purchased, π_{it}^I, the indemnity payment will equal the maximum of either the loss, net of the premium and deductible, or zero when the insured loss threshold is not exceeded.

Assuming a risk-averse producer, whose behavior can be modeled by a von Neumann-Morgenstern utility function that is increasing, strictly concave, and differentiable, the risk management decision reduces to a comparison of the expected utility of profits under irrigated production against nonirrigated uninsured and insured:

$$(1)\qquad \iiint EU(\pi_{it})\, dp\, dr\, dw \;\lesseqgtr\; \iiint EU(\pi_{it}^h)\, dp\, dr\, dw \;\lesseqgtr\; \iiint EU(\pi_{it}^I)\, dp\, dr\, dw.$$

A risk management alternative dominates only when a strict inequality holds. In order to compare the dominance of irrigated, insured, or uninsured production, the expected utility of each alternative is converted to its monetary certainty equivalent. Assuming a negative exponential utility function, the certainty equivalent (CE) is determined as $CE = \ln(EU(\pi))/c$, where $c > 0$ represents the coefficient of absolute risk aversion. Under the assumption of constant absolute risk aversion, a positive difference between the certainty equivalents of the gambles may be interpreted as the insurance benefit to, while a negative difference is a premium of, the decision alternative (Hyde et al., 1999).

The expected net benefits to irrigation are modeled in a stochastic simulation where the net returns from rainfed and irrigated production are derived. Irrigation water demand is conditional upon a rainfall deficit, and the decision to irrigate is

[2] Under a supplemental irrigation strategy, the only crop production input that might be affected by irrigation will be harvest labor if yields are greater than nonirrigated.

determined by summing the difference between the agronomic recommendation of one inch per week and the observed rainfall amounts until a cumulative one-inch deficit is achieved. Historical data on daily rainfall amounts are available from the National Climatic Data Center (NCDC) for several thousand locations in the United States (National Oceanic and Atmospheric Administration/NCDC, 2002). Once the deficit occurs, the field is irrigated so that one inch of water reaches the crop. The amount of water applied is dependent upon the application efficiencies of the irrigation alternatives. The benefit to supplemental irrigation is derived by comparing production with and without irrigation. To do so, potato yield response functions to water are estimated and described in the appendix.

Since irrigation is not an essential tool for crop production in humid regions, growers consider adopting irrigation only partially over their land base. Consequently, technology alternatives were analyzed at 50, 100, and 200 acres to derive the scale minimum at which irrigation begins to mitigate production risk. Three alterative irrigation systems were evaluated to determine the tradeoffs between initial investment and annual operating expense.

Application of this model is made to an important Northeastern agricultural commodity that is generally grown under rainfed production conditions. Less than 12% of potato acreage in Maine is grown under irrigation. Only 7.5% of growers rely on full irrigation for production, and 9.6% rely partially on irrigation. Irrigation and crop insurance alternatives are evaluated for a typical Maine potato farm with 300 acres in potatoes and another 300 acres in rotation crops.

Economic Costs of Supplemental Irrigation

Three irrigation systems were considered that span the tradeoffs between low to high initial investment and low to high variable expense per operation. The handline moveable gun system was popular in the past because of its low initial investment cost. Low-pressure center pivot systems require nearly twice the initial investment per acre of coverage. The advantage of the center pivots lies in their ease of, and less-costly, operation when compared to the handline gun systems. Average labor costs per acre for center pivots are less than one-fifth of the handline system, and power expense is more than 20% less (Dalton, Porter, and Winslow, 2003). An intermediate alternative lies with hose reel systems. These systems, along with the handlines, have additional advantages in that they are more flexible and can be moved between fields and locations with greater ease than fixed, or even towable, center pivots.

Capital investment costs were determined through interviews with irrigation engineers and equipment dealers familiar with irrigation in humid regions. For each system and field size, investment costs were calculated over five cost centers: (*a*) permitting and water source development, (*b*) the pumping system, (*c*) the mainline and lateral delivery system, (*d*) the water application system, and (*e*) miscellaneous and system-specific costs. Total investment costs were calculated based upon prevailing market conditions in the fall of 2001 and the first quarter of 2002[3] (table 1). Overall, table 1 illustrates the dichotomy between "flexible" lower cost systems and more capital-intensive systems. By comparison, the center pivot irrigation systems are between 46% and 68% more expensive than the lowest cost moveable large gun systems.

Total investment costs are converted to annual ownership costs using annual equivalent worth analysis. This approach converts total investment cost to an annual basis using amortization and other time-value-of-money techniques to derive an economic value for fixed equipment with a lifespan of more than one year (see, e.g., Park, 2001; Collier and Glagola, 1998):

$$(2) \qquad z_{it}^{h} = \sum_{j=1}^{J} \left(r_j^h \frac{i(1+k)^n}{(1+k)^n - 1} - SV_j \frac{k}{(1+k)^n - 1} + r_j^h a \right).$$

As presented in equation (2), equipment item j is amortized based on the original cost (r_j^h), expected life (n), salvage value (SV), and the real investment interest rate (k). The life cycle of a particular piece of equipment was estimated by the irrigation engineers and equipment dealers who were interviewed for this study. In addition to depreciation and interest charges, replacement insurance, a, is added to annual ownership cost.

[3] The total investment cost for each system is calculated based upon representative conditions facing growers in this region: a water source that is approximately one-half mile from the fields, an elevation change of 125 feet, and a flat fee of $15,000 for permitting and engineering studies on water withdrawal. All remaining components are sized to ensure that one inch of water per week may be applied to the fields.

Table 1. Total Investment Costs for Irrigation System Establishment in 2002 ($/field)

	Field Size		
Irrigation System	50 Acres	100 Acres	200 Acres
Handline Large Gun	56,568	71,772	95,409
Hose Reel Traveler	59,077	75,828	117,677
Center Pivot	94,933	106,229	151,186

Source: Interviews with irrigation engineers and equipment dealers, fall 2001 and first quarter 2002.

In comparison to the fixed annual cost of supplemental irrigation, annual operating cost is contingent upon the demand for irrigation water. Annual variable costs associated with irrigation include labor to prepare the system for its first usage, the labor required per irrigation set, fuel to operate the pumping system, maintenance and upkeep charges, and financing charges linked to operating expenses accrued during the season. These costs are based upon observed input price levels for 2001.

Labor costs accumulate from two different sources: initial setup and end-of-season takedown of the system, and variable labor usage per irrigation. A $9.40 hourly wage rate is applied in the calculations. This wage rate is based upon the 2001 Adverse Effect Wage Rate of $8.17 and inflated by 15% to account for meals and other benefits entitled to immigrant workers (USDA, 2002a, b). Alternatively, it can be seen as the benefits premium (Social Security, Unemployment Compensation, Workers Compensation Insurance) attached to attract local workers from nonagricultural employment alternatives.

Power costs are calculated by determining the number of hours the pumping unit operates to apply the required amount of irrigation water. Total pumping time is inflated by 10% to account for flushing, system testing, and mistakes. Total pumping time is then multiplied by hourly fuel-consumption rates of the different diesel motors and then by the price of diesel fuel ($1.25/gallon). Average fuel costs decline as acreage increases, reflecting economies of size in motor pumping. Maintenance and upkeep charges are calculated for these systems as a fixed coefficient of initial purchase price. Maintenance and upkeep coefficients are derived from interviews with equipment dealers and referenced against Patterson, King, and Smathers (1996a, b).

The final component of the operating budget is an interest charge on working capital used during the production season. The interest charge represents the financial cost of a short-term operating loan or the opportunity cost of producer capital used to pay for these expenses before potato receipts are received. A short-run nominal operating credit interest rate of 8% is assumed and converted to a real rate using the procedure described in the following section.

Stochastic Biological and Economic Factors

Uncertainty in cost estimation arises from not knowing with precision how much irrigation water will be required during the season and the economic cost of the factors of production. Since usage is not known with certainty, the underlying cost and return functions also are not known with certainty. Water applied through irrigation is a function of the inputs used in the irrigation process, given the stock of capital, and the technical requirements of the irrigation technology alternative. The decision to invest in the technology is made without perfect foresight of the bioeconomic conditions governing the return to the investment. In order to capture these uncertainties, several input parameters in the net return calculations (summarized in table 2) are modeled as stochastic using probability distributions derived form observed data.

Based upon weather data between 1959 and 2002 from the center of Maine's potato production region, total seasonal rainfall from June 1 to August 31 is normally distributed with a mean of 11.8 inches, a standard deviation of 2.4 inches, an observed minimum of 3.5 inches, and maximum in excess of 14 inches (National Oceanic and Atmospheric Administration/NCDC, 2002). Therefore, irrigation requirements range from zero inches to 10.5 inches per season, but average 2.2 inches per year.

In addition to yield and irrigation cost uncertainty, the annual price of potatoes is stochastic. Nominal potato prices were obtained from the USDA's National Agricultural Statistics Service for the period 1980–2001. All nominal data were converted to real data using the producer price index deflator for "Irish Potatoes for Consumer Use" (series WPS 011304) obtained from the U.S. Department of Labor, Bureau of Labor Statistics (2002). The real price series was detrended using an exponential regression to isolate systematic price effects from the stochastic component of the price series captured in the residuals. The residuals from the regression were then analyzed using the BestFit add-in to Excel to determine the probability distribution that fit the observed residuals. The empirical

Table 2. Input and Derived Output Distributions and Distributional Moments for Uncertain Parameters

Description	Distribution	Minimum	Mean	Maximum	Standard Deviation	Skewness	Kurtosis
Input Parameters:							
June, July & August rainfall (inches)	normal	3.51	11.82	20.02	2.41	0	2.97
US#1 potato price residual ($/cwt)	logistic	!0.636	0	0.642	0.149	0	3.99
Nominal investment interest rate (%)	uniform	8.10	9.00	9.90	0.50	—	—
Inflation rate (%)	extreme	0.60	3.10	5.40	0.80	0.365	2.56
Diesel price ($/gallon)	uniform	1.12	1.25	1.37	0.07	—	—
Wage rate ($/hour)	uniform	8.46	9.40	10.34	0.54	—	—
Derived Output Parameters:							
Yield response (irrigated-nonirrigated yield):							
< Quadratic (cwt/acre)	Gumbel	0	33	153	27	0.768	3.32
< Logistic (cwt/acre)	Gumbel	0	36	157	29	0.696	3.07
< Mitscherlich (cwt/acre)	Gumbel	0	33	152	27	0.748	3.29
US#1 potato price ($/cwt)	log-logistic	3.23	6.17	11.60	0.93	0.690	4.94
Real investment interest rate (%)	beta	2.90	5.70	8.60	1.00	!0.090	2.59

distribution of the residuals, representing the stochastic component of the price distribution, was then added to the deterministic forecasted output price for 2002.

The nominal interest rate on the investment was derived through interviews with lending agencies active in servicing capital loans. This rate was varied uniformly around its expected value (from 8.1% to 9.9%) to account for heterogenous credit ratings. It was converted to a stochastic real interest rate by netting out the annual inflation rate drawn from the distribution of annual interest rates from the period 1980 to 2001. In addition to these economic factors, the fuel price and wage rate were uniformly varied around their expected values by 10%.

The profitability of each alternative was simulated using Monte Carlo techniques by simultaneously sampling with replacement from each of the distributions representing the stochastic factors using the @Risk software program. Ten simulation models (three acreage levels, three irrigation systems, plus the nonirrigated uninsured) were run for each of the three functional forms representing the yield response relationship of potato yield to water.[4] In addition to irrigated versus nonirrigated production, multiple-peril crop insurance policies were simulated and indemnities calculated. A standard policy was calculated without options from the policy calculator provided by the USDA's Risk Management Agency (2003). The catastrophic coverage level was simulated in addition to buy-up coverage from 50% to 75% coverage levels. Each model was simulated 2,000 times, which was the maximum number of iterations required for convergence under a 1% criterion. Once the probability distributions were calculated, the expected utility of each alternative was derived at three levels of aversion to risk using the negative exponential utility function to represent risk-averse behavior.

Results

Because demand for irrigation water is dependent upon rainfall, the resulting cost estimates will have a stochastic component mirroring the derived demand for irrigation water. While total cost increases with the amount of irrigation water applied, average cost per acre-inch of water declines. When this budget is added into the nonirrigated crop production budget, total annual cost of production will be greater under irrigation in all states of nature. Insured crop production is costlier than nonirrigated due to the coverage premium.

Holding product price constant, revenue will vary according to total annual rainfall since production is nondecreasing in water. Revenue variability is decreased under irrigated production, but the expected impact will not always be greater than nonirrigated production, i.e., in years when supplemental irrigation is not required. As a result, the net

[4] The simulation models and empirical data are available from the authors upon request.

Table 3. Net Return Statistics for Three Crop Response Model Specifications ($/acre)

	Quadratic			Logistic			Mitscherlich		
Description	Expected Value	Coeff. of Variation	Median	Expected Value	Coeff. of Variation	Median	Expected Value	Coeff. of Variation	Median
Nonirrigated Uninsured	736	0.47	719	735	0.48	717	734	0.47	716
50 Acres:									
Handline Gun	748	0.45	728	748	0.45	727	746	0.45	725
Hose Reel Traveler	744	0.45	725	745	0.46	724	742	0.45	720
Center Pivot	736	0.46	715	737	0.46	716	734	0.46	724
100 Acres:									
Handline Gun	773	0.42	749	775	0.43	753	772	0.43	747
Hose Reel Traveler	769	0.43	746	771	0.43	747	768	0.43	743
Center Pivot	769	0.43	744	771	0.43	747	767	0.43	743
200 Acres:									
Handline Gun	827	0.39	806	833	0.39	811	826	0.39	804
Hose Reel Traveler	813	0.40	792	818	0.39	797	811	0.40	790
Center Pivot	825	0.39	803	830	0.39	809	823	0.39	801
Nonirrigated with Crop Insurance Coverage:									
50%	701	0.49	684	700	0.50	682	699	0.49	680
55%	694	0.50	677	693	0.51	675	692	0.50	673
60%	690	0.50	673	689	0.51	671	688	0.50	670
65%	680	0.51	662	678	0.52	660	677	0.51	659
70%	676	0.51	658	675	0.52	656	674	0.51	655
75%	666	0.51	647	666	0.52	645	664	0.51	644

return to irrigation may not always be positive, especially in years when limited water is applied to the crop. Revenue under insured nonirrigated production will exceed uninsured nonirrigated only when yield does not exceed the insured coverage level and an indemnity payment greater than the cost of the insurance is made. Summary statistics of the yield response, output price, and real interest rate derived from the simulations are presented in the lower portion of table 2.

The net return distributions were analyzed against the null hypothesis that they were drawn from a normal distribution using a Kolmogorov-Smirnoff test with a Lilliefors significance test correction. In all cases, the null hypothesis was rejected at a critical value of α # 0.01. The resulting nonnormally distributed net return estimates were positively skewed, which could lead a risk-averse producer to overestimate the probability of a high return outcome. In addition, a pairwise comparison of the distributions determined that all were significantly different from one another at a critical value of α # 0.01 using a Wilcoxon test. Given these conditions, the expected value, coefficient of variation, and median net returns per acre were calculated for the technology alternatives over the three field sizes. In addition, the return to insured and uninsured nonirrigated production was calculated.

Descriptive statistics for these net return distributions are presented in table 3. Under all three specifications of the yield response function, the median net return to irrigated production equaled or exceeded nonirrigated production and the coefficient of variation of net returns was reduced. By contrast, the median net return under insured production was lower than uninsured nonirrigated production. Even at high levels of buy-up insurance coverage, the coefficient of variation of net returns increased.

Certainty Equivalent Estimation

Based upon the calculated expected utility of the risk management strategy, the certainty equivalent was derived for a producer with constant absolute risk aversion. The certainty equivalent of the nonirrigated uninsured scenario was subtracted from each of the irrigation alternatives and the crop insurance coverage levels. A positive (negative) difference indicates that the irrigation alternative or insurance mitigates (increases) production risk. As individuals' tolerance for risk varies, three columns of certainty equivalents are presented. These represent increasing aversion to risk as represented by the partial coefficient of relative risk aversion. The three values representing producer's preference may be qualitatively

Table 4. Annual Certainty Equivalent Differences for Three Crop Response Models and Three Levels of Relative Risk Aversion ($/acre)

	Quadratic			Logistic			Mitscherlich		
Description	0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0	2.0
50 Acres:									
Handline Gun	14	16	20	16	18	22	14	16	20
Hose Reel Traveler	10	12	16	12	14	18	10	12	15
Center Pivot	2	5	9	4	7	11	2	4	8
100 Acres:									
Handline Gun	41	45	53	45	49	57	41	45	52
Hose Reel Traveler	37	41	48	41	45	52	37	40	47
Center Pivot	37	41	48	40	45	53	37	40	48
200 Acres:									
Handline Gun	97	102	113	104	110	122	97	102	112
Hose Reel Traveler	82	88	98	89	95	106	82	87	97
Center Pivot	95	100	111	102	108	120	95	100	110
Crop Insurance Coverage:									
50%	!35	!35	!35	!35	!35	!35	!37	!37	!36
55%	!42	!42	!42	!42	!42	!42	!44	!44	!43
60%	!46	!46	!45	!46	!46	!45	!48	!47	!46
65%	!56	!56	!55	!56	!56	!55	!58	!58	!56
70%	!60	!59	!57	!60	!59	!57	!62	!61	!59
75%	!68	!67	!64	!68	!67	!63	!71	!69	!66

Notes: All results are significantly greater than zero at the 99% confidence level. Relative risk aversion levels of 0.5, 1.0, and 2.0 correspond to "slightly," "normally," and "rather" risk averse, respectively (Hardaker, Huirne, and Anderson, 1997).

described as "slightly risk averse" (0.5), "somewhat or normally averse" (1.0), and "rather risk averse" (2.0) (Hardaker, Huirne, and Anderson, 1997). The estimated certainty equivalent differences are presented in table 4.

Nonirrigated uninsured production dominates the catastrophic coverage levels and all buy-up levels of insured production irrespective of the level of risk aversion. Buy-up coverage at the 75% level paid an indemnity payment in only 2.6% of the simulations; at the 70% level an indemnity was paid in 1.1% of the years. Current premium subsidies and production guarantee levels are inefficient at reducing producer exposure to rainfall risk.

As more acreage is placed under irrigation, the difference between certainty equivalents increases. While the certainty equivalents differ, depending on functional specification of the response function, the risk premium for nonirrigated production is equal to, or greater than, irrigated production. Under no situation, however, does irrigation first-order stochastically dominate nonirrigated production. Irrigation does dominate, under the second-order stochastic dominance criterion, for producers who are "normally" averse to risk. Functional specification of the yield response estimates does not affect any of the dominance results. When fixed water development costs are limited to $15,000, the break-even scale minimum is approximately 50 acres (or slightly less), or 1/6 of the land base of the operation. A "slightly" risk averse producer is indifferent to nonirrigated production and irrigation using the center pivot systems, but would prefer irrigation with the other two systems over nonirrigated production. As risk aversion increases, all irrigation systems provide risk management benefits.

The most capital-intensive system—the center pivot—reduces average profitability at 50 acres. While functional specification did affect the absolute value of the certainty equivalents, technology rankings were insensitive to potential specification bias. Overall, low-investment-cost handline systems dominated all other technologies. Only under extreme situations of risk aversion would a capital-intensive system dominate technology selection. Limited adoption of irrigation, despite these results, is largely linked to geographic constraints and limited acreage of large continuous tracts where large-acreage systems are most cost- and risk-effective. Secondly, investment analysis information on smaller-scale irrigation systems has been limited and the results more ambiguous, especially when evaluated in a risk-neutral framework.

Table 5. Annual Certainty Equivalent Differences Under Increased Water Development Costs for Three Levels of Relative Risk Aversion, Based on Results for the Quadratic Functional Form ($/acre)

	Total Water Source Development Cost					
	$65,000			$115,000		
Description	0.5	1.0	2.0	0.5	1.0	2.0
50 Acres:						
Handline Gun	2*	4*	9*	!9	!7	!3
Hose Reel Traveler	!1	0	4*	!13	!11	!7
Center Pivot	!9	!7	!3	!20	!18	!14
100 Acres:						
Handline Gun	30*	34*	41*	18*	22*	30*
Hose Reel Traveler	26*	29*	36*	14*	18*	25*
Center Pivot	25*	29*	37*	14*	18*	25*
200 Acres:						
Handline Gun	85*	91*	101*	74*	79*	90*
Hose Reel Traveler	71*	76*	86*	60*	65*	75*
Center Pivot	83*	89*	100*	72*	78*	88*

Notes: An asterisk (*) denotes significantly greater than zero at $p = 0.01$. Relative risk aversion levels of 0.5, 1.0, and 2.0 correspond to "slightly," "normally," and "rather" risk averse, respectively (Hardaker, Huirne, and Anderson, 1997).

Resource Development Costs and EQIP

One of the greatest sources of uncertainty facing potato producers is the cost of developing a water source to meet irrigation demands. The presented scenario is representative of historical water source development costs, but largely underestimates current and future costs. Most growers who currently irrigate are located in areas where direct water withdrawal from rivers and streams is possible. This technique is currently in disfavor by state and federal authorities with jurisdiction over permitting and will be highly regulated in the near future [Maine Agricultural Water Management Advisory Committee (MAWMAC), 2003].

In the future, all irrigators will be required to withdraw water from impoundments, wells, or ponds, rather than directly from streams or rivers, and thereby increase engineering and construction cost. In addition to higher expected construction cost, these ponds will require state permitting and environmental impact assessment. Currently, environmental best practices call for the development of upland ponds rather than lowland ponds located streamside. Both alternatives signal significantly higher development costs. Upland ponds are extremely expensive because sandy soil conditions, along this point in the topography, are conducive to infiltration. For these ponds to retain water, an artificial impermeable layer must be constructed. On the other hand, if a pond is created in a lowland area, the producer may be required to mitigate any damage to the surrounding lowland or wetland ecology. As such, most experts believe the $15,000 previously spent to develop a water source will only cover basic environmental engineering and permitting application costs (MAWMAC, 2003). Construction, nontrivial engineering, and environmental impact assessment plus wetland mitigation will increase initial investment and annual ownership expense.

The cost of water source development is a key factor in the decision to invest in irrigation or not. The certainty equivalent analysis is reevaluated from the case above by increasing the cost of water development from the base level of $15,000 by $50,000 and $100,000, to $65,000 and $115,000. This is a substantial increase in the cost of irrigation, but one realistic of recent grower experience. Revised certainty equivalent difference estimates are presented in table 5.

As resource development costs increase, the certainty equivalents of the irrigation alternatives decrease as a result of the lower expected value of the gambles. Two robust results emerge from the sensitivity analysis. Increasing water development cost does not affect the risk efficiency of any of the technology options at the 200-acre scale. While the value of the certainty equivalent does decline, irrigation still increases net returns per acre and decreases the standard deviation.

On the other hand, the decision to adopt limited irrigation, at 50 acres, is sensitive to initial water development cost. When costs increase to $65,000, only the low-investment cost system is risk efficient for a "slightly" risk-averse producer at the 50-acre scale, and the choice set expands to the medium investment system for "highly" averse producers.[5] At $115,000 of start-up cost, nonirrigated production dominates all irrigation technologies at 50 acres of coverage. Increasing water development costs has an important impact on the scale level of a producer's decision to adopt irrigation technology. The results indicate that as these costs increase, the scale at which these technologies must be adopted to have a beneficial risk management effect increases.

Holding all other constraints constant, current environmental policy to regulate water development will increase the breakeven scale at which irrigation becomes risk efficient. These regulations may achieve conservation objectives if they discourage adoption of irrigation technology. On the other hand, current policy could increase demand for water resources by increasing the breakeven minimum scale where irrigation begins to mitigate production risk. Under the 2002 Farm Bill, the Ground and Surface Water Conservation Program under the Environmental Quality Incentives Program (EQIP) may be used to achieve Pareto improving solutions through cost-sharing water development investment. Under the second scenario, where resource development costs are estimated at $65,000, a 77% cost share would reduce the scale minimum to 50 acres; an 87% cost share, under the high-cost scenario, would achieve the same result. Under the EQIP program, cost shares are available to 75% of a project's total cost and up to 90% for beginning farmers. Maximum payments cannot exceed $450,000. The EQIP program provides an opportunity to encourage best management water use practices and reduce producer exposure to production risk by reducing the risk-efficient scale of irrigation investment and counteracting increased resource development costs.

Conclusions

This study has used a bioeconomic simulation approach to derive the risk management benefits of supplemental irrigation and crop insurance over nonirrigated uninsured production. Irrigation investment is occurring much more rapidly in the humid production regions of the East than in the arid West. The model presented here is flexible and adaptable for analyzing investment decisions in other areas and commodities where supplemental irrigation is being considered to manage production risk. Commodity producers in humid production regions have limited options for reducing weather-related risk. Multiple-peril crop insurance policies rarely issue indemnity payments due to high deductibles and low coverage levels. Current federal risk management education strategies designed to increase participation in crop insurance programs in underserved states will have little impact unless policies are redesigned to cover perils indigenous to those states.

On the other hand, supplemental irrigation has often been described as an "insurance policy" for producers in humid regions. This research has shown that scale and technology choice are key components in correctly defining the risk-reduction benefits of supplemental irrigation, and as such, the "insurance policy" effects are only partially accurate. This occurs for several reasons related to investment costs and the relative factor share of capital to variable expense, the underlying shape of the cost curve describing total average cost per acre, the response of potatoes to water, and the probability that a moisture deficit will occur.

Three distinct technology alternatives were evaluated representing the dichotomy between capital-intensive and variable cost-intensive systems. Since supplemental irrigation is frequently not required, or is required in limited amounts, the fixed portion of their total annual cost dominates any revenue effects from supplemental irrigation. Only in rare circumstances, when five or more applications of water are required (10% or less of the time), do capital-intensive systems (center pivots) become less costly than their counterparts (the handline large gun or traveler systems).

Due to the high investment costs associated with irrigation, size economies are an important component of feasibility. Many of the lumpy costs associated with a system—for example, permitting charges or engines—are fixed or increase disproportionately with increasing acreage. Average fixed costs decrease with field size. Increasing the scale of technology adoption increases the risk management benefits of irrigation. Current state and federal farm policy is promoting water development cost sharing. These policies will have an important role

[5] Under the logistic representation of the yield response function, only the handline and traveler systems were risk efficient.

in inducing the adoption of systems for farmers who are seeking to adopt smaller scale systems. In contrast, farmers who do not qualify for cost shares will be required to adopt irrigation on a larger scale in order to generate risk management benefits. These cost-share programs, designed to achieve environmental objectives, will be an important tool to devolve risk management from federal relief to producers, and may have a greater impact than targeted crop insurance education programs.

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Appendix: Alternative Crop Response Models of Potato Yield Response to Water

Potato yield response functions were estimated from eight years of irrigation experiments on the Maine Agricultural and Forestry Experiment Station's Aroostook Farm in Presque Isle, Maine. Aroostook Farm is located in the heart of Maine's potato producing region. Summary statistics for the yield response data are presented in table A1.

Three alternative potato yield response models were formulated to determine whether yield response is sensitive to functional specification. Historically, polynomial functions have been used to represent crop response to nutrients and water. The quadratic function is represented as:

$$\text{(A1)} \qquad Y_i = \alpha + \beta_1 W_i + \beta_2 W_i^2 + \varepsilon_i,$$

where Y_i is potato yield (cwt/acre), W_i is crop water (inches) over the three-month period of June through August, and the β_j are estimated parameters. If $\beta_1 > 0$ and $\beta_2 < 0$, the function is concave for all values of W_i. The quadratic function is limited in its ability to represent all three stages of a yield response function. It can represent decreasing marginal productivity to water, the majority of stage II, and it can also represent stage III of the production function if water is over-applied. Its linear formulation has led to its historical popularity in the literature (Frank, Beattie, and Embleton, 1990).

By contrast, the logistic function can represent both increasing and decreasing marginal productivity of water (stages I and II) through its characteristic *S*-shaped form when $\alpha > 0$ and $\beta_1 < 0$ [equation (A2)]. The function asymptotically approaches a maximal yield, α, as W_i approaches infinity, thereby imposing a plateau growth assumption. Due to this restriction, the function cannot represent the third stage of the production function. The function has the advantage of representing both convex and concave stages of the production function which captures increasing marginal productivity impacts of water application during extreme drought conditions:

$$\text{(A2)} \qquad Y_i = \frac{\alpha}{1 + \exp(\beta_1 + \beta_2 W_i)} + \varepsilon_i.$$

A third alternative that accommodates plateau growth is the Mitscherlich function. The function is expressed as:

$$\text{(A3)} \qquad Y_i = \alpha\big(1 - \exp(\beta_1 + \beta_2 W_i)\big) + \varepsilon_i,$$

where maximal attainable yield is represented by α. The Mitscherlich function imposes decreasing marginal productivity of water when $\beta_1 < 0$, and does not allow for decreasing yield through over-watering. It has intuitive appeal because of its plateau water-yield relationship consistent with von Liebig's law of plant growth.

To each of these three models is added a binary dummy variable, φ_i. This binary variable takes on a value of 1 for experiments during 1993 and a value of 0 otherwise. During 1993, an atypical outbreak of pink rot affected yield performance of the trials. This binary variable acts to control for this outbreak and shift the α variables in equations (A1)–(A3). In addition, an additive random error term $\varepsilon_i \sim \text{nid}(0, \sigma)$, is appended to the equations to complete the regression models.

Table A1. Summary Statistics of Potato Yield Response to Water, 1992–2000

Description	Mean	Variance	Minimum	Maximum
Total yield (cwt/acre)	343.6	3,141.5	194	432
US#1 yield (cwt/acre)	296.2	3,413.8	140	377
June, July & August water (inches)	12.4	9.2	3.2	18.7

Each of these three models is estimated for potato yield. Since model (A1) is linear in parameters, it is estimated using ordinary least squares, while (A2) and (A3) are estimated using nonlinear least squares estimation due to their nonlinear formulation. Regression results for yield response to water are presented in table A2. All regressions were statistically significant at a p-value ≤ 0.001, as were the parameter estimates underscoring the nonlinearity of the response models. The dummy variable for 1993 was significant in all equations, indicating pink rot significantly affected yields during that year.

To evaluate the functional specification of the yield response function, three nonnested hypothesis tests were conducted. The Cox *N*-test, the Davidson and McKinnon *J*-test, and the *P*-test were conducted by holding each of the three functional forms as the maintained null hypothesis and testing the alterative formulations. In addition to the individual test of each null against an alterative specification, a joint *P*-test of the null against both alternatives was conducted. Results of these tests are presented in table A3. The functional form in the first column of table A3 is the maintained null hypothesis. It is tested against the two alternative specifications. The joint *P*-test against both alternative specifications is located in the last column of the table.

One difficulty of testing alternative specifications against a maintained hypothesis is that the results can be contradictory, or inconclusive, depending upon which specification is maintained as the null. In panel A of table A3, the null hypothesis of the quadratic functional form is not rejected when compared against the Mitscherlich, but the null hypothesis of the Mitscherlich function is rejected in favor of the quadratic in the first column of panel C. These results suggest the quadratic specification is preferred over the Mitscherlich. By contrast, the logistic function is rejected against both alternatives in panel B. However, both alternative specifications are rejected in favor of the logistic (the logistic column of panels A and C), thereby producing contradictory and inconclusive results. As a result, ex post functional form tests prove inconclusive on which function best represents the data.

Graphical representation of the yield response is presented in figure A1. As observed from this figure, the three functional forms largely coincide over the support of the data. In general, the three functional forms predict similar yields at 14 inches of water. Below that level, the yield response will be the greatest for the logistic function and the quadratic. Visual inspection reveals that the greatest divergence in yield response results will occur during years with limited rainfall. Consequently, the potential cost of misspecification is investigated by comparing risk management results for the three alternative yield response specifications.

Table A2. Alternative Models of Potato Yield Response to Water (N = 63)

Model	α	β_1	β_2	φ	Adjusted R^2	Log of Likelihood Function	R^2 Between Observed and Predicted
Quadratic	88.65**	28.16*	!0.56***	!22.67**	0.71**	!302.5	0.72
	(2.24)	(4.11)	(!1.94)	(!2.06)			
Logistic	463.58*	1.03*	!0.18**	!33.79**		!301.4	0.73
	(12.13)	(5.34)	(!4.42)	(!2.44)			
Mitscherlich	585.33*	!0.16**	!0.06*	!22.38**		!302.8	0.72
	(4.21)	(!2.56)	(!1.85)	(!2.35)			

Notes: Asterisks *, **, and *** denote statistical significance at the 99%, 95%, and 90% levels, respectively. Values in parentheses are *t*-ratios.

Table A3. Nonnested Hypothesis Tests on Functional Form Specification

	Alternative Hypothesis			
Null Hypothesis	Quadratic	Logistic	Mitscherlich	Joint *P*-Test
A. Quadratic		!3.16*	1.53	9.73*
		3.14*	!1.80	
		!3.14*	1.80	
B. Logistic	2.50*		2.65*	13.36*
	0.60		7.30*	
	3.65*		1.93**	
C. Mitscherlich	!2.95*	!11.10*		11.32*
	!1.98**	3.09*		
	!2.65*	!3.19*		

Notes: Asterisks * and ** denote statistical significance at a *p*-value of 0.01 and 0.05, respectively. The three statistics in each grouping are the Cox *N*-test, the Davidson and McKinnon *J*-test, and the *P*-test.

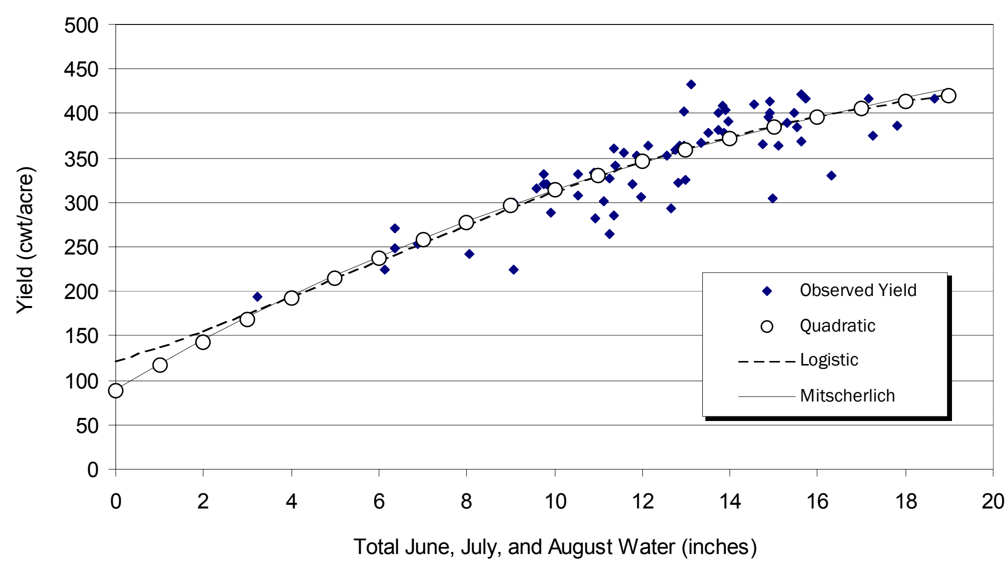

Figure A1. Predicted yield (cwt/acre) of three alternative models of potato yield response to water