



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Weather Insurance to Protect Specialty Crops against Costs of Irrigation in Drought Years

By

Edouard K. Mafoua

Post-Doctoral Associate
Food Policy Institute
Rutgers, The State University of New Jersey
New Brunswick, NJ 08901
Phone: (732) 932-1966, ext.3113
E-mail: mafoua@AESOP.RUTGERS.EDU

and

Calum G. Turvey

Professor
Department of Agricultural, Food and Resource Economics
Rutgers, The State University of New Jersey
New Brunswick, NJ 08901
Phone: (732) 932-9155, ext.224
E-mail: turvey@AESOP.RUTGERS.EDU

***Paper prepared for presentation at the American Agricultural Economics Association
Annual Meeting, Montreal, Canada, July 27-30, 2003***

Copyright 2003 by Edouard K. Mafoua and Calum G. Turvey. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

Abstract

The purpose of this research is to develop a rainfall insurance product to insure irrigation costs applied to NAP crops, and to compare the efficacy of this insurance on a dollar basis relative to conventional crop insurance. An economic model is developed that illustrates the relationship between rainfall, crop yields, costs of irrigation and profits.

I. Introduction

Despite the best efforts of the U.S. Risk Management Agency, there remain many specialty crops in the U.S. under Noninsured Crop Disaster Assistance Programs (NAP) with insurance policies that do not represent the true nature of risks. Given their economic significance, it is surprising that so little attention has been provided to specialty crops in terms of risk management.

Weather insurance, a new approach to risk management, is based on transparent, easily observed weather at a specific site and provides firms with the ability to manage volumetric risk that derives from seasonal deviations from longer-term climatic norms. Although several studies have explored the issue of rainfall insurance in agriculture, Bardsley, Abey, and Davenport (1984), Gautman, Hazell, and Alderman (1994), Patrick (1988), Quiggen (1986), Sakurai and Reardon (1997), Turvey (2000, 2001), there are no known studies dealing with weather insurance to protect specialty crops against costs of irrigation in drought years.

Water is used to manage growth in many vegetable, fruit, and cereal crops. Drought years create significant difficulty for these crops as production costs soar from the use of irrigation pumps, fuel and labor. In many instances, state governments have had to sign Emergency Disaster Relief bills to cover unprotected crops. From an economic point of view, a loss due to a shortfall in yields is not different on a dollar for dollar basis than a loss due to increased costs of irrigation. Since the purpose of irrigation is to achieve the maximum yield potential of a normal rainfall year, the main consequence of rainfall or drought risk is in the cost of irrigation. However, in the same way that a wheat producer on non-irrigated land would suffer greater loss due to yield shortfalls in a year of drought, the

wheat farmer on irrigated land mitigates the yield loss but incurs an additional cost of irrigation.

The purpose of this research is to develop a rainfall insurance product to insure the costs of irrigation applied to NAP crops. To this end, the next sections provide the theoretical framework of modeling the irrigation cost insurance. This is followed by a description of the cross sectional data and estimation procedure. The fourth section presents the empirical results and the last section discusses the usefulness of this new product and provides a conclusion to the research.

2. Conceptual Framework

In this section, we develop an economic model of irrigation cost insurance to illustrate the relationship between a weather variable (rainfall = ω), crop yields $y(\omega)$, costs of irrigation $c(\omega)$ and profits $\pi(\omega)$. We consider multiple states of nature but essentially we simplify the process by defining a maximum potential yield that occurs when weather is favorable or good. That is

$$Y_{max} = y(\omega_{good}) \quad (1)$$

Since the maximum potential yield acts as an absorbing barrier for all of the weather stated as good the marginal value product of irrigation above the threshold ω_{good} is zero. When rainfall falls below ω_{good} the marginal productivity of rainfall increases but at an increasing rate. The production function for output is thus

$$Y = \text{MIN}(y_{max}, f(\omega)) \quad (2)$$

where $y_{max} = f(\omega_{good}) > f(\omega)$. Therefore for $\omega < \omega_{good}$

$$\frac{\partial}{\partial \omega} f(\omega) > 0 \quad (3)$$

and

$$(4) \quad \frac{\partial^2}{\partial \omega^2} f(\omega) < 0$$

which simply states that as water to the plants increases, plant growth increases but at an increasing rate.

We now consider the cost of irrigation C. The cost function is given by

$$(5) \quad C = \text{MAX}(0, c(\omega))$$

If $\omega > \omega_{\text{good}}$ there is no need to irrigate so the cost is zero. Otherwise the cost increases as ω decreases. That is

$$(6) \quad \frac{\partial}{\partial \omega} c(\omega) < 0$$

and

$$(7) \quad \frac{\partial^2}{\partial \omega^2} c(\omega) > 0$$

The profit function can now be described in terms of the rainfall variable, output, and irrigation costs as

$$(8) \quad \pi = P \text{MIN}(y_{\text{max}}, f(\omega)) - \text{MAX}(0, c(\omega))$$

Where P is the per unit price of the commodity. From (8) it can be seen that profits are given as $P y_{\text{max}}$ if rainfall is adequate and $P f(\omega) - c(\omega)$ if rainfall is inadequate. Furthermore, assuming that rainfall is inadequate, marginal profits obey

$$(9) \quad \pi_{\omega} = P \left(\frac{\partial}{\partial \omega} y(\omega) \right) - \left(\frac{\partial}{\partial \omega} c(\omega) \right) > 0$$

Marginal profits are positive since the first term is increasing in ω , while the second term is decreasing in ω . In terms of risk and risk mitigation the result states that as rainfall decreases output will fall. In order to increase output, rainfall, in the form of costly irrigation, must be applied. Therefore in years of drought the dual effects of decreased yields and increased irrigation costs result in significant economic losses. Even if irrigation increases yields to its maximum level, the cost of irrigation remains as an uncertain cost to the producers.

The essential economic elements to this problem from drought are the potential yield loss from lack of rainfall and the costs of mitigation. Since the latter is a risk reduction response to the former then the insurable quantity is not necessarily yield per se, but the cost of irrigation. The yield loss component is economically significant only if irrigation is too costly or not available. To see how an indemnity structure works we can calculate the loss in profit from the following identity:

$$Z = P(y_{max} - y(\omega)) + c(\omega) \quad (10)$$

Equation (10) says that the indemnity is equal to the yield shortfall time price plus the cost of irrigation. If irrigation is not available then $c(\omega)=0$ and the indemnity is given by the yield shortfall only. This is $P(y_{max} - y(\omega))$ and this is similar to conventional crop insurance. If irrigation is available then irrigation may increase yields so that the term $P(y_{max} - y(\omega)) \rightarrow 0$, but in this case $c(\omega) > 0$ and this becomes the insurable event.

The notion of rainfall insurance is now clear. Since both $y(\omega)$ and $c(\omega)$ are functions of rainfall, and rainfall is a random variable, then yield and cost uncertainty can be established by defining the probability distribution functions for y and c . Let $g(\omega)$ be the probability distribution function for rainfall, then the indemnity function for profits is calculated by taking the expected deviation from the maximum potential yield, or some other target, by defining the amount of rainfall that produces the maximum potential yield. In the current discussion this has been denoted by the variable ω_{good} . Hence the indemnity function is given by

$$Indemnity = \int_0^{\omega_{good}} (P(y_{max} - y(\omega)) + c(\omega)) g(\omega) d\omega \quad (11)$$

Equation (11) is for the general case. When irrigation is not available then the insurance form is similar to conventional crop insurance (CI) by writing (11) as

$$CI = \int_0^{\omega_{good}} P(y_{max} - y(\omega)) g(\omega) d\omega \quad (12)$$

The final insurance product under consideration is irrigation insurance. Since y_{\max} is an absorbing barrier for $\omega > \omega_{\text{good}}$ then an irrigation strategy that provides irrigation in the amount of $\omega_{\text{good}} - \omega$ will have $y = y_{\max}$ so that the first term in the general indemnity function (11) goes to zero leaving the irrigation cost recovery (ICR) indemnity function

$$(13) \quad ICR = \int_0^{\omega_{\text{good}}} c(\omega) g(\omega) d\omega$$

Notice that the irrigation cost recovery indemnity is simply the expected value of irrigation costs below the amount that produces the output y_{\max} .

Next, we consider possibilities for implementing a rainfall based insurance scheme. In all of the above equations the stochastic variable of interest is in fact rainfall. To estimate the above indemnity schedules, we require information that is not readily available for underwriting purposes. Furthermore, yields or revenues or irrigation costs are not readily observable without incurring substantial costs. In contrast, rainfall is readily observable since most jurisdictions record rainfall, at least at the county level. A rainfall based insurance policy can also be designed to mimic or approximate the indemnities for crop, revenue, or irrigation cost insurance by using the following rainfall indemnity schedule (RIS);

$$(14) \quad RIS = z \int_0^{\omega_{\text{good}}} (\omega_{\text{good}} - \omega) g(\omega) d\omega$$

In (14) the integral component gives the probability weighted expectation of rainfall below the good amount (e.g. millimeters of rain per month). The value of z represents the economic value of rainfall per millimeter or inch. In general, z in equation (14) can be

any value elected by the insurer but would normally be defined in the neighborhood of average irrigation cost:

$$z = \frac{c(\omega)}{\omega} \quad (15)$$

For example suppose that $z = \$1,000$ and $\omega_{\text{good}} = 10$ inches, then for every inch of rainfall below ω_{good} , the insured receives \$1,000. If there is no rainfall then the insured would receive \$10,000 (10 in x \$1,000/in) to cover yield, revenue, or cost shortfalls, but if actual rainfall exceed ω_{good} then the indemnity is zero. By defining and empirically estimating $C = c(\omega)$, it is possible to map on this cost function the range of critical rainfall outcomes by defining the inverse function, $\omega = c^{-1}(C)$. From this relationship, an indemnity schedule and insurance premium can be developed.

3. Empirical Estimation and Data Specification

In this paper, a constant elasticity cost of irrigation function is assumed:

$$C = A\omega^\beta \quad (16)$$

where C represents the total variable cost of irrigation, A is an intercept multiplier, ω , is annual rainfall, and β is the cost elasticity of rainfall¹. The two coefficients of the model A and β are expected to be positive and negative, respectively. Using the above functional form, the marginal cost of rainfall is given by

$$\frac{\partial}{\partial \omega} c(\omega) = c'(\omega) = A\beta\omega^{\beta-1} \quad (17)$$

¹ It is important to note the simplifications made here. Our cost function is assumed only to be a function of rainfall, when other factors may well affect the cost of irrigation. Also, our use of annual rainfall is probably naïve. A more likely measure would be cumulative rainfall during the summer months, or as in Turvey (2001) specific periods throughout the growing season.

The necessary condition for rainfall insurance to be effective is that $c'(\omega) < 0$ so that rain has an impact on the cost of irrigation. For the empirical estimation, the constant elasticity cost function is written equivalently as

$$\ln C = \ln A + \beta \ln \omega \quad (18)$$

Effectiveness can be measured by the cost elasticity of rainfall, β , which measures the percentage change in the cost of irrigation given a percentage change in rainfall.

The primary data are cross-sectional data from the 1998 Farm and Ranch Irrigation Survey (FRIS), a survey of operators of irrigated farms (U.S Department of Commerce). This survey provides cross-sectional data on annual operating (maintenance and repairs, and energy) cost of irrigation. In contrast, Rainfall data are obtained from NOAA records and are merged with the FRIS data. Since cross sectional data of average farms in 48 U.S. states are used, unobserved heterogeneity among farms is accounted for in this study through the use of regional dummy variables in an OLS regression.²

Table 1 presents the sample data used in the analysis. Average farm costs for machinery and repairs, energy and irrigation are \$3,037.69, \$6,157.75, and \$9,195.44, respectively. The mean annual rainfall across all states is 39.17 inches. Table 2 shows the correlations between the variables. Of importance are correlations between rainfall and different categories of irrigation costs. These correlations are negative. They indicate that a decrease in rainfall will most likely correspond with higher cost of irrigation.

Since there are regional differences in terms of climate, the least-square dummy variable (LSDV) estimator is used to estimate the long-run cost function. It is expressed as:

² Our use of cross-sectional, state-wide data is not the most desirable source of data. Our preferred approach would be to use consistent time-series for a county, state or region. However, such data are not readily available. While our estimates are useful for illustrative purposes, readers should be cautious about using the estimates for real world applications.

$$\ln C_f = \ln A + \sum_{r=1}^{n-1} \alpha_r D_r + \beta \ln \omega_f + \varepsilon_f \quad (19)$$

where C_f is the total variable farm cost of irrigation for the state farm average; α_r is the regional-specific fixed-effect; D_r is the regional-effect dummy variable that takes the value 1 for region r and zero otherwise. Since the number of regions n is small, the estimation of equation (19) is achieved (using OLS) by suppressing the constant term and adding a dummy variable for each of the n regions, or equivalently, by keeping the constant term and adding $n-1$ dummies; ω_f is the vector of observed rainfall; β is the unknown cost elasticity parameter; and ε_f is the error term which is independently and identically distributed (i.i.d.) across average (state) farms and uncorrelated with the rainfall variable. The coefficient on rainfall, β , is expected to be negative. The regional fixed-effects represented by different dummy variables associated with α_r are expected to be positive or negative. Two versions of the model were run. The first used total irrigation costs (maintenance and repairs), while the second used only the cost of energy.

After estimating empirically equation (19), it is possible to map on the total or energy cost function the range of critical rainfall outcomes. Several strike levels of rainfall are calculated by inverting equation (19) and using the estimated parameters of the LSDV model and the mean values in Table 1. The purpose of the inversion is to provide some relationship between the rise in cost of irrigation and the rainfall deficit. To determine the critical rainfall values, energy and total costs of irrigation are held constant at their mean in the first case. The rainfall strike level is determined by $\omega^* = \omega(C^*, A, \beta)$. outcomes The inverse function is defined as follows:

$$(20) \quad \omega^* = \left(\frac{c(\omega)}{A} \right)^{\frac{1}{\beta}}$$

$$(21) \quad \frac{\partial}{\partial c} \omega^* = \frac{1}{\beta} \left(\frac{c(\omega)}{A} \right)^{\frac{1-\beta}{\beta}}$$

In our example, we provide estimates for the state of New Jersey. Since the Mid Atlantic regional dummy variable was dropped, the estimates in Table 3 with all dummy coefficients set to zero gives an estimate for the Mid Atlantic region. Annual rainfall in New Jersey is 45.47 inches. Substituting 45.47 inches into the regressions resulted in an estimate of $c(\omega)$ of \$1,045.32 for energy and \$2,449.85 for total costs. By incrementing $c(\omega)$ from 0% to 25%, we use equation (20) to extract the appropriate rainfall strike level.

Using the above computed range of critical rainfall outcomes, premiums are computed as follows:

$$(23) \quad premium = \frac{c(\omega)}{\omega} \int_0^{\omega^*} (\omega^* - \omega) g(\omega) d(\omega)$$

for an option-like insurance policy, and

$$(24) \quad premium = z \int_0^{\omega^*} g(\omega) d(\omega)$$

for a lump sum payments. The difference between (23) and (24) is that the former, the indemnity increases with reduced rainfall, whereas in the latter a lump sum payment of z is paid if rainfall falls below ω^* with a probability $\int_0^{\omega^*} g(\omega) d(\omega)$.

5. Empirical Results

Table 3 presents the results of the LSDV regressions of the energy cost model and total irrigation. These cost models may be interpreted as long-run cost models of irrigation since we used cross-sectional data. The estimated parameters as well as associated standard errors are presented. Both models have low explanatory power but most of their coefficients are significant at least at the 0.01 level of significance. The parameters of the cost elasticity of rainfall are negative, indicating that an increase in rainfall will decrease the cost of irrigation. Energy cost of irrigation is more sensitive to change in rainfall than the total cost of irrigation. This is due to its highly negative correlation (-0.453) with the rainfall variable.

The estimated models were used to predict the energy and total costs of irrigation for New Jersey. Using equation (15) and the predicted costs, average total and average energy costs of irrigation were computed ($2,449.85/45.47=\$53.88$) and ($1,045.32/45.47=\22.99). These unit costs represent the economic values of rainfall per inch.

Tables 4 and 5 present the results of irrigation insurance calculations. Using time-series data of New Jersey precipitation from 1949 to 2000, the mean rainfall is about 45.47 inches with a standard deviation of 6.6 inches, suggesting that drought is a relatively rare event in New Jersey. Assuming a normal probability distribution function for rainfall, Monte Carlo simulations were used for insurance premium computation.

Two types of rainfall insurance products are used for illustration in Tables 4 and 5: the put option and the lump sum option. Premiums for the put option are generated using equation (23). For the lump sum option, the economic value of rainfall is assumed to be

constant at the level of \$2,000 and \$1,000 for total cost and energy cost of irrigation, respectively. As shown in both tables, premiums are positively associated with strike levels of rainfall. Table 4 shows the insurance costs when the insurance is tied to the energy costs of irrigation, while Table 5 reports the results for total irrigation cost. To interpret these results consider the 10% increase row in Table 4. If an insured wants to protect or insure costs of about \$1,149.85 then equation (20) the corresponding level of rainfall to insure is 30.04 inches. Since, with a standard deviation in annual rainfall of only 6.6 inches per year, the cost of this insurance is low and only \$0.53. For a lump sum payment of \$1,000 if rainfall is below 30.04 inches, the insurance cost is \$9.8.

6. Conclusions

With a growing interest in weather-based insurance products, this paper has advanced the proposition that rainfall insurance can be used to insure against costly irrigation. A theoretical model was developed along the lines of tradeoff between the loss in revenues from unirrigated crops and the cost of irrigation to preserve yields in years or periods of drought. A simple cost function was estimated to illustrate the salient points of our proposition, and an example of costs of irrigation and insurance were calculated for New Jersey. Two types of insurance products were presented. The first has option like qualities wherein the payoff is linear with respect to rainfall increments below a strike (in inches). The second offered a lump sum payment if rainfall falls below the strike. Monte Carlo simulation was used (5000 iterations) and the results reported.

This paper is intended to be illustrative and did not examine the efficacy of irrigation insurance relative to other forms of insurance such as crop insurance. Such a

study should be undertaken. We also noted some deficiencies in the modeling approach we used. The use of cross sectional models using annual rainfalls is far less desirable. Then using time-series costs for a particular farm, region or state, with rainfall measured over specific time periods throughout the growing season.

Nonetheless, this paper provides a reasonable starting point for examining how weather-based insurance product can be used to mitigate excessive irrigation costs for farmers.

References

Bardsley, P.A., A. Abey, and S. Davenport. "The Economics of Insuring Crops Against Drought". *Australian Journal of Agricultural Economics*, 28 (1984):1-14.

Patrick, G.F. "Mali Wheat Farmers' Demand of Crop and Rainfall Insurance." *Australian Journal of Agricultural Economics*, 32 (1988):37-49.

Sakurai, T and T. Reardon. "Potential Demand for Drought Insurance in Burkina Faso and Its Determinants." *American Journal of Agricultural Economics*, 79 (1997):1193-1207.

Turvey, C.G. "Weather Derivatives for Specific Event Risks in Agriculture." Review of *Agricultural Economics*, 23(2001):333-351.

Turvey, C.G. "The Pricing of Degree-Day Weather Options." Working Paper 02/05. Department of Agricultural Economics and Business, University of Guelph, Ontario.2000.

Table 1: Statistics on Irrigation Costs and Rainfall (Cross sectional Data)

	Machinery/Repair Cost (\$)	Energy Cost (\$)	Total Cost (\$)	Rainfall (inches)
Mean	3,037.69	6,157.75	9,195.44	39.17
Standard Deviation	2,565.62	6615.00	8,828.89	14.09
Minimum	270.00	134.02	439.64	13.45
Maximum	12,742	32,190.02	44,932.02	63.38

Table 2: Correlation Matrix

	Machinery/Repair Cost	Energy Cost	Total Cost	Cumulative Rainfall
Machinery/Repair Cost	1.000			
Energy Cost	0.813	1.000		
Total Cost	0.900	0.985	1.000	
Cumulative Rainfall	-0.148	-0.453	-0.382	1.000

Table 3: Estimated Regression Equations of Cost of Irrigation

Variable	Total Cost	Energy Cost
Intercept	8.30 (2.03)	7.83 (2.19)
LRain	-0.13 (0.53)	-0.23 (0.57)
New England	-0.47 (0.57)	-0.73 (0.61)
South	0.75 (0.47)	1.01 (0.51)
Midwest	0.95 (0.49)	1.32 (0.53)
Southwest	2.17 (0.70)	2.63 (0.75)
West	1.30 (0.60)	1.79 (0.65)
Number of Observations	48	48
F-Statistic	4.68	7.31
RMSE	0.930	0.998
R-Square	0.41	0.51

Table 4: Irrigation (Energy) Cost Recovery Indemnity for New Jersey

	Predicted Energy Cost (\$)	Rainfall Strike level (inches)	Premium Option Energy (\$)	Premium Lump Sum Energy (\$)
Mean	1,045.32	45.47	65.82	500
5% Increase	1,097.58	36.78	7.24	94
10% Increase	1,149.85	30.04	0.53	9.8
15% Increase	1,202.12	24.76	0.03	0.8
20% Increase	1,254.38	20.58	0	0
25% Increase	1,306.65	17.23	0	0

Table 5: Irrigation (Total) Cost Recovery Indemnity for New Jersey

	Predicted Total Cost (\$)	Rainfall Strike level (inches)	Premium Option Total (\$)	Premium Lump Sum Total (\$)
Mean	2,449.85	45.47	131.63	1,000
5% Increase	2,572.34	31.24	1.81	31
10% Increase	2,694.83	21.84	0	0.4
15% Increase	2,817.33	15.52	0	0
20% Increase	2,939.82	11.18	0	0
25% Increase	3,062.31	8.17	0	0

