

FARM-LEVEL RISK MANAGEMENT USING IRRIGATION
AND WEATHER DERIVATIVES

by

SHANSHAN LIN

(Under the direction of Jeffrey D. Mullen)

ABSTRACT

This thesis presents an analysis of the role of irrigation in farm-level risk management and the effectiveness of water pricing policies and weather derivatives in reducing water use for corn, cotton, peanut, and tomato productions in Mitchell, Miller, and Lee Counties in Georgia. Water resources in Georgia are under increasing pressure from human activity, highlighting the value of efficient management of irrigation water. It is expected that certain policies can effectively reduce irrigation water use.

Two conclusions developed from the findings of this study. First, the optimal irrigation strategy can greatly increase producers Certainty Equivalent Revenue, and recent changes in water pricing policies would only have a limited impact on the amount of water used for crop production in this region. Second, across levels of risk preference, the contracts are found to increase Certainty Equivalent Revenue and reduce accumulative water use when compared to a base scenario without weather derivative contracts.

INDEX WORDS: Risk Management, Irrigation, Weather Derivative Contract, Water Pricing Policy, DSSAT, Expected Utility, CER, Contract Design

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Agricultural production has always been a risky endeavor. The inherent biophysical nature of agricultural systems combined with the various external stimuli (e.g., economics) makes it vulnerable to various sources of risk. Two primary risks are market risk and production risk. The market risk is in terms of price variation resulting from the market supply and demand changes. The production risk addressed is in terms of variability of crop yield due to spatial and temporal weather, which includes extreme rainfall or temperature events as well as natural disasters. Weather conditions greatly affect the production of farmers and therefore their revenue.

Irrigation has been identified as an important risk management strategy in agricultural production [3]. In Georgia, although annual rainfall is adequate for most agricultural crops, the distribution of rainfall across a year is highly unpredictable. Thus, irrigation is extensively used in Georgia to offset the impact of rainfall variability on crop yield and to reduce the risk associated with weather variability.

In the financial world, U. S. policy makers have been concerned with helping farmers manage agricultural production risk through insurance for a long time. United States government involvement in the provision of crop insurance goes back to the 1930s. Title V of the Agricultural Adjustment Act of 1938 established the Federal Crop Insurance Corporation (FCIC) to provide crop farmers with Multiple Peril Crop Insurance (MPCI) policies that protect against individual farm yield losses[14]. The major reforms in federal crop insurance

started with the Federal Crop Insurance Act of 1980 which provided for nationwide expansion of a comprehensive crop insurance plan. The Act authorized the FCIC to extend the insurance to all commercial crops in all agricultural counties, and permitted the federal government to subsidize farmer premium payments. The Federal Agricultural Improvement and Reform (FAIR) Act of 1994 modified the Federal Crop Insurance Act of 1980 by authorizing a premium-free new catastrophic (CAT) coverage level available to farmers. The Agricultural Risk Protection (ARPA) Act of 2000 essentially maintains the same structure of subsidies that was largely put in place during the last century, but increased crop insurance premium subsidies substantially[1].

1.2 PROBLEM STATEMENT

In recent years, water scarcity has become an increasing social and economic concern for policy makers and competitive water users. The term "water use" is defined to include consumptive use of water¹, withdrawals plus deliveries, return flow, offstream and instream uses (USGS, Glossary of water-use terminology). Irrigation is the largest contributor to water consumption, with a consumption of 85% withdrawn in the United States, with a consumption of 85% of the total water withdrawn in the United States[56]. It is widely suggested that farmers should increase irrigation efficiency and reduce water use.

The development of analytical and simulation tools has been proposed as one of several possible solutions to the problem of inefficient water use and water scarcity in many agricultural areas in the United States. Several studies have been conducted to analyze on-farm adoption of irrigation using the engineering notion of irrigation water (i.e., ratio of water stored in the crop root zone to the total water diverted for irrigation). Some combinations of water savings and yield increase comparing with contemporary practices are found[27, 29, 35]. For example, in Lyle's paper, a dynamic optimization model was used to evaluate the potential contributions associated with the adoption of Low Energy Precision Application (LEPA) irrigation system technology and anticipated biotechnological advances

in crop production on ground water conservation. The results indicated that adoption of these technologies could contribute significantly to ground water conservation efforts while increase yield simultaneously.

Despite the appeal of these studies in analyzing the benefits of advanced irrigation technologies in agriculture, they lack economic intuition; the decision environment is typically non-optimizing, and the issue of risk is rarely considered adequately.

Apart from technology-based approaches, economic incentive policies are used extensively to encourage water conservation. In 1982, Congress enacted the Reclamation Reform Act (P.L. 97-293) to address a number of concerns about water entitlements and pricing. The 1992 Central Valley Project Improvement Act (P.L. 102-575) goes a step further by requiring conservation plans for districts with new, amended, or interim water service contracts to include tiered pricing or receive an exemption.

Irrigation districts have been slow to prepare conservation plans and reluctant to adopt new price incentive rate structures. Repeated changes in regulations have led to confusion about the objectives and requirements of conservation plans. Districts and farmers also continue to express concerns about potential legal ramifications regarding conserved water ownership and use, effects on water right entitlements, and district and farm fiscal and economic impacts.

The US Bureau of Reclamation (BOR) recommends four "fundamental" measures as applicable to all districts' conservation programs: (a) water measurement and accounting systems, (b) water pricing, (c) information and education programs, and (d) assignment of responsibility for conservation activities[60]. Although water pricing entails aspects of all four elements, pricing is a separate element "that encourages efficiency improvements by water users" [60].

Rate structures are categorized as either providing incentives or disincentives to efficiency improvements by water users. "To encourage efficient use, a pricing and billing strategy is based, at least in part, on the quantity of water delivered" [60]. Examples provided of pricing

disincentives to improvements in water use are decreasing block rate structures and fixed charge (per acre) rates that are assessed regardless of the quantity of water used.

In the financial world, it is well documented that government-subsidized agricultural insurance is costly, complex, and leads to potentially significant inefficiencies[41]. Ever since the mid-1980s, insurance payments are mostly based on the actual production history (APH) yield for the insured unit. In 2004, APH-based insurance products accounted for over 90% of FCIP premiums. Several studies have described how APH-based insurance products are subject to adverse selection and moral hazard problem[52, 62, 49]. In addition, APH-based insurance products have high transaction costs related to establishing and verifying APH yields and conducting on-farm adjustment. If efficiency is a performance goal, there are no successful experiences with government supported farm-level crop insurance in the world[53].

An emerging trend has been the development of new financial instruments such as catastrophe options, weather derivative contracts, etc. that allows insurers to mitigate correlated risks and circumvent the limitations of traditional insurance markets. A characteristic feature of these instruments is that their payoff depends on values of a specially designed measure, or index, which is related to the risk being hedged against.

Index-based policies minimize both moral hazard and adverse selection problems, as well as eliminate individualized product set-up, inspection, and loss adjustment requirements. There are currently markets for temperature-based weather derivatives traded on the Chicago Mercantile Exchange as well as more personal markets for over-the-counter weather derivatives exchanged in the form of weather swaps and options. While the market for weather derivatives based on temperature indexes has grown significantly, the market for precipitation-based derivatives is still in its infancy making it a natural area for further research.

1.3 OBJECTIVES AND ORGANIZATION

The primary objective of this study is to present a theoretical framework that conceptualizes irrigation and weather derivative choices of farmers who face yield uncertainty and vary in their risk preferences. This topic is at the borderline of different disciplines, in particular agricultural and financial economics, meteorology, and agronomy. The specific objectives are, however, more pertinent to three studies: (1) using irrigation to protect against production losses caused by rainfall variability; (2) exploring financial instruments in weather markets and assessing their potential role in reducing farm-level risk and irrigation water use; and (3) analyzing the impact of climate change on optimal water use and weather derivative contract design.

The thesis is divided into 6 chapters. Chapter I is an introduction to irrigation and financial tools. Chapter II presents a review of literature on irrigation scheduling and programming, current APH-based insurance, and weather derivative products. Chapter III provides detailed descriptions of the methodology used in this study, including decision-making under uncertainty, the crop simulation model and irrigation application criteria, and design of the proposed weather derivative product. Chapter IV includes the data utilized in the empirical analysis, followed by Chapter V that presents the results and discussion. Chapter VI provides the conclusion.

CHAPTER 2

LITERATURE REVIEW

In order to coherently piece together the concepts that are needed for this approach, selected literature will be divided into three sections. First, relevant works concerning irrigation scheduling and programming will be summarized. Second, selected studies on APH-based insurance products and index-based insurance will be considered. Third, relevant works on climate change prediction will be summarized.

2.1 WORKS ON IRRIGATION MANAGEMENT USING SIMULATION MODELS

The performance of irrigation systems in many parts of the world is generally perceived to be poor compared to design intentions and investment expectations (World Bank, 1990). In many parts of the world, irrigation is based on traditional methods of water distribution and application. Often, traditional irrigation methods fail to meet the variable water demands of different crops due to inadequate management of soil water[23]. Many irrigation systems were laid out when land and water appeared unlimited. Rehabilitation of schemes and design of new ones continue to be based on old concepts of unlimited water resources in many parts of the world[50].

Alternative ways for improving water management practices are needed. One option is to utilize data on such variables as climate, soil, hydrology, agriculture, and management commonly collected in many irrigation areas and to formulate decision support tools to develop water delivery strategies which more closely meet crop water requirements. The growth of computer technology provides the opportunity to move beyond record keeping. Advances in the understanding of the physical, chemical, and biological environment of

the soilplantatmosphere continuum and environmental monitoring technology offer us the opportunity to base crop performance and assessment on sounder scientific principles[30].

The practice of irrigation scheduling has received considerable attention in the applied economics[43] and agronomics literature. Agronomic studies give general recommendations about irrigation applications over a season[54]. However, most of the approaches provide little accurate information on how to schedule a single crop under uncertain weather conditions. Hence, a simulation model can be an effective alternative to support irrigation management decisions.

There are a number of studies which use simulation models to evaluate irrigation schedules based on plant growth relationships, and some combination of water savings and yield increase is found in the studies[25, 29, 35]. The primary contributions of these studies are improved specifications of the agronomic relationships describing the irrigation-plant growth environment and incorporation of multiple crops in the decision framework.

For example, Zavaleta, Lacewell, and Taylor (1980)[67] use the grain sorghum growth model by Maas and Arkin (1978)[36] to consider stochastic weather and allow irrigation timing and quantity decisions to be based on an expected profit maximization criterion. Numeric search procedures, referred to as open-loop stochastic control, are used to derive irrigation strategies which maximize expected profits over the eight discrete irrigation periods of the crop year.

Harris and Mapp (1980) use the same grain sorghum plant growth model to analyze intensive and water-conserving irrigation strategies[25]. A number of irrigation strategies are simulated with their modifications to the plant growth model. Stochastic dominance procedures are used to identify risk efficient irrigation strategies.

Harris and Mapp (1988)[26] evaluate the potential water savings which might be generated by low pressure delivery systems using irrigation scheduling to time water applications in accordance with plant needs. The approach taken utilizes a daily plant growth model for

grain sorghum and twenty-three years of daily historical weather data to generate yields and net returns. Recursive programming is used to optimize water use within the growing season.

Endale and Fipps (2001)[18] apply Irrigation District Decision Support System (IRD-DESS), a crop growth and irrigation district simulation model capable of predicting biomass development and yields for fields varying in soil type and irrigation management scenarios, to a large irrigation scheme in the Middle Awash Valley of Ethiopia. Crop yields are simulated over a 12-year period in order to determine which of 12 separate irrigation schedules in use meet certain specified objectives. Results show which of the 12 schedules will meet specific objectives of maximizing yields or minimizing water use and illustrate the potential of such a decision support system in evaluation and management.

Singh and Singh (1996)[51] apply the SWASALT (Simulation of Water And SALT) model after calibration and validation at CCS Haryana Agricultural University Farm, Sirsa (India) to estimate the optimum irrigation schedule for cotton resulting in minimum percolation losses. The sprinkler line source technique is adopted for creating various irrigation regimes at different crop growth stages. The results suggest that the optimal irrigation scenario resulted in zero percolation loss accompanied by 74% relative transpiration and 14 per cent soil moisture depletion.

Fortes, Platonov, and Pereira (2004)[21] apply the ISAREG model, a conceptual non-distributed water balance model for simulating crop irrigation schedules in the field, to support improved irrigation scheduling in the Syr Darya basin, Uzbekistan. The model is integrated with a Geographical Information System (GIS) so as to use the spatial and weather GIS databases and to produce crop irrigation maps and time dependent irrigation depths at selected aggregation modes. The resulting information on alternative irrigation schedules shows the appropriateness of implementing 1520-day time intervals between irrigations.

2.2 WORKS ON CROP INSURANCE PRODUCTS

The Federal Crop Insurance Program came into existence in 1938. The first insurance policy was written for wheat in 1939. Since then, the program has experienced enormous change. The major reforms in federal crop insurance started from the Federal Crop Insurance Act of 1980 which provided for nationwide expansion of a comprehensive crop insurance plan. The Agricultural Risk Protection Act (ARPA) of 2000 increased crop insurance premium subsidies substantially (Babcock and Hart, 1999).

Currently the U.S. crop insurance products can be defined by two determinants: (1) what is insured yield, price, or revenue; (2) what the insured yield is based on APH-based or index-based.

APH-based agricultural insurance schemes are known to be plagued by problems of asymmetric information and systemic risk[41]) and, consequently, in order to be operated need substantial government support. In supporting such programs the intention of policy makers is usually to provide more market-oriented policy instruments reducing producers incentives to rely on free disaster aid and, compared to disaster relief intervention, to attain a more efficient and equitable use of resources[53]. Given such policy orientation, a significant number of innovative and sophisticated insurance programs were tested and developed. This vigorous development of supported insurance markets raised a number of questions regarding the actual impact of such programs on production and trade, leading some researchers to question the actual progress in efficiency, and to suggest the need to reconsider the scope and use of such programs [53].

Weather derivatives are structured as swap, call, and put contracts based on weather indexes. Commonly referenced weather indexes include, but are not limited to, heating degree day (HDD), cooling degree day (CDD), precipitation, and snowfall. For example, a major energy user can hedge the risk associated with lower-than-average winter temperatures by buying a winter HDD call. As another example, a snowmobile retailer can hedge against lower-than-expected revenue by purchasing a snowfall put. The flexibility of defining weather

indexes allows innovative structures to be developed using these instruments to manage a wide variety of weather-related risks. Sellers of weather derivatives usually include major energy companies which use the instruments to hedge their own risks and to make trading profits. Insurance and reinsurance companies are also important providers of capacity, as they look for alternative ways to deploy their capital. Thus, weather derivatives appeal to a wide array of investors as an uncorrelated asset class.

These opportunities to trade on the weather also pose challenges for financial and risk management professionals[31], which include pricing, analysis, and portfolio management. First, the no-arbitrage option pricing model is not a practical pricing tool for weather derivatives because the underlying weather indexes are not traded instruments. Second, there also exist difficulties in implementing actuarial techniques for pricing, because the underlying weather indexes are non-stationary. Rather, they are characterized by long-term variations and trends with scales greater than the length of the historical record. In addition, historical weather indexes exhibit a high degree of autocorrelation. This further reduces the number of independent observations. These characteristics make it impossible for traditional actuarial techniques to provide reliable statistical inferences based on the data. Third, reliably measuring and accounting for volatility in the absence of pricing data is problematic. In fact, there is no universal method for estimating volatility associated with weather derivatives, because the economic exposure to weather risk varies greatly among businesses and individuals, but is not yet commonly traded.

The no-arbitrage model is not a practical choice because the underlying weather indexes are not traded. The ability of the traditional actuarial approach is limited by the particular statistical properties of the underlying weather indexes, namely the existence of a high degree of autocorrelation and long-term variations in the historical data. Lixin Zeng (2000)[68] uses a biased sampling Monte Carlo approach to alleviate these problems by taking advantage of the seasonal climate forecast, based on a hybrid dynamic-statistical model.

Mount (2002)[44] combines a forward contract, with fixed price for both base load and peaking power, and a collar option for the number of hot days in a summer as an effective way to reduce the risk of purchasing electricity in a spot market. The main advantages are: 1) effectiveness of price signals is strengthened by making peaking power expensive, and 2) correlation between payouts from the weather option and high prices is increased.

Brix, Jewson and Ziemann (2002)[6] address the problem of pricing weather derivatives based on linear temperature indices. Anticipating the development of a liquid weather swap market, they address the issue of pricing weather derivative options using weather swaps as hedging instruments. The analysis starts by considering stochastic dynamics that are appropriate for the modeling of actively traded swaps, which is an issue that involves weather forecast considerations. It then proceeds to an adaptation of the continuous-time mathematical theory that ensures the absence of arbitrage opportunities within the weather derivative market, and provides formulae for the no-arbitrage prices of weather derivative options. The results derived include the modifications of the Black and Scholes formulae that are appropriate for weather derivative pricing.

Richards et al. (2004) found that a temperature-based weather index insurance product could be used to offset production risks faced by nectarine growers in Fresno County, California[46]. Skees et al. (2001) found that a rainfall index insurance scheme could be feasible in Morocco and Argentina[53]. Turvey (2001) examined the economics and pricing of weather index insurance in Ontario and suggested that temperature-and precipitation-based insurance contracts could be used to insure against yield losses for some crops[58]. Vedenov and Barnett (2004) investigated the feasibility of using weather index insurance to protect against shortfalls in corn and soybean yields in Iowa and Illinois and cotton yields in Mississippi and Georgia[62].

2.3 WORKS ON FUTURE CLIMATE PREDICTION

Atmospheric scientists are now able to predict seasonal climate variations, with a relatively high level of skill. Knowledge of climatic conditions allows us to develop a seasonal management strategy for crop productions. Breuer et. al. (2000) provides strategies to consider for pine plantation establishment in Florida and southern Alabama and Georgia. They propose that seasonal climate conditions can be better predicted for this region because it is affected by the El Nio Southern Oscillation (ENSO) phenomenon[5].

Unlike weather prediction, where the time frame is no more than the up-coming week, climate forecasting can predict a wet, cool summer or a hot, dry winter. These types of forecasts refer to seasonal climate variability. Oscillations of the Pacific Ocean's sea surface temperature above and below normal are a major contributing factor in determining seasonal climate in the southeastern United States. Generally, the effect is stronger further south than north, and stronger in winter-spring than in summer-fall. Table 1 summarizes seasonal variations in the southeast[5]. Table A.1 in Appendix A provides the information on how ENSO phases influence conditions in Alabama, Florida, and Georgia.

Frame (2005)[22]propose that the range of possibilities for future climate evolution needs to be taken into account when planning climate change mitigation and adaptation strategies, which requires ensembles of multi-decadal simulations to assess both chaotic climate variability and model response uncertainty. Thus, they carried out a grand ensemble (an ensemble of ensembles) exploring uncertainty in a state-of-the-art model. Uncertainty in model response is investigated using a perturbed physics ensemble in which model parameters are set to alternative values considered plausible by experts in the relevant parameterization schemes. Individual simulations are carried out using idle processing capacity on personal computers volunteered by members of the general public.

Because of the uncertainties surrounding prediction of climate change, it is common to employ climate scenarios[64]to estimate the impact of climate change on a system. Climate scenarios are sets of climatic perturbations which are used with impact models to test the

sensitivity of the system to the projected changes. The design of an impact study should include more than one scenario, so that a range of possible effects may be defined. Realism is increased when the climate change scenarios are internally consistent, i.e., the climate variables within the scenario should vary in a physically realistic way[64].

CHAPTER 3

METHODOLOGY

This section describes the method used to accomplish our objectives. Specifically, the plant-available water threshold will be identified such that it maximizes an expected utility function, and design precipitation contracts for irrigated farms in selected counties in Georgia. Three counties - Miller, Mitchell, and Lee, located in the heavily irrigated southwest part of Georgia - are considered in the study. A microeconomic farm model is developed for each of the counties to demonstrate the impact of proposed water pricing policies and precipitation insurance on producer optimal decisions.

3.1 IRRIGATION DECISION UNDER UNCERTAINTY

This section describes the method used to accomplish our first objective. Specifically, we will identify the plant-available water threshold such that it maximizes an expected utility function. The potential impact of water pricing policies (in the form of increasing irrigation pumping cost) on irrigation water use will also be investigated.

3.1.1 DSSAT SIMULATION PROGRAM

DSSAT (Decision Support System for Agro-technology Transfer) is a computer simulation model developed by a small group of modelers and system scientists. It combines the models (programmed in FORTAN), databases (dBASE or .dbf format) and an application program (in BASIC) into computer software and provides users with easy access to simulate, analyze, and display outcomes of alternatives management strategies specified by the user.

The soil water balance is calculated in the DSSAT in order to evaluate the possible yield reduction caused by soil and plant water deficit. The model evaluates the soil water balance of a crop on a daily basis as a function of precipitation, irrigation, transpiration, soil evaporation, run-off and drainage from the profile. The soil water is distributed in several layers with depth increments specified by the user. The limit to which water can increase or decrease is input for each soil layer as the difference between saturated upper limit and lower limit(SUL-LL).

Irrigation schedules are developed for individual crops. Irrigation may be scheduled in two ways:

(1) Rule-based scheduling. The cropping season can be divided into a maximum of 12 periods, during which different scheduling rules can be applied. The rules (e.g., irrigate at 40% soil water capacity (SUL-LL) and refill to field capacity) determine the timing of irrigation and the amounts to be applied.

(2) Calendar scheduling. Irrigations can be specified for fixed dates (e.g. apply 60mm 30 days after planting) to simulate irrigation by a fixed calendar. This option can also be used to simulate the impact of an actual irrigation schedule.

Outputs from the crop simulation model are later incorporated into an economic model for the determination of optimal irrigation scheduling.

3.1.2 EXPECTED UTILITY CRITERIA

In order to study the decision problem of a risk averse competitive agricultural producer under output price and weather risks, an expected utility maximizing model is used. The objective is to maximize the expected value of a von Neumann-Morgenstern utility function of profit $u(\pi)$, with $u' > 0$ and $u'' < 0$. As empirical studies have demonstrated that farmers in many areas exhibit decreasing absolute risk aversion³ (Babcock and Feinermean, 2005) i.e. $R_a'(y) = \frac{-u''u + u'^2}{u'^2} < 0$, given that $u' > 0$, $u'' < 0$, a necessary condition for decreasing absolute risk aversion is $u''' > 0$.

A widely used representation of expected utility that satisfies the maintained hypothesis of $u' > 0$, $u'' < 0$ and $u''' > 0$ is the constant relative risk aversion utility function that is best parameterized as:

$$U = \frac{R^{1-\xi}}{1-\xi} \quad (3.1)$$

where R is the return to the decision maker; ξ is the relative risk aversion coefficient. Producers are classified into two relative risk aversion levels - one is slightly risk averse, with relative risk aversion coefficient equal to 1.5, the other one is highly risk averse level, with relative risk aversion coefficient equal to 6 [17].

3.1.3 RISK REDUCTION MEASURE

Certainty-equivalent revenues (CER) is used to assess the robustness of the risk reduction performance of the optimal irrigation and precipitation contract. For a specified utility function, CER is the level of return that if received with certainty would generate a level of utility equal to the expected utility of the risky investment. While it allows for consideration of higher moments of the return distribution, CER also requires one to make assumptions about the decision-makers utility function over returns [12]. CER are calculated by using the same utility function (Equation (1)) in the last section. Then, the CER can be calculated as:

$$CER = ((1-\xi)(EU(R)))^{\frac{1}{1-\xi}} \quad (3.2)$$

3.2 WEATHER DERIVATIVE CONTRACT DESIGN

The research methodology to accomplish the second objective involves an investigation into the design of a precipitation contract for irrigated farms at selected counties in Georgia. The

aim of this investigation is to analyze the potential impact of the contract on farm irrigation decision-making and risk reduction.

3.2.1 PARAMETERS OF WEATHER DERIVATIVE CONTRACT

The critical components in the precipitation contract design involve setting the indemnity payments and the premium of the contract. Indemnity refers to the payments made to the holder of the contract when events as specified in the contract trigger a payment. A host of indemnity designs exist in the literature[40]. The proposed insurance product would function much like a put option on the precipitation. In particular, the precipitation contract envisaged here is designed to trigger a payment when rainfall in the said time period falls short of a certain set strike rainfall amount. The indemnity is paid conditional on the realization of the precipitation according to the following schedule:

$$f(i|x, i^*, \lambda) = x \times \begin{cases} 0, & \text{if } i > i^*; \\ \frac{i^* - i}{i^* - \lambda i^*}, & \text{if } \lambda i^* < i \leq i^*; \\ 1, & \text{if } i \leq \lambda i^*. \end{cases} \quad (3.3)$$

where $f(i|x, i^*, \lambda)$ is the indemnity, i is the rainfall index for a specific period measured not at the farm as in (3) (in the crop simulation model) but rather at the weather station referenced in the insurance contract, i^* is the strike, x is the maximum indemnity. As the irrigation cost during the worst years is considered a good proxy for the value at risk, and thus can be used to establish a liability estimate by crop. Therefore, maximum liability is set to be the pumping cost corresponding to the 85% irrigation threshold strategy in each county.

The contract triggers an indemnity whenever i falls below i^* , λ is the limit parameter which decides the threshold of rainfall when maximum indemnity is paid, i.e., the maximum indemnity x is paid whenever the index falls below the limit λi^* . Thus, the contract can be uniquely identified by fixing the three parameters i^* , λ , and x .

The premium on the precipitation standard contract is a function of i^* , λ , and x , and the probability distribution of i . The distribution can be estimated based on historical precipitation data either by fitting a standard parametric distribution or by using a nonparametric approach such as kernel smoothing. For this study, kernel smoothing is used to derive a continuous probability density function $h(i)$ of i . Formally, for index realization of i , $t = 1, \dots, T$, the kernel density function of the index is calculated as:

$$h(i) = \frac{1}{T\Delta} \sum_{t=1}^T K\left(\frac{i - i_t}{\Delta}\right) \quad (3.4)$$

where $K(\cdot)$ is a kernel function, and Δ is a degree of smoothness or bandwidth[24]. The expected payoff and hence the actuarially fair premium for the standard contract can be determined by:

$$\pi_{fair}(x, i^*, \lambda) = \int (i|x, i^*, \lambda)h(i)di \quad (3.5)$$

$$= x \int_0^{\lambda^*} h(i)di + x \int_{\lambda i^*}^{i^*} \frac{i^* - i}{i^*(1 - \lambda)} h(i)di \quad (3.6)$$

The above formulation for calculating the pure premium is based on the pure loss cost history and does not cover for the transaction costs or risk preference of partners. Reinsurance firms usually load the pure premium based on the variance of the loss costs. If one further assumes that a proportional premium load γ ($\gamma \geq 0$) is applied to the actuarially fair premium to cover transaction costs, return on investment, and reserve-building, then the loaded premium is:

$$\pi_{loaded}(i^*, \lambda, \gamma) = (1 + \gamma)\pi_{fair} \quad (3.7)$$

For the purposes of this study, a 10% load is imposed on the standard deviations of indemnity payments per liability. Using the above procedure, preliminary estimates for indemnity payments, pure premium rates, and loaded premium rates (the ratio of premium to maximum liability) for the six counties can be derived at given strike, limit, and liability.

3.2.2 DECISION MAKING CRITERIA

A producer is suppose to value investment returns in relation to maximizing the expected value of above utility function. Further suppose a representative producers decision making consists only of irrigation and precipitation contracts. The mathematical formulation of the farm level model is as presented below:

$$Max(EU) = \sum_{t=1976}^{2000} \frac{[(NR_{without})_t + f_t(i_t|x, i^*, \lambda) - \pi(x, i^*, \lambda)]^{1-\xi}}{1 - \xi} h(i) \quad (3.8)$$

$$= \sum_{t=1976}^{2000} \frac{[(qP_{crop} - wC_{pumping} - FC)_t + f_t(i_t|x, i^*, \lambda) - \pi(x, i^*, \lambda)]^{1-\xi}}{1 - \xi} h(i) \quad (3.9)$$

where E denotes the expectation operator, $NR_{without}$ denotes net return to an irrigated farm without weather derivative contract for a specific year t , which is equal to output price times quality and minus all production costs (these economic variables will be specified in DATA Section); $C_{pumping}$ denotes per unit irrigation cost; w denotes irrigation amount; q denotes crop yield; P denotes crop price; f_t denotes instrument payoff (indemnity) for year t ; π is contract premium; xi denotes relative risk aversion coefficient.

The decision variables, namely the strike, the limit parameter λ , and irrigation threshold, are selected for each analysis unit so as to maximize the Expected Utility function over an historic period (1976-2000).

Limit parameters are changed from 0.01 to 0.99 in steps of 0.01; strikes are changed from 1/3 of expected precipitation⁵ to expected precipitation during growing season, in steps of 10 millimeters. Maximum liability is set to be the pumping cost corresponding to the 85% irrigation threshold strategy in each county, as the irrigation cost during the worst years is considered a good proxy for the value at risk and thus can be used to establish a liability estimate by crop.

The irrigation scheduling criteria includes the ability to suspend irrigation due to rainfall, or constrain the schedule due to limiting system capacity. In our study, irrigation scheduling

criteria is set to be a percentage of the difference in saturated upper limit (SAT) and low limit (LL). For example, if the irrigation target is 40%, it means that the threshold to trigger irrigation is when soil water content falls below 40% of the (SUL-LL). Outcomes (yields and water use) from fifteen irrigation strategies (20% to 85% soil water content as irrigation threshold, in steps of 5%, in addition to a no-irrigation strategy) are simulated using DSSAT.

The corresponding expected utilities are then calculated and compared in order to find the combination of irrigation and weather contract strategy that maximizes the utility function.

Once the optimal irrigation thresholds (%) are solved, they can then be plugged into DSSAT model to find optimal water use amounts (mm/acre) for each year, and then the expected water use over 25 years can be calculated; Once the optimal contract parameters (strike, maximum liability and limit) are solved, indemnity payments and premium rates can also be calculated.

The model is run 144 times (three soil types, four crops, three counties, four weather scenarios). These scenarios will be discussed more specifically in the DATA section. In each scenario, the impacts of water-pricing policy and optimal weather derivative contract (optimal combination of limit parameter and strike, from producers perspective) on optimal irrigation decision and resulting certainty equivalent revenues will be analyzed.

CHAPTER 4

DATA

This section describes the data need to put into the model. The DSSAT crop growth model utilizes crop management data, daily weather data, and soil data. Economic model requires output price data and crop management cost data. One group of data are crop management data, which are fixed across years and across different counties for a given crop, including fertilizer materials, application schedules and amounts; crop planting schedules; and cultivars choices. The other group of data are not fixed across years, which includes weather scenarios; soil types, and economics data (input and output price levels).

4.1 CROP MANAGEMENT DATA

Crop management data are fixed for a given crop across three counties. Crop management includes crop cultivar choice, planting date, planting population, and fertilizer applications.

CORN

The variety of corn chosen is Dekalb 485, one of the most intensively grown hybrids. Lee Dewey, Extension grain agronomist[34], suggests that if soil temperatures are near 55°F, and projections are for a warming trend, corn planting can proceed, and that early planted corn out-yields late planted corn.

Irrigated corn requires higher plant population than dryland corn to fully exploit the potential of irrigation. Generally, 26,000 to 32,000 plants/acre are recommended for most intensively grown hybrids. Most farm equipment in Georgia is set to plant in 36-inch (about

90cm) rows. Thus, final plant stand is chosen to be 28,000 plants per acre (about 7 plants per square meter) for the 90 cm row spacing[34]. Planting depth is set to be 7cm.

Table 4.1: a Corn Production Information in Georgia

Maize	
Cultivar	DEKALB 485
Planting Date	4-15
Planting Method	Dry Seed
Planting Distribution	Rows
Plant population at seeding, plant/ m^2	7
Row Spacing, cm	90
Planting Depth, cm	7

Corn fertilizer application follows the recommendation in Field Corn Production Guide[65, 9]. It is suggested that early fertilization is favorable and further fertilization is needed for another 2 months. The first application contains 56kg/ha of N, and the following application contains 28kg/ha of N, with one application every two weeks. Fertilizer material is ammonium nitrate and application method is broadcast, not incorporated.

Table 4.2: Corn Fertilizer Application in Georgia

Date	Fertilizer material	Fertilizer applications	Depth, cm	N, kg/ha
03/05/76	Ammonium nitrate	Broadcast, not incorporate	10	56
03/20/76	Ammonium nitrate	Broadcast, not incorporate	10	28
04/02/76	Ammonium nitrate	Broadcast, not incorporate	10	28
04/16/76	Ammonium nitrate	Broadcast, not incorporate	10	28
04/30/76	Ammonium nitrate	Broadcast, not incorporate	10	28
05/17/76	Ammonium nitrate	Broadcast, not incorporate	10	56

COTTON

The variety of cotton chosen is DP 455 BG/RR, which is one of the top yielders among varieties (Day and Thompson, 2005). DP 455 BG/RR is the most popular variety planted in Georgia in the 2005 season, accounting for almost 73% of the total cotton acreage[7].

Planting date is May 1, 2005 and final plant stand is 1.5 plants per foot for the 10" plant spacing, following the suggestions from UGA Cooperative Extension Service Berrien Co. and the Department of Crop and Soil Sciences, UGA[7].

Table 4.3: Cotton Production Information in Georgia

Cotton	
Cultivar	DP 455
Planting Date	5/1/1976
Planting Method	Dry Seed
Planting Distribution	Rows
Plant population at seeding, plant/ m^2	10
Plant population at emergence, plant/ m^2	10
Row Spacing, cm	90
Planting Depth, cm	4

Cotton fertilizer application follows the recommendation in Nitrogen Fertilization[25]. It is suggested that early fertilization is favorable and further fertilization is needed for another 2 months with one application every two weeks. The first fertilization is on the planting date, with 10kg/ha of N, 75 kg/ha of P, and 25kg/ha of Ca. Additional fertilizer is applied for one month, with two applications total. Fertilizer material is anhydrous ammonia and application method is injected.

Table 4.4: Cotton Fertilizer Application in Georgia

Date	material	applications	Depth, cm	N, kg/ha	P, kg/ha	Ca, kg/ha
5/1/1976	Anhydrous ammonia	Injected	5	10	75	25
5/21/1976	Anhydrous ammonia	Injected	5	25		
06/01/76	Anhydrous ammonia	Injected	5	25		

PEANUTS

Georgia is the number one peanut-producing state in the country, accounting for approximately 45 percent of the crop's national acreage and production. In 2005, Georgia farmers harvested 755,000 acres of peanuts, the official state crop, for a yield of 2.2 billion pounds.

The variety of peanut chosen is Georgia Green, which is a new runner-type peanut cultivar released in 1995 by the Georgia Agricultural Experiment Stations. Developed at The University of Georgia Coastal Plain Experiment Station, Georgia Green is highly productive and has very good stability across many environments. In numerous tests conducted in the southeastern United States from 1990-1994, Georgia Green was found to have an approximately 10% higher yield and dollar return than Florunner. It also produced a significantly higher percentage of total sound mature kernels (TSMK). Georgia Green has also shown good resistance to tomato spotted wilt virus, comparable to Southern Runner[2].

Recommended planting date for peanuts in Georgia is dictated by tomato spotted wilt virus (TSWV)[33]. The recommended time to plant peanuts in Georgia was April 15 to May 20. The recommended seeding rate is 20 seeds per squared meter of row for runner-type peanuts.

Table 4.5: Peanut Production Information in Georgia

Peanut	
Cultivar	Georgia Green
Planting Date	4/16/1976
Planting Method	Dry Seed
Planting Distribution	Rows
Plant population at seeding, plant/ m^2	20
Plant population at emergence, plant/ m^2	18
Row Spacing, cm	90
Planting Depth, cm	4

Peanut fertilizer application also follows the recommendation of UGA Cooperative Extension Service and the Department of Crop and Soil Sciences[2]. Fertilizer is assumed to be

applied once every year at the planting date, which contains 10kg/ha of N, and the application depth is 10cm. Fertilizer material is urea and application method is banded beneath surface.

Table 4.6: Peanuts Fertilizer Application in Georgia

Date	Fertilizer material	Fertilizer applications	Depth, cm	N, kg/ha
04/16/76	Urea	Banded Beneath Surface	10	10

TOMATO

Tomatoes are planted by direct seeding and seedling transplant in Georgia, with more than half by seedling transplant. Typical planting distances are 48 to 72 inches between rows (72 inches being the most common) and 12 to 24 inches between plants in a row (18 inches being the most common). Maximum density of plants is approximately 4840 plants per acre. Nearly all of the states tomato crop is grown on plastic-mulched, raised beds, using stake culture and drip or seep irrigation.

In our study, tomato management is based on the small plot trials conducted at The University of Georgias Tifton Vegetable Park in Tifton, Georgia. Tomatoes (BHN 640 variety) were staked and grown in a plasticulture production system. Plants were established in a commercial greenhouse and transplanted to the field on April 6. Plots were established and plants produced on plastic mulch with drip irrigation. Plots consisted of a single row of tomatoes planted on raised beds that were spaced six feet apart (from center to center). In-row spacing is 21.6 inches per plant. Plots were each 24 feet long and were replicated four times[47].

Tomatoes in these tests were fertilized and watered regularly and were never exposed to excessive stress. As suggested by Riley, Department of Entomology University of Georgia, when 100% or 75% of the total N was at planting applied as Vitamin, the marketable yields were higher than with other program[47]. Thus, 75% of the total recommended N is applied

at planting and 25% of the total N is applied as a supplemental application later during the season. Two rounds of fertilizer are applied - one at the planting date, with 160kg/ha of N, the other two weeks later, with 53kg/ha of N. The application depth is 10cm each time. Fertilizer material is ammonium nitrate and application method is broadcast, not incorporated.

Table 4.7: Tomato Production Information in Georgia

Tomato	
Cultivar	BHN-66.
Planting Date	4/6/1976
Planting Method	Transplants
Planting Distribution	Rows
Plant population at seeding, plant/ m^2	1.2
Plant population at emergence, plant/ m^2	1.2
Row Spacing, cm	180
Row Direction, degrees from North	90
Planting Depth, cm	1
Planting material dry weight, kg/ha	3
Transplant age, days	28
Temperature of transplant environment, C	25
Plant per hill (if appropriate)	1
Initial spout length, cm	0

Table 4.8: Tomato Fertilizer Application in Georgia

Date	Fertilizer material	Fertilizer applications	Depth, cm	N, kg/ha
4/6/1976	Ammonium nitrate	Broadcast, not incorporate	10	160
4/20/1976	Ammonium nitrate	Broadcast, not incorporate	10	53

4.2 WEATHER DATA

The DSSAT model requires daily reference evapotranspiration and rainfall data. An accompanying utility, WeatherMan, is provided for calculating reference evapotranspiration from daily weather data using Priestley-Taylor Methods. Climate data is imported from text files and screened for missing or out-of-range data. Data errors are then flagged and edited with WeatherMan. The climate data for Mitchell County is plotted in Figure 4.1.

Weather data (precipitation data specifically) is also needed for weather derivative contract design. Precipitation insurance contracts involve risk sharing by multiple partners and require a few prerequisites and data requirements. These include:

1. Data measured and reported by a third party,
 2. Quality of time series must be analyzed,
 3. Missing data must be documented,
 4. Changes to the location of measurement (relocation of measuring instruments or changes to environment affecting measurements) must be documented,
 5. Changes to method of measurement and reporting of the data must be documented,
- and
6. Changes/replacements of measuring instruments must be documented.

Existing meteorological infrastructure in Georgia suggest that weather data can satisfy the above requirements. Using daily weather data available from the United States National Climate Data Center (NCDC), one can construct objective and transparent weather insurance indices that cannot be manipulated by insurance purchasers. These data are available for many weather stations across the United States that are associated with the National Oceanic and Atmospheric Administration (NOAA). Since the data used to construct the weather index are widely available, there are no information asymmetry problems such as adverse selection and moral hazard. Twenty five years of annual rainfall data for each county is collected from the NCDC.

The model is run under 4 different weather scenarios. The first is historic weather scenario, which is exactly the same data as the data from the three weather stations (for three counties). Future weather scenario consists of Future A, Future B, and Future C. Future A weather scenario suggests fewer rainy days or a longer dry period and keeps the accumulative rainfall unchanged compared with current weather conditions. The number of rainy days is assumed to decrease by 20%; to keep the overall rainfall amount roughly unchanged, daily precipitation amount is increased by 20%. Specifically, a dummy variable RAIN is established, and is set to 1 when precipitation occurs that day, to 0 otherwise. Then the probability of rainfall is calculated as the ratio of the number of rainy days/365. In future A scenario, the probability of rainfall is assumed to decrease by 20%, and based on this new probability, a new distribution of the dummy variable $RAIN^*$ is generated by SAS. If both RAIN and $RAIN^*$ is 1, then daily rainfall is set to be 1.2 times the original daily rainfall amount; if $RAIN^*$ is 1 and RAIN is 0, then daily rainfall is set to be 1.2 times the original average rainfall amount; if both RAIN and $RAIN^*$ is 0, then daily rainfall is set to be 0.

Future B weather scenario suggests higher accumulative rainfall amount (15% higher) and keeps the rainy days unchanged. This is easily accomplished by increasing daily rainfall amount by 15%.

Future C weather scenario suggests less rainy days (20% less) and higher accumulative rainfall amount (increase precipitation amount by 40% each time). The procedure is similar as that for Future A, except for increasing daily rainfall amount by 40% instead of 20%.

Table 4.9: Weather Data for Mitchell County under Four Weather Scenarios. srad: sun radiation; tmax: daily maximum temperature ($^{\circ}C$); tmin: daily minimum temperature ($^{\circ}C$); rain: daily precipitation amount (mm).

	STATISTIC	srad	tmax	tmin	rain
Historic	MIN	3.00	-3.30	-16.50	0.00
	MAX	30.70	41.20	28.60	157.50
	MEAN	16.61	25.73	12.90	3.58
	STD	6.31	7.23	7.84	10.85
Future A	MIN	3.00	-3.30	-16.50	0.00
	MAX	30.70	41.20	28.60	153.60
	MEAN	16.61	25.74	12.90	3.64
	STD	6.31	7.22	7.84	9.67
Future B	MIN	3.00	-3.30	-16.50	0.00
	MAX	30.70	41.20	28.60	173.30
	MEAN	16.61	25.73	12.90	3.93
	STD	6.31	7.23	7.84	11.93
Future C	MIN	3.00	-3.30	-16.50	0.00
	MAX	30.70	41.20	28.60	179.20
	MEAN	16.61	25.74	12.90	4.25
	STD	6.31	7.22	7.84	11.29

Table 4.10: Weather Data for Miller County under Four Weather Scenarios. srad: sun radiation; tmax: daily maximum temperature ($^{\circ}C$); tmin: daily minimum temperature ($^{\circ}C$); rain: daily precipitation amount (mm).

	STATISTIC	srad	tmax	tmin	rain
Historic	MIN	3.00	-2.20	-16.50	0.00
	MAX	31.10	40.20	26.40	199.90
	MEAN	16.62	25.72	12.57	3.77
	STD	6.28	7.24	7.80	11.64
Future A	MIN	3.00	-2.20	-16.50	0.00
	MAX	31.10	40.20	26.40	145.10
	MEAN	16.62	25.72	12.58	3.83
	STD	6.28	7.24	7.80	10.12
Future B	MIN	3.00	-2.20	-16.50	0.00
	MAX	31.10	40.20	26.40	219.90
	MEAN	16.62	25.72	12.57	4.15
	STD	6.28	7.24	7.80	12.81
Future C	MIN	3.00	-2.20	-16.50	0.00
	MAX	31.10	40.20	26.40	169.30
	MEAN	16.62	25.72	12.58	4.47
	STD	6.28	7.24	7.80	11.81

Table 4.11: Weather Data for Lee County under Four Weather Scenarios. srاد: sun radiation; tmax: daily maximum temperature ($^{\circ}C$); tmin: daily minimum temperature ($^{\circ}C$); rain: daily precipitation amount (mm).

	STATISTIC	srاد	tmax	tmin	rain
Historic	MIN	3.00	-3.60	-14.00	0.00
	MAX	30.20	41.30	29.90	206.70
	MEAN	16.45	25.38	12.69	3.65
	STD	6.12	7.71	8.06	10.43
Future A	MIN	3.00	-3.60	-14.00	0.00
	MAX	30.20	41.30	29.90	126.10
	MEAN	16.46	25.39	12.70	3.59
	STD	6.12	7.71	8.06	8.79
Future B	MIN	3.00	-3.60	-14.00	0.00
	MAX	30.20	41.30	29.90	227.40
	MEAN	16.45	25.38	12.69	4.02
	STD	6.12	7.71	8.06	11.47
Future C	MIN	3.00	-3.60	-14.00	0.00
	MAX	30.20	41.30	29.90	147.10
	MEAN	16.46	25.39	12.70	4.19
	STD	6.12	7.71	8.06	10.26

Under each weather scenario, the methodology described in Section 3.1 and 3.2 is used to see the impact of proposed water price policies and risk aversion levels on optimal water use and producers Certainty Equivalent Revenue.

4.3 SOIL DATA

Three common soil types in Georgia (Norgram Sandy Soil, Tifton Loamy Sand, and Norfolk Loamy Sand) are included in the study. For each soil, Soil properties required by DSSAT include water contents at lower limit (LL), drained upper limit (DUL), and saturated upper limit (SAT) at different depth intervals. LL, DUL and SAT were defined using measurements of wilting point and field capacity for soil samples from the irrigation station, measured in the laboratory using pressure plates[8, 32].

4.4 ECONOMIC DATA

Economic data include output prices and input costs data. Output prices data is obtained from the National Agricultural Statistic Service. Prices are multiplied by CPI (Consumer Price Index) to adjust for inflation. Year 2000 is used as base year.

Cost data include variable costs and fixed costs. As fertilizer application is fixed for a given crop, fertilizer cost is classified as fixed cost. All costs except irrigation data are obtained from the Extension Agricultural and Applied Economics at The University of Georgia[13]. Irrigation cost is assumed to consists of two parts: pumping cost and application cost. In this study, application cost is set to be \$12/application[59], and assume it to be constant in our analysis. Currently, there is no water market in Georgia, so irrigation pumping cost is used to approximate current water price. Pumping cost depends on flow rate, pipe size (diameter), overall pipe length, pipe characteristics (surface roughness, material, etc.), and properties of the fluid being pumped. Irrigation pumping costs across all energy sources averaged about \$37.70 per acre in 1998, ranging from \$29.41 per acre for the smallest irrigated farms (FS \leq \$100,000) to \$41.36 per acre for the largest (FS \geq \$500,000)[59]. Due to water scarcity issues,

water price is assumed to be increasing in the future. Thus, in our analysis, water price increases from \$30/acre-foot to \$80/acre-foot in the step of \$10/acre-foot.

Table 4.12: Corn Production Costs

VARIABLE COSTS (\$/acre):	
SEED	23.625
LIME	12
FERTILIZER:	0
MACHINERY/PREHARVEST:	
FUEL	4.675
REPAIRS & MAINT.	10
MACHINERY/HARVEST:	
FUEL	4.25
REPAIRS & MAINT.	15
LAND RENTAL	0
LABOR	24
INTEREST ON OP.CAP	9.836642
DRYING8 POINTS	52.7856
TOTAL VARIABLE COST	156.1722
FIXED COST	
MACHINERY:	
PRE-HARVEST	15.204
HARVEST	28.525
OVERHEAD	14.06071
MANAGEMENT	14.06071
LAND	0
TOTAL FIXED COST	71.85043
TOTAL COST EXCEPT IRRIGATION	228.0227

Table 4.13: Cotton Production Cost

VARIABLE COSTS (\$/acre):	
SEED	5.28
LIME	7.92
FERTILIZER:	0
MACHINERY/PREHARVEST:	
FUEL	7.65
REPAIRS & MAINT.	8
MACHINERY/HARVEST:	
FUEL	8.5
REPAIRS & MAINT.	18
LAND RENTAL	0
LABOR	36
INTEREST ON OP. CAP.	12.29901
GINNING	90
MARKET PREP. CHARGES	31
TOTAL VARIABLE COST	224.649
ADJUSTMENT TO COSTS, COTTONSEED	56
ADJUSTED TOTAL VARIABLE COST	168.649
FIXED COST:	
MACHINERY:	
PRE-HARVEST	21.609
HARVEST	49
OVERHEAD	20.33052
MANAGEMENT	20.33052
LAND	0
TOTAL FIXED COST	111.27
TOTAL COST EXCEPT IRRIGATION	335.919

Table 4.14: Peanut Production Cost

VARIABLE COSTS	
PreHarvest Costs	
Plants 1/	48
Lime, applied	12
Fertilizer	55.85377
Sidedressing	23.125
Insecticide	110
Machinery	27.32
Labor	225.5
Labor, staking	450
Stakes	300
Twine	96
Insurance	140
Land rent	0
Interest on Oper. Cap.	75.24383
Total PreHarvest	1563.043
Harvest and Marketing Costs	
Picking and hauling	650
Grading and packing	2500
Buckets	25
Machinery	9.63
Total Harvest and Marketing	3184.63
Total Variable Costs	4747.673
FIXED COST	
Machinery & Irrigation	114.9406
Land	0
Overhead and Management	262.0993
Total Fixed Costs	377.0399
Total cost except irrigation per acre	5124.712

Table 4.15: Tomato Production Cost

VARIABLE COSTS:	
SEED	85
LIME	22.5
INOCULANT	6
FERTILIZER:	0
AT PLANTING	45
MACHINERYPREHARVEST:	
FUEL	10.2
REPAIRS & MAINT.	20
MACHINERYHARVEST:	
FUEL	9.35
REPAIRS & MAINT.	28
LAND RENTAL	0
LABOR	60
OTHER	0
INTEREST ON OP. CAP.	21.01845
CLEANING	24.5
DRYING	42
COMMODITY COMMISSION	3.5
ASSESSMENT	7.1225
TOTAL VARIABLE COST	384.191
FIXED COST:(Press Button for Annual Fixed Cost)	
MACHINERY:	
PRE-HARVEST	29.76
HARVEST	30.38
OVERHEAD	28.26088
MANAGEMENT	28.26088
LAND	0
TOTAL FIXED COST	116.6618
TOTAL COST EXCEPT IRRIGATION	500.8527

CHAPTER 5

RESULTS AND DISCUSSION

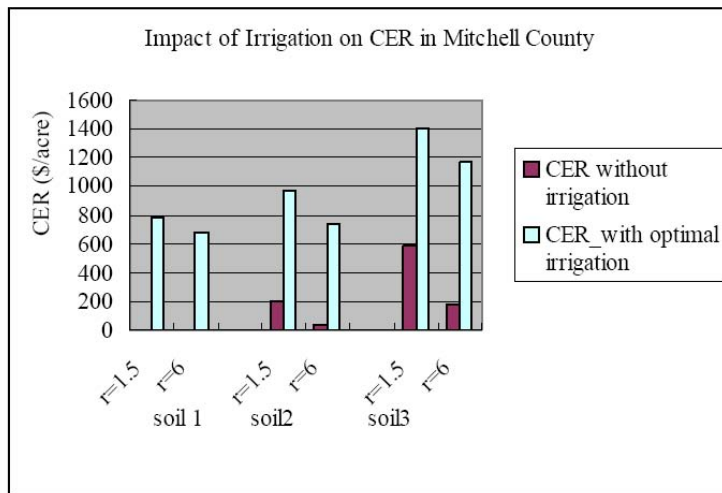
In Georgia, agricultural irrigation is the mainly consumptive water users of water resources. In recent years, water scarcity has become an increasing social and economic concern for policy makers and competitive water users, and there is a need to look at whether the current irrigation is overusing water resources. In an article of Boken and Hoogenboom, they estimated the actual irrigation water use in Georgia: for individual farmers, observed irrigation averaged 29.4 cm (0.96 feet) for corn, 20.7cm (0.68 feet) for cotton, and 22.2cm (0.73 feet) for peanuts[4]. In this section, this actual water use will be compared with the 'optimal' irrigation water use resulting from our model.

The results and discussion are divided to answer the three major questions behind this research. The first part analyzes whether irrigation is a viable tool in farm-level risk management. The second part analyzes the impact of proposed water pricing policies on irrigation decisions. The third part is the regional estimates for the precipitation insurance across the selected three areas and the analysis on the impact of the precipitation insurance on irrigation decisions and risk management.

5.1 IRRIGATION IN FARM-LEVEL RISK MANAGEMENT

To analyze the role of irrigation in farm-level risk management, certainty-equivalent revenues (CER) is used to assess the robustness of the risk reduction performance of the optimal irrigation. Figure 5.1 to 5.4 shows the impact of the optimal irrigation on producers certainty equivalent revenue for corn, cotton, peanut, and tomato production in Mitchell County.

Figure 5.1 shows the differences in CERs between rain-fed and optimal irrigation (which maximizes producers' CER) for corn producers in Mitchell County. This graph indicates that in all soil types and for both high risk-averse producers (with relative risk aversion coefficient equal to 6) and low risk-averse producers (with relative risk aversion coefficient equal to 1.5) the differences in CER are large. On Soil 1, Norgram Sandy Soil, the CER's without irrigation for high and low risk-averse producers are almost zero. With the optimal irrigation application, CER increases significantly to 700\$/acre for high risk averse producers and 780\$/acre for low risk averse producers. On Soil 2, Tifton Loamy Sand, CER's before irrigation application are 40\$/acre and 210\$/acre for low and high risk averse producers respectively; after the optimal irrigation application, the resulting CER's are 780\$/acre and 900\$/acre respectively. On Soil 3, Norfolk Loaming Sand, CER's before irrigation are 200\$/acre and 600\$/acre for high and low risk averse producers; after irrigation application, CER's are 1180\$/acre and 1400\$/acre respectively. These results indicate that irrigation is a viable and effective tool in farm-level risk management for corn producers in Mitchell County.



Soil 1: Norgram Sandy Soil
 Soil 2: Tifton Loamy Sand
 Soil 3: Norfolk Loamy Sand
 r: relative risk aversion level

Figure 5.1: Impact of the Optimal Irrigation on Producers Certainty Equivalent Revenue for Corn Production in Mitchell County.

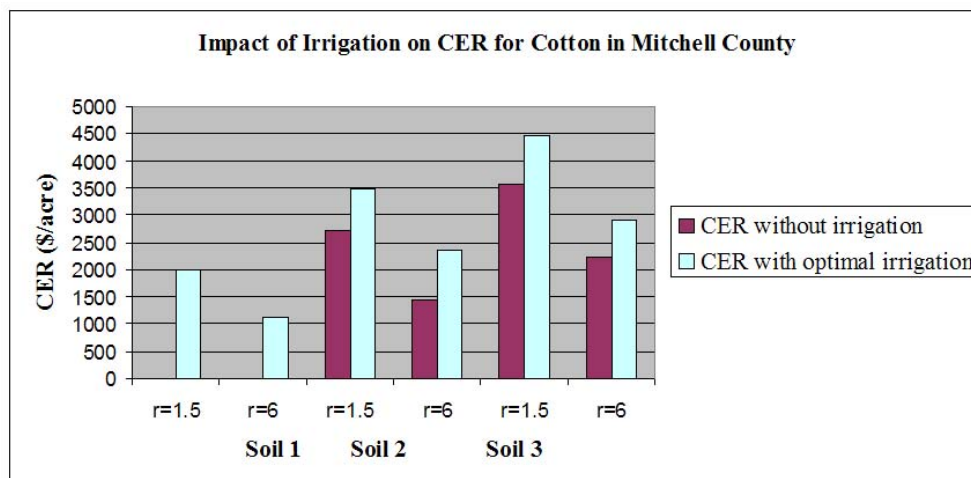


Figure 5.2: Impact of the Optimal Irrigation on Producers Certainty Equivalent Revenue for Cotton Production in Mitchell County.

Figure 5.2 shows the differences in CER's for cotton producers in Mitchell County. This graph shows similar results as those for corn producers. In Soil 1, CER increases from almost zero to 1080\$/acre for high risk averse producers, and from almost zero to 2000\$/acre for low risk averse producers. In Soil 2, CER increases from 1480\$/acre to 2400\$/acre for high risk averse producers, and from 2525\$/acre to 3500\$/acre for low risk averse producers. In Soil 3, CER increases from 2250\$/acre to 2900\$/acre for how risk averse producers and from 3510\$/acre to 4450\$/acre for low risk averse producers. This figure indicates that irrigation is a useful risk management tool for cotton producers in Mitchell County.

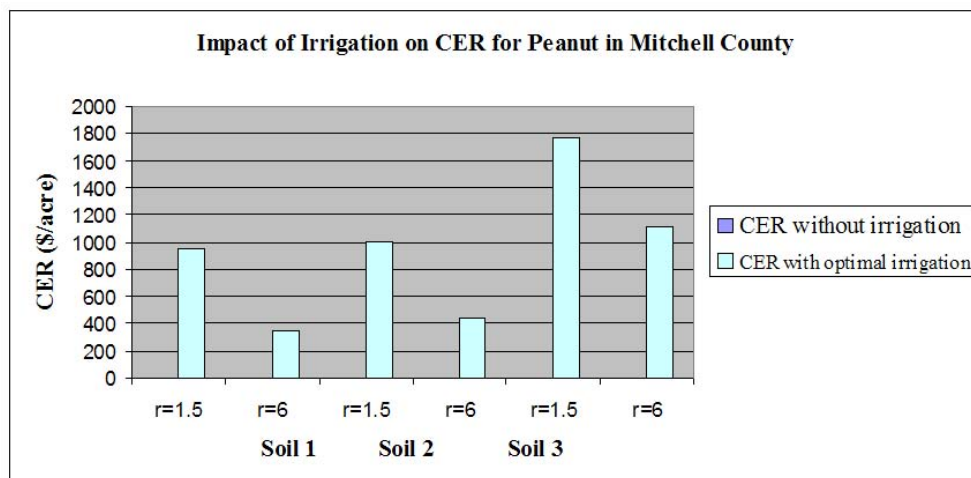


Figure 5.3: Impact of the Optimal Irrigation on Producers Certainty Equivalent Revenue for Peanut Production in Mitchell County.

Figure 5.3 shows the differences in CER's for peanut producers in Mitchell County. In all soil types and for both high and low risk-averse producers, without irrigation, CERs are almost zero, with irrigation, CERs increase substantially, indicating the significance of irrigation in risk management for peanut production in Mitchell County.

Figure 5.4 shows the differences in CERs for tomato producers in Mitchell County. Tomato production shows a quite different scenario, where the CERs with and without irrigation are all very low, nearly zero, for both risk aversion level producers and on all soil types. This graph implies that tomato production would not be appropriate in Mitchell County, even with irrigation application.

Results of the impact of optimal irrigation on producers' CER in other counties are included in Appendix C. The graphs shows similar results as those in Mitchell County, indicating the risk mitigating role of irrigation in corn, cotton, and peanut production, as well as the unprofitability of tomato production in those two counties.

The impact of potential water pricing policies on irrigation water use is analyzed by graphing the relationship between irrigation pumping cost and expected water use. Pumping

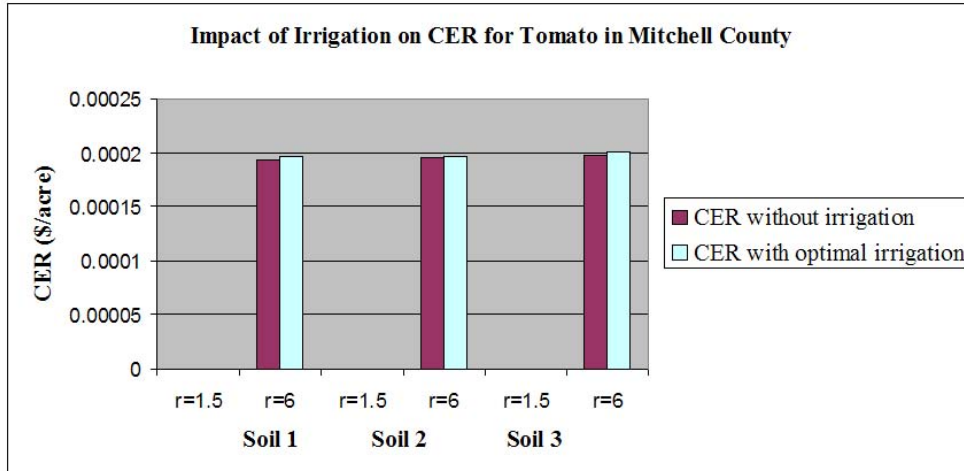


Figure 5.4: Impact of the Optimal Irrigation on Producers Certainty Equivalent Revenue for Tomato Production in Mitchell County.

cost is assumed to increase from 30\$/acre-foot to 80\$/acre-foot. Producers respond to increasing pumping cost by changing their irrigation strategy (varying their irrigation threshold criteria), which changes irrigation water use amount during each growing season. As long as water use amount during each growing season is solved, the expected value of water use during 25 years can be solved.

Figure 5.5 shows the relationship between pumping cost and expected water use for corn, cotton, peanut, and tomato productions on Soil 1 (Norgram Sandy Soil) in Miller County. For corn production, expected water use doesn't change at all with the increase in pumping cost for both high and low risk averse producers, and there is no difference in expected water use between high and low risk averse producers. For cotton production, expected water use drops immediately (when pumping cost rises just above \$30/acre-foot) to zero for high risk averse producers, and drops to zero when pumping cost rises above \$80/acre-foot for low risk averse producers. For peanut producers, the results are similar as those for corn producers, where there is no relationship between expected water use and pumping cost, and there is no difference in expected water use between high and low risk averse producers. For tomato

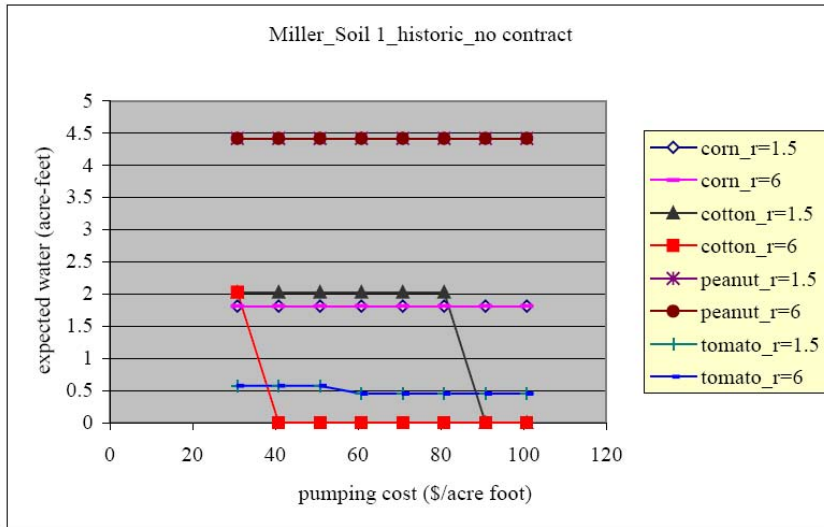


Figure 5.5: Impact of Potential Water Pricing Policy on Producers Optimal Water Use for Miller Soil 1 under Historical Weather Scenario.

producers, the two demand curves for high and low risk averse producers overlap with each other, and show a gradual decrease in expected water use when pumping cost increases, which is consistent with the shape of ordinary good's demand curve.

Figure 5.6 shows the relationship between pumping cost and expected water use for 4 crops on Soil 1 (Norgram Sandy Soil) in Miller County under Future A weather scenario (decrease the number of rainy days by 20% comparing with historic weather). For corn production, expected water use keeps constant at 1.4 acre feet/acre with the increase in pumping cost for both high and low risk averse producers, and there is no difference in expected water use between high and low risk averse producers. This is the same with the corn production under historic weather scenario, the only difference from the results under historic weather scenario is that expected water use is 0.4 acre-feet/acre less than that in historic weather scenario. For cotton production, expected water use keeps zero for high risk averse producers, and drops from 1.7 acre-feet/acre to zero when pumping cost rises above

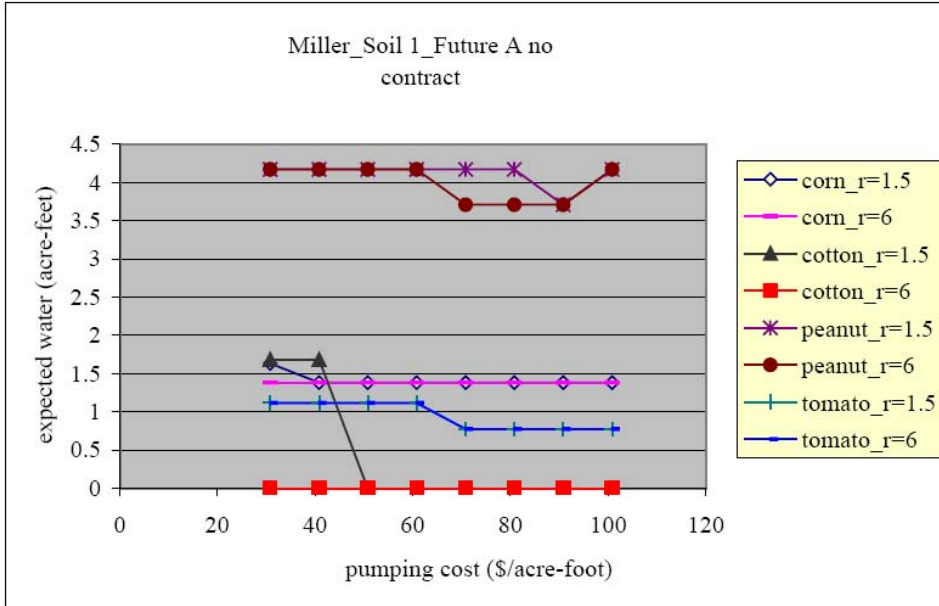


Figure 5.6: Impact of Potential Water Pricing Policy on Producers Optimal Water Use for Miller Soil 1 under Future A weather Scenario (Decreasing Rainy Days)

\$40/acre-foot for low risk averse producers. For peanut producers, the results shows a positive relationship between water price and water use when price goes up above \$80/acre-foot for high risk averse producers, implying that peanut acts like a Giffen good when price goes up too high. For tomato production, again, like the tomato production under historic weather scenario, the two demand curves for high and low risk averse producers overlap with each other, and show a gradual decrease in expected water use when pumping cost increasing, which is the only case here consistent with the shape of ordinary good's demand curve.

Figure 5.7 shows the relationship between pumping cost and expected water use for 4 crops on Soil 1 in Miller County under Future B weather scenario (increase precipitation amount by 20% comparing with historic weather). For corn production, expected water use keeps constant at 1.7 acre feet/acre with the increase in pumping cost for both high and low risk averse producers, and there is no difference between high and low risk averse producers.

This is the same with the corn production under historic and Future A weather scenario, the only difference is that expected water use is 0.1 acre-feet/acre less than that under historic weather scenario, and 0.3 acre-feet/acre more than that under Future A weather scenario. For cotton production, expected water use keeps zero for high risk averse producers, and drops from 1.7 acre-feet/acre to zero when pumping cost rises above \$50/acre-foot for low risk averse producers. For peanut producers, the results are similar as those for peanut producers under historic weather scenario, where the expected water use keeps constant at 4.4 acre-feet/acre with increasing pumping cost, and there is no difference between high and low risk averse producers. For tomato production, again, like the tomato production under historic and Future A weather scenario, the two demand curves for high and low risk averse producers overlap with each other, and show a gradual decrease in expected water use when pumping cost increasing, which is the only case here consistent with the shape of ordinary good's demand curve.

Figure 5.8 shows the relationship between pumping cost and expected water use for 4 crops on Soil 1 in Miller County under Future C weather scenario (increase precipitation amount by 20% comparing with historic weather). For corn production, expected water use keeps constant at 1.4 acre feet/acre with the increase in pumping cost for both high and low risk averse producers, and there is no difference between high and low risk averse producers. This is the same as the case of corn production under Future A weather scenario. For cotton production, expected water use keeps at 1.4 acre-feet/acre for high risk averse producers, and drops from 1.4 acre-feet/acre to zero when pumping cost rises above \$40/acre-foot for low risk averse producers. For peanut production, the high risk averse producers didn't change their irrigation amount before pumping cost hit 80\$/acre-foot, and decrease water use to 3.3\$/acre-foot thereafter; the low risk averse producers keep water use constant before pumping cost hit 85\$/acre-foot and then decrease water use to 3.3\$/acre-foot thereafter. For tomato production, the two demand curves for high and low risk averse producers overlap with each other, and keep constant when pumping cost increases.

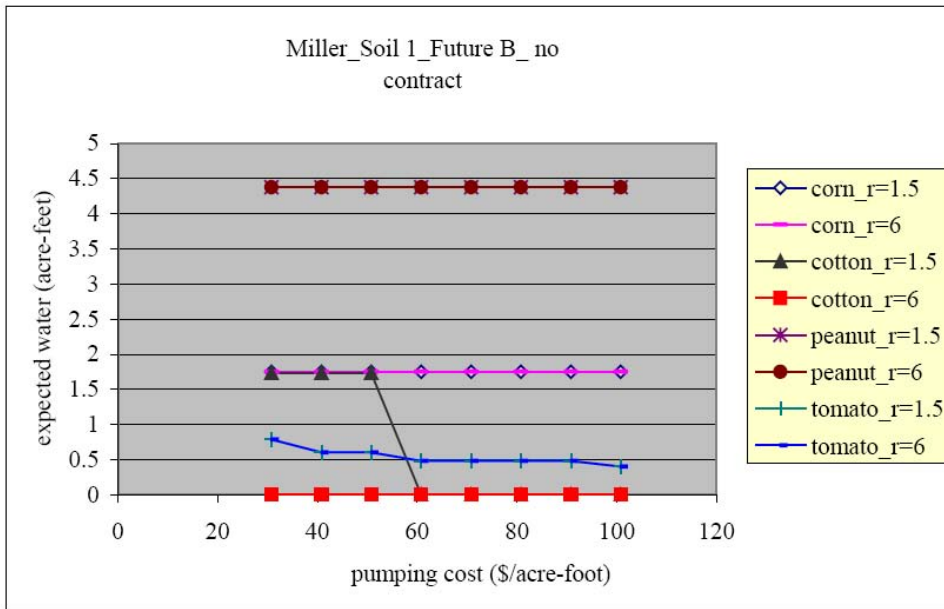


Figure 5.7: Impact of Potential Water Pricing Policy on Producers Optimal Water Use for Miller Soil 1 under Future B Weather Scenario (Increasing Precipitation Amount).

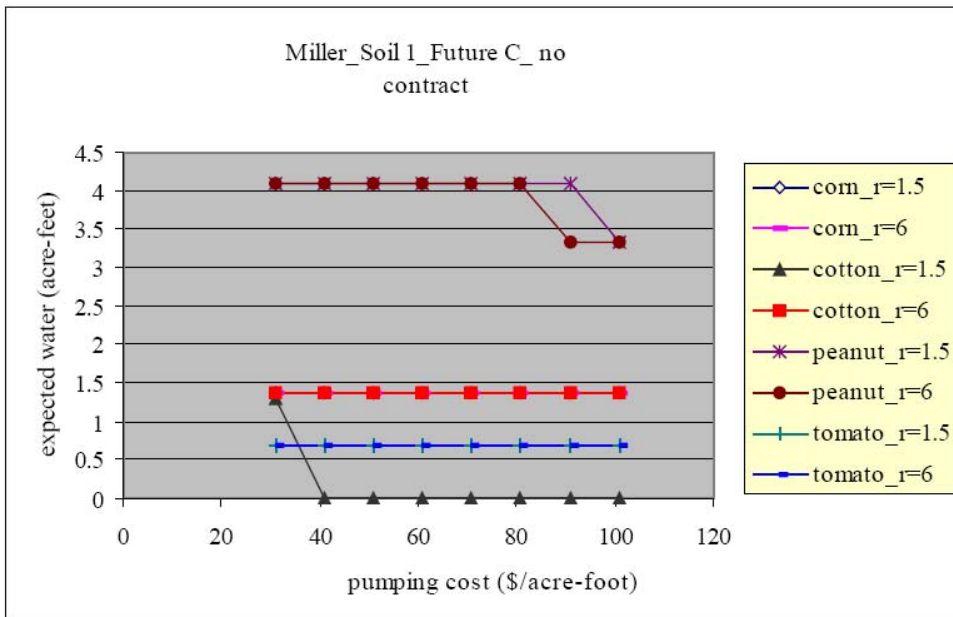


Figure 5.8: Impact of Potential Water Pricing Policy on Producers Optimal Water Use for Miller Soil 1 under Future C Weather Scenario (Decreasing Rainy Days and Increasing Precipitation Amount).

The relationship between pumping cost and water use for other counties are shown in Appendix C. Most of the graphs show flat lines unless pumping cost increases significantly, indicating that the water demand is inelastic with respect to its own price. These graphs indicate that the proposed water pricing policy would have limited effect on irrigation water use. There are exceptions for cotton production, where some of the graphs shows large drops in water use when water price increases. These exceptions can be partly explained by Figure ??, which show the relationship between expected yield and expected water use for the four crops. These Figures indicate that cotton yield is not responsive to water use, which means that by cutting back water use, producers can save water costs without much loss in revenues.

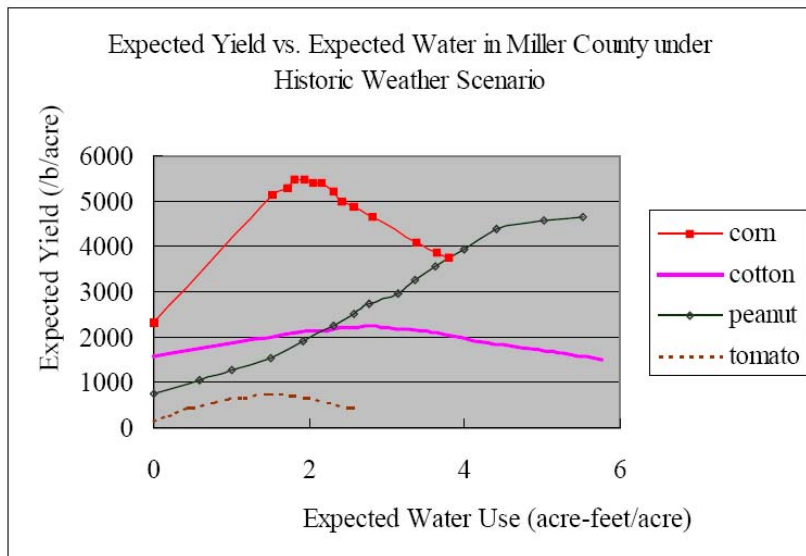


Figure 5.9: Relationship between Expected Yield and Expected Water Use in Miller County Soil 1 under Historic Weather Scenario

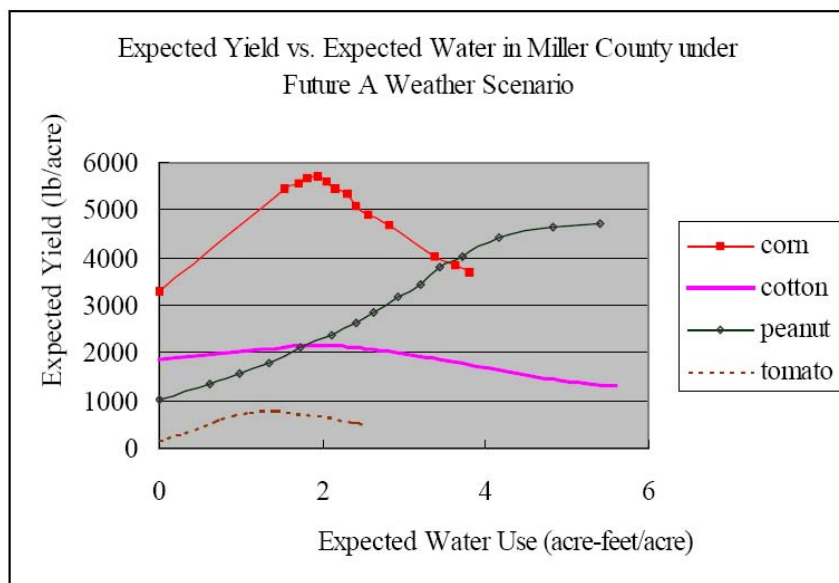


Figure 5.10: Relationship between Expected Yield and Expected Water Use in Miller County Soil 1 under Future A Weather Scenario (Decreasing Number of Rainy Days).

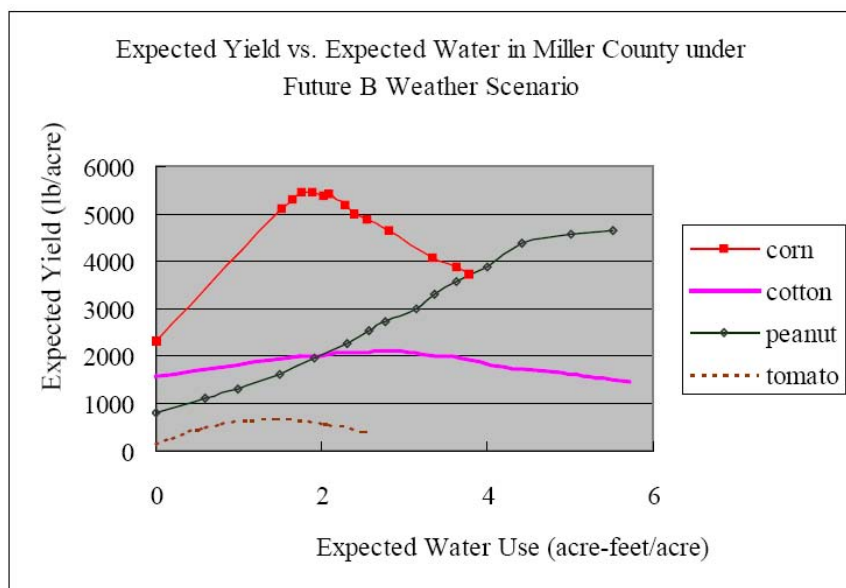


Figure 5.11: Relationship between Expected Yield and Expected Water Use in Miller County Soil 1 under Future B Weather Scenario (Increasing Precipitation Amount).

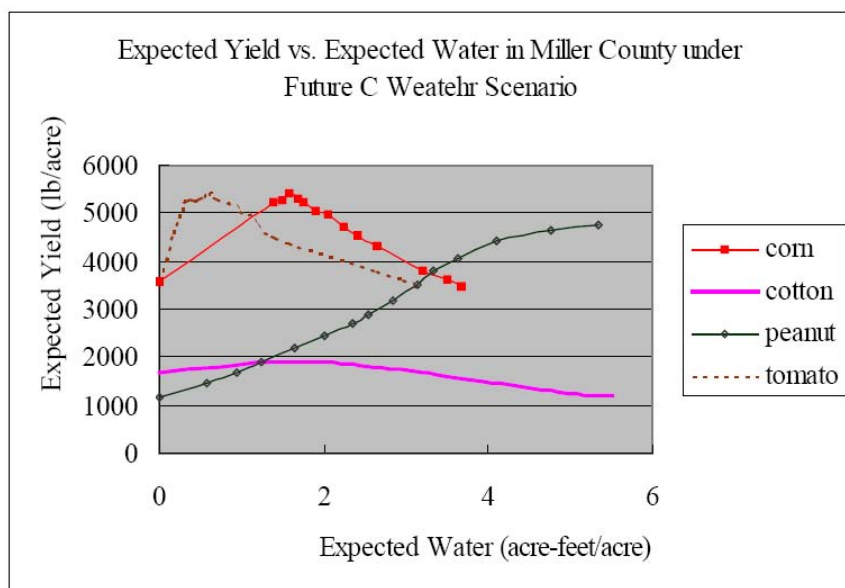


Figure 5.12: Relationship between Expected Yield and Expected Water Use in Miller County Soil 1 under Future C Weather Scenario (Decreasing Number of Rainy Days and Increasing Precipitation Amount).

5.2 REGIONAL ESTIMATES FOR PRECIPITATION CONTRACTS

Regional estimates for the contract design are presented from Table D.1 to Table D.12 (Appendix D). The three areas in Georgia provide a range of estimates. This indicates a range of underlying risk scenarios embedded in the system.

For given combinations of i^* and limit parameter λ , the fair premium is calculated according to (3) and (4), and the loaded premium is calculated by fixing load factor $\gamma = 10\%$. The loaded premium rate is arrived at by dividing the loaded premium by the maximum liability and expressed in percentages. Based on the figures, a tick (i.e. maximum $liability/(i^* - \lambda i^*)$) is set for the precipitation design. This would mean that the contract would pay the insured tick for the total value of the insured liability for each mm of annual precipitation below the strike.

Our results show that optimal derivative contracts designed to maximize producers expected utility function are different for different crops under different growing conditions and location. For the contract hedging corn production in Miller County 5.4, the optimal strikes are much smaller than the average precipitation in all areas, which results in 0 payoff and thus the fair premium is 0 (\$5 load is assumed onto the fair premium). The premium rates associated with the weather contracts turned out to be low, ranging from 0.01 to 0.03 for both risk aversion levels.

Table 5.2 shows the optimal weather derivative contracts in Miller County for cotton producers. In most cases, the optimal strikes are much smaller than the average precipitation, resulting in low premium rate, mostly less than 0.02. However, there are exceptions for which premium rate is high for high risk averse producers under Future A weather scenario (decreasing rainy days only) on Soil 3 (Norfolk Loamy), premium rate is as high as 0.19; for high risk averse producers under Future B weather scenario (increasing rainy amount) on Soil 3Sand (Norfolk Loamy Sand), the premium rate is as high as 0.32. In these two cases, the strikes are set much higher than in other cases, which leads to higher probability of trigger contract payment. Their ticks are also much higher than in other cases (\$33.05/mm and

Table 5.1: Contract Parameters for Corn Production in Miller County. Max_L: maximum liability (\$/acre); E_rain: expected rain fall amount during growing season (mm); tick: payoff for each mm of rainfall below strike (\$/mm); prem_rate: premium rate

	soil	R	Max_L	E_rain	strike	limit	tick	prem_rate
historic	1	1.5	714	574	159	0.77	19.51	0.01
	1	6	714	574	159	0.77	19.51	0.01
	2	1.5	506	574	159	0.84	19.9	0.02
	2	6	506	574	159	0.83	18.72	0.02
	3	1.5	457	574	159	0.76	11.95	0.02
	3	6	457	574	159	0.76	11.95	0.02
FutureA	1	1.5	676	588	330	0.77	8.91	0.01
	1	6	676	588	330	0.75	8.19	0.01
	2	1.5	436	588	330	0.81	6.94	0.02
	2	6	436	588	330	0.81	6.94	0.02
	3	1.5	359	588	330	0.76	4.53	0.03
	3	6	359	588	330	0.75	4.35	0.03
FutureB	1	1.5	713	632	177	0.77	17.51	0.01
	1	6	713	632	177	0.77	17.51	0.01
	2	1.5	492	632	177	0.84	17.39	0.02
	2	6	492	632	177	0.84	17.39	0.02
	3	1.5	427	632	177	0.77	10.49	0.02
	3	6	427	632	177	0.77	10.49	0.02
FutureC	1	1.5	677	687	389	0.75	6.95	0.01
	1	6	677	687	389	0.75	6.95	0.01
	2	1.5	420	687	389	0.81	6.68	0.02
	2	6	420	687	389	0.81	6.68	0.02
	3	1.5	343	687	389	0.75	3.53	0.03
	3	6	343	687	389	0.75	3.53	0.03

\$29.12/mm respectively, meaning that producers would get 33.05 and 29.12 when precipitation is 1 mm lower than the contracted strike), and thus the contracts have higher values and higher premium rates.

Table 5.2: Contract Parameters for Cotton Production in Miller County. Max_L: maximum liability (\$/acre); E_rain: expected rain fall amount during growing season (mm); tick: payoff for each mm of rainfall below strike (\$/mm); prem_rate: premium rate

	soil	R	Max_L	E_rain	strike	limit	tick	prem_rate
historic	1	1.5	1254	1123	705	0.76	7.41	0.01
	1	6	1254	1123	735	0.75	6.83	0
	2	1.5	649	1123	705	0.8	4.6	0.02
	2	6	649	1123	705	0.8	4.6	0.02
	3	1.5	652	1123	705	0.75	3.7	0.02
	3	6	652	1123	705	0.75	3.7	0.02
FutureA	1	1.5	1188	1101	777	0.76	6.37	0.01
	1	6	1188	1101	807	0.75	6.89	0
	2	1.5	634	1100	777	0.81	4.29	0.02
	2	6	634	1100	777	0.77	3.55	0.02
	3	1.5	620	1101	777	0.82	4.43	0.02
	3	6	620	1101	937	0.98	33.06	0.19
FutureB	1	1.5	1254	1237	778	0.75	6.45	0.01
	1	6	1254	1237	808	0.75	6.21	0
	2	1.5	647	1237	778	0.82	4.62	0.02
	2	6	647	1237	778	0.79	3.96	0.02
	3	1.5	631	1174	694	0.77	3.95	0.02
	3	6	631	1174	1084	0.98	29.12	0.32
FutureC	1	1.5	1161	1284	910	0.75	6.11	0.01
	1	6	1161	1284	940	0.75	4.94	0
	2	1.5	603	1284	922	0.81	3.44	0.02
	2	6	603	1284	922	0.77	2.84	0.02
	3	1.5	620	1285	922	0.75	2.69	0.02
	3	6	620	1285	952	0.75	2.6	0

For peanut production, similar to the corn case, the optimal strike for Lee is also much smaller than the average precipitation, resulting in low premium rate, ranging from 0.01 to 0.02.

For tomato production, similar to the cotton case, premium rates are also very low in most instances, In this tomato case, premium rates are mostly no larger than 3%. Exceptions

Table 5.3: Contract Parameters for Peanut Production in Miller County. Max_L: maximum liability (\$/acre); E_rain: expected rain fall amount during growing season (mm); tick: payoff for each mm of rainfall below strike (\$/mm); prem_rate: premium rate

	soil	R	Max_L	E_rain	strike	limit	tick	prem_rate
historic	1	1.5	1032	1033	690	0.86	10.69	0.01
	1	6	1032	1033	690	0.86	10.69	0.01
	2	1.5	567	1034	690	0.88	6.83	0.02
	2	6	567	1034	690	0.88	6.83	0.02
	3	1.5	676	1034	690	0.84	6.12	0.01
	3	6	676	1034	690	0.84	6.12	0.01
FutureA	1	1.5	994	1005	688	0.86	10.32	0.01
	1	6	994	1005	688	0.86	10.32	0.01
	2	1.5	562	1007	688	0.88	6.81	0.02
	2	6	562	1007	688	0.87	6.29	0.02
	3	1.5	576	1007	688	0.84	6.23	0.02
	3	6	576	1007	688	0.84	6.23	0.02
FutureB	1	1.5	1003	1138	762	0.86	9.41	0.01
	1	6	1003	1138	762	0.86	9.41	0.01
	2	1.5	559	1138	762	0.88	6.12	0.02
	2	6	559	1138	762	0.88	6.12	0.02
	3	1.5	659	1137	762	0.84	6.41	0.02
	3	6	659	1137	762	0.84	6.41	0.02
FutureC	1	1.5	993	1172	806	0.86	8.8	0.01
	1	6	993	1172	806	0.86	8.8	0.01
	2	1.5	547	1177	806	0.88	6.65	0.02
	2	6	547	1177	806	0.87	6.22	0.02
	3	1.5	548	1176	806	0.85	4.53	0.02
	3	6	548	1176	806	0.85	4.53	0.02

includes low and high risk averse producers under historic weather scenario on Soil 2, where premium rate is 7%; and high and low risk averse producers under Future B weather scenario on Soil 2, the premium rate is also 7%. In these two cases, the strikes are set much higher than in other cases, which leads to higher probability of trigger contract payment. Their ticks are also much higher than in other cases (\$61.69/mm and \$56.3/mm respectively)

Table 5.4: Contract Parameters for Tomato Production in Miller County. Max_L: maximum liability (\$/acre); E_rain: expected rain fall amount during growing season (mm); tick: payoff for each mm of rainfall below strike (\$/mm); prem_rate: premium rate

	soil	R	Max_L	E_rain	strike	limit	tick	prem_rate
historic	1	1.5	549	410	88	0.81	32.86	0.02
	1	6	549	410	88	0.81	32.86	0.02
	2	1.5	331	410	268	0.98	61.69	0.07
	2	6	331	410	268	0.98	61.69	0.07
	3	1.5	333	410	88	0.83	22.25	0.03
	3	6	333	410	88	0.83	22.25	0.03
FutureA	1	1.5	505	397	185	0.83	16.05	0.02
	1	6	505	397	185	0.83	16.05	0.02
	2	1.5	302	397	215	0.75	6.63	0.01
	2	6	302	397	215	0.75	6.63	0.01
	3	1.5	306	397	185	0.83	9.74	0.03
	3	6	306	397	185	0.83	9.74	0.03
FutureB	1	1.5	535	451	99	0.81	28.42	0.02
	1	6	535	451	99	0.81	28.42	0.02
	2	1.5	331	451	299	0.98	56.3	0.07
	2	6	331	451	299	0.98	56.3	0.07
	3	1.5	333	451	99	0.84	21.02	0.03
	3	6	333	451	99	0.84	21.02	0.03
FutureC	1	1.5	616	384	189	0.78	14.79	0.02
	1	6	616	384	189	0.78	14.79	0.02
	2	1.5	447	384	189	0.85	16.76	0.02
	2	6	447	384	189	0.85	16.76	0.02
	3	1.5	489	384	189	0.81	13.63	0.02
	3	6	489	384	189	0.81	13.63	0.02

The optimized combinations of i^* and λ for other crops and in other weather stations are presented in Appendix D. These are the combinations that yield the largest expected utility for a specific risk aversion level ξ . The variety of indices and contract types presented from

Table D.1 to D.12 indicate that weather derivatives cannot be designed in a one-size-fits-all manner, even for the same crop (corn in Mitchell vs. corn in Miller) or within the same area (Mitchell corn vs. Mitchell cotton).

5.3 IMPACT OF PRECIPITATION CONTRACT ON IRRIGATION AND RISK MANAGEMENT

Tables 5.5 to Table 5.5 present changes in producers irrigation decisions after purchasing precipitation insurance, as well as changes in producers well-being as measured by CER.

Table 5.5 reports the results of the impact of weather derivative contracts on irrigation decisions and certainty equivalent revenues for corn producers in Miller County. Under all weather scenarios and for both risk-aversion-level producers, WD contract doesn't change irrigation water use or make the risk-averse crop producers better off.

Table 5.6 reports the impact of weather derivative contracts on irrigation decisions and certainty equivalent revenues for cotton producers in Miller County. The changes in expected water in most cases are zero. The risk-averse crop producers in three counties are not generally made better off by purchasing WD insurance. The exceptions includes high risk averse producers under historic weather scenario on Soil 1, expected water use decreases by 2.03 acre feet, and producers are made worse off by decreasing CER by 12\$/acre, high risk averse producers under Future B and Future C weather scenario on Soil 3 , expected water use decreases by 1.29 and 1.23 acre feet respectively, and producers are made better off by increasing CER by 44 and 52\$ respectively.

Table 5.7 shows the impact of weather derivative contract on optimal irrigation and CER for peanut production in Miller County. This table indicates that the change in expected water are all zero and the changes in CER are all negative, implying that WD insurance wouldn'tt change irrigation water use or make the risk-averse producers better off for peanut production in Miller County.

For tomato production, without weather derivative contract, the optimal irrigation amounts are very low, all less than 1 acre-feet, and the net revenues are very low too,

Table 5.5: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Corn Producers in Miller County

	soil	relative risk aversion coefficient	CER_with contract	EW_with contract	CER_without contract	EW_without contract	change in CER	change in EW
historic	1	1.5	770	1.81	781	1.81	-11	0
	1	6	599	1.81	613	1.81	-14	0
	2	1.5	986	1.29	997	1.29	-10	0
	2	6	866	1.18	877	1.18	-11	0
	3	1.5	1415	1.05	1426	1.05	-10	0
	3	6	1300	1.05	1311	1.05	-11	0
FutureA	1	1.5	839	1.63	850	1.63	-11	0
	1	6	660	1.39	674	1.39	-14	0
	2	1.5	1097	0.86	1106	0.86	-10	0
	2	6	991	0.86	1002	0.86	-11	0
	3	1.5	1441	0.76	1452	0.76	-10	0
	3	6	1321	0.74	1333	0.74	-11	0
FutureB	1	1.5	732	1.75	743	1.75	-11	0
	1	6	540	1.75	555	1.75	-15	0
	2	1.5	1003	1.25	1013	1.25	-10	0
	2	6	875	1.25	887	1.25	-12	0
	3	1.5	1419	1.03	1429	1.03	-10	0
	3	6	1304	1.03	1316	1.03	-11	0
FutureC	1	1.5	778	1.38	789	1.38	-11	0
	1	6	547	1.38	561	1.38	-16	0
	2	1.5	1134	0.77	1145	0.77	-10	0
	2	6	1024	0.77	1037	0.77	-11	0
	3	1.5	1455	0.58	1466	0.58	-10	0
	3	6	1332	0.58	1343	0.58	-11	0

Table 5.6: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Cotton Producers in Miller County

	soil	relative risk aversion coefficient	CER_with contract	EW_with contract	CER_without contract	EW_without contract	change in CER	change in EW
historic	1	1.5	1397	2.03	1417	2.03	-18	0
	1	6	567	0	577	2.03	-12	-2.03
	2	1.5	2790	1.14	2804	1.14	-14	0
	2	6	1647	1.14	1660	1.14	-13	0
	3	1.5	3707	1.16	3719	1.16	-13	0
	3	6	2423	1.16	2437	1.16	-13	0
FutureA	1	1.5	1592	1.69	1608	1.69	-17	0
	1	6	764	0	767	0	-3	0
	2	1.5	2964	1.01	2978	1.01	-14	0
	2	6	1790	0.69	1803	0.69	-13	0
	3	1.5	3884	1.29	3897	1.29	-13	0
	3	6	2628	0	2584	1.29	44	-1.29
FutureB	1	1.5	1237	1.73	1256	1.73	-20	0
	1	6	547	0	550	0	-2	0
	2	1.5	2665	1.26	2679	1.26	-14	0
	2	6	1546	0.97	1559	0.97	-13	0
	3	1.5	3882	1.23	3895	1.23	-13	0
	3	6	2786	0	2734	1.23	52	-1.23
FutureC	1	1.5	1359	1.3	1376	1.3	-17	0
	1	6	614	0	616	0	-2	0
	2	1.5	2765	0.87	2779	0.87	-14	0
	2	6	1632	0.56	1646	0.56	-13	0
	3	1.5	3643	0.66	3656	0.66	-13	0
	3	6	2390	0	2391	0	-1	0

Table 5.7: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Peanut Producers in Miller County

	soil	relative risk aversion coefficient	CER_with contract	EW_with contract	CER_without contract	EW_without contract	change in CER	change in EW
historic	1	1.5	791	4.42	809	4.42	-19	0
	1	6	182	4.42	201	4.42	-19	0
	2	1.5	844	2.53	859	2.53	-16	0
	2	6	287	2.53	307	2.53	-18	0
	3	1.5	1504	2.8	1517	2.8	-12	0
	3	6	1006	2.8	1021	2.8	-15	0
FutureA	1	1.5	904	4.17	918	4.17	-14	0
	1	6	417	4.17	435	4.17	-17	0
	2	1.5	1026	2.36	1038	2.36	-13	0
	2	6	604	2.1	619	2.1	-16	0
	3	1.5	1598	2.31	1610	2.31	-12	0
	3	6	1206	2.31	1219	2.31	-13	0
FutureB	1	1.5	796	4.38	814	4.38	-18	0
	1	6	199	4.38	218	4.38	-19	0
	2	1.5	868	2.46	883	2.46	-15	0
	2	6	349	2.46	366	2.46	-18	0
	3	1.5	1517	2.68	1528	2.68	-12	0
	3	6	1027	2.68	1042	2.68	-15	0
FutureC	1	1.5	922	4.1	936	4.1	-14	0
	1	6	458	4.1	474	4.1	-16	0
	2	1.5	1064	2.24	1077	2.24	-13	0
	2	6	639	2	653	2	-14	0
	3	1.5	1618	2.27	1630	2.27	-12	0
	3	6	1204	2.27	1216	2.27	-13	0

resulting almost zero CER. With weather derivative contract, there are slight changes in expected water use, but still very low, and the CERs are still almost zero. This result implies that tomato production is not profitable in Miller County, even with irrigation and weather derivative contract.

The impact of purchasing weather derivative contract on irrigation water use and on producers' well-beings (CER) in other two counties are listed in Appendix E). These tables show that in most situations WD insurance doesn't change irrigation water use or make the risk-averse crop producers better off.

The exceptions occur for contracts based on corn production in Soil 1 under historic weather scenario (+7), Soil 1 (+30) and Soil 3 (+46) under Future C weather scenarios, cotton production in Mitchell County Soil 1 under historic weather scenario (+7), in Soil 1 (+29) and Soil 3 (+46) under Future B weather scenario, cotton production in Miller County Soil 3 under Future A weather scenario (+43), and cotton production in Lee County Soil 3 under Future C weather scenario (+9), where the CER measures indicate that the insurance purchase would make the representative producer slightly better off, and producers will cut off water use completely from initial optimal irrigation to nonirrigation completely.

Therefore, the results indicate that the risk-averse crop producers in three counties are not generally made better off by purchasing WD insurance. The optimal strikes are normally set much lower than the expected rainfall during the growing season, which makes the indemnity each year very low, and this leads to low fair premium and loaded premium, as shown by the very low loaded premium rate. As a result, producers gain little profits from buying weather derivative contracts each year, and the 10% proportional load only increases their cost. If the weather derivative contract is applied on non-irrigated crops, it may increase producers utility because of its role in variance reduction. But in our case, with irrigation application, the variance of profits during the 25 years is already much lower than that for non-irrigated crops, and thus the role of weather derivative contracts in variance reduction is not promising compared with its cost which decreases the expected value of producers net revenue.

Table 5.8: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Tomato Producers in Miller County

	soil	relative risk aversion coefficient	CER_with contract	EW_with contract	CER_without contract	EW_without contract	change in CER	change in EW
historic	1	1.5	0	0.78	0	0.78	0	0
	1	6	0	0.78	0	0.78	0	0
	2	1.5	0	0	0	0.09	0	-0.09
	2	6	0	0	0	0.09	0	-0.09
	3	1.5	0	0.64	0	0.64	0	0
	3	6	0	0.64	0	0.64	0	0
FutureA	1	1.5	0	1.12	0	1.12	0	0
	1	6	0	1.12	0	1.12	0	0
	2	1.5	0	0	0	0	0	0
	2	6	0	0	0	0	0	0
	3	1.5	0	0.66	0	0.66	0	0
	3	6	0	0.66	0	0.66	0	0
FutureB	1	1.5	0	0.79	0	0.79	0	0
	1	6	0	0.79	0	0.79	0	0
	2	1.5	0	0	0	0.18	0	-0.18
	2	6	0	0	0	0.18	0	-0.18
	3	1.5	0	0.81	0	0.81	0	0
	3	6	0	0.81	0	0.81	0	0
FutureC	1	1.5	0	0.7	0	0.7	0	0
	1	6	0	0.7	0	0.7	0	0
	2	1.5	0	0.72	0	0.72	0	0
	2	6	0	0.72	0	0.72	0	0
	3	1.5	0	1.2	0	1.2	0	0
	3	6	0	1.2	0	1.2	0	0

CHAPTER 6

CONCLUSIONS

This thesis presents an analysis of the role of irrigation in farm-level risk management and the effectiveness of water pricing policies and weather derivatives in reducing water use. The three studies included here are (1) analyzing the impact of irrigation on producers' certainty equivalent revenue (CER); (2) analyzing the impact of potential water pricing policy on optimal water use; and (3) exploring market-based financial instrument in weather markets and assessing their potential role in reducing farm-level risk and irrigation water use. These three studies are focused on corn, cotton, peanut, and tomato production in Mitchell, Miller, and Lee Counties in Georgia, and under four assumed weather scenarios (historic, Future A, Future B, and Future C).

The first study uses an agronomic crop growth model, Decision Support System for Agro-Technology Transfer (DSSAT), together with a well-behaved expected utility function representing constant relative risk aversion, to examine irrigation strategies across different levels of risk aversion coefficients. Specifically, it: (1) derives optimal irrigation decisions for farmers who vary in their risk preferences, crop types, and production weather conditions; (2) compares producers certainty equivalent revenues under optimal irrigation with rainfed production. The results indicates that irrigation plays an important role in protecting against production losses caused by rainfall variability. Moreover, the optimal irrigation amounts resulting from our model are generally less than the observed amounts in Georgia. Does this implies that farmers are not over-applying water, and that there is no inefficiency problem in irrigation?

The answer depends on how water use efficiently is defined. The technical concept of efficiency of irrigation water use is usually measured by the ratio between total water supplied by the system to total water taken by the plant. It is measured in terms of the physical layout of the canal systems such as conveyance, distribution and application efficiencies. These follow accounting of the loss of irrigation water due to seepage and percolation, and evaporation during conveyance and water use at the farm level[15]. There are, however, a wide range of efficiency measures other than technical efficiency, such as economic efficiency and ecological efficiency.

The economic efficiency of irrigation water use is measured in terms of crop output per unit of water applied or overall financial returns in terms of net benefits from the project. Economic efficiency usually measured in terms of cost-benefit ratio, has long been used in investment decision making, which seeks to derive maximum return from the irrigation system over the project life period. It also does include impacts by price policies and incentives for farmers to move to high value crops, which implies that water needs to be used with maximum possible efficiency. In general, economic efficiency indicates the Pareto optimality condition and considers not only the private costs and benefits but also the internalization of the non- financial social costs and benefits. Economic efficiency also refers to the maximization of overall socio-economic net benefits from different water using sectors, and seeks to minimize inter-sectoral and intra-sectoral socio-economic opportunity cost[42]. From the sustainability viewpoint, the concept of economic efficiency could be defined in terms of weak sustainability considering water as a "critical capital"[57]. To some extent, increasing investment in water augmentation could also minimize the scarcity of water.

The term ecological efficiency in case of irrigated agriculture is deeply rooted in the concept of environmental sustainability. For example, water used for irrigation purposes also results into negative impacts such as increased water logging, salinization, and soil erosion.

Thus, the term 'water use efficiency' needs to be considered in a broader perspective and should include factors involving technical efficiency, opportunity cost of water, and

externality costs generated by the irrigated agriculture[55]. Our analysis only compares the 'optimal' water use amount with actual water use amount from individual farmers' perspectives, not considering the overall efficiencies among competitive uses (including downstream users, in-situ environmental services etc.), as well as the negative externality of irrigation. Thus, it is not appropriate to conclude that irrigation is not over-applied in South Georgia.

The second study analyzes the effectiveness of potential water price policy on irrigation water use. Pumping cost is used to approximate current water price, and is assumed to increase from 30/acrefoot to 80/acre foot in the future (almost tripled).

Our results suggest that the potential water pricing policy would like to have a limited effect on irrigation water use. The main reason for this result is that the water demand price elasticity is very low for crop production[66], and thus farmers would not decrease water use much unless very large increase in water price. The implication for this result is: if water charge is based on the fixed or flat rate system, water pricing policy may not function well in encouraging irrigation water conservation. It should be noted this result is based on the assumption of constant technology; but the fact is: an increase in price could lead to the adoption of more water conserving/ efficient technologies[48]. However, even if this is true, irrigation amount would not decrease significantly unless substantial increase in water price to justify technology investment. First, technology investment is costly. Second, farmers would like to substitute water for other factors of production such as labor rather than technology. For example, in rice farming, ponding of water in greater depth helps to allow less weed growth and would reduce labor costs[11]. The substantial increase in water price would cause new problems, such as income inequality. The use of monetary means such as increased water price could also have negative impact on the smallholder farmers and those practicing subsistence level farming. Usually in irrigated areas, the larger producers have gained more than the small producers[16]. In addition, implementation of monetary measures such as those based on marginal cost pricing (input pricing) and marginal value product (output-based pricing) are very difficult to design and implement due to problems

in observing and collecting sufficient information needed to estimate the optimal price based on marginal cost and benefits (asymmetric information).

The third study analyzed the impact of market-based financial instrument on irrigation water use. A precipitation contract is designed as a supplement of irrigation to help farmers manage risk. Specifically, (1) individual precipitation contracts are developed to protect against crop production risk faced by corn, cotton, peanut, and tomato producers in Mitchell, Miller, and Lee Counties respectively; and (2) their potential role in reducing farm-level risk and irrigation water use is assessed.

Our results indicate that, under the assumption of perfect competitive market and perfect information symmetry, weather derivative contracts would not be effective at mitigating risk to irrigated crop productions or affect irrigation amount. In cases it does, producers would switch completely from irrigation to WD contract, presenting an Either or situation. Thus, market-based weather derivative contracts may not fit in irrigation management, and may not serve as a viable supplemental mechanism to mitigate weather risk.

From the results of this study, irrigation is not over-applied from individual farmer's point of view (maximizing expected utility); neither regulatory policies nor market-based incentives are effective in reducing irrigation water use. Then the question is how to improve water use efficiency and what location/sector across the state should be targeted at.

As has been argued before, water use efficiency is affected by many factors, some of which are exogenous to the decision maker. Water loss due to evaporation from open channels, wind drift, bare soil and weeds is usually responsible for 20-30 percent of total water loss. Various factors such as surface losses, canal flow not applied to the field, runoff from the field, and outflow from drains, etc. are responsible for water loss. These factors are mainly influenced by agro-ecological characteristics, type of technology and methods of cultivation practiced by farmers, socio-economic factors and organizational effectiveness, etc., and efforts towards reducing water loss and improving water use efficiency thus require an integrated approach, e.g., a combination of legislative measure, technology-based incentives,

and economic incentives. For example, establish barriers against unnecessary water use, set up crop zoning based on land capability and suitability analysis, establish block rate pricing structure, setting up of uniform charges for covering operation and maintenance costs in order to finance for minimizing evaporation water loss, etc.

CHAPTER 7

LIMITATIONS OF THIS STUDY

This section discusses the limitations of the studies. It should be noted that the analysis is conditioned on some assumptions.

First, the loaded premium is based on the expected value of indemnity during the analysis years (25 years), which is exactly the insurance coverage duration. In reality, insurance companies may not set the premium in this way. They may set the fair premium based on a much longer duration.

Second, the strike and limit parameter are optimized so as to maximize producers' expected utility, which implies that the purchaser knows the exact value of these parameters, and that the contract is designed exactly from the farmers perspective (for maximizing the risk-reducing capability of the weather derivative), which is an unpractical assumption, because these kind of insurance product may not exist in the market, unless perfect competitive market is assumed. To mitigate for such limitation, future research should give consideration to the objectives of insurance companies.

Third, for each crop/weather combination, the relationship between yield and irrigation is achieved by using the DSSAT crop simulation model, and a weather derivative contract is constructed based on the simulated relationship; however, the relationship between irrigation and yields may not be so accurate. In future research, actual observed relationships between rainfall and yield (other than simulated relationships using the DSSAT model) could be used.

Fourth, the irrigation technology is assumed to be constant with respect to water price. However, an increase in price could lead to the adoption of more water conserving/ efficient technologies, which will decrease water use eventually. Further research could investigate the

substitution effect of water pricing policy, as well as other economic incentives and regulatory policies. It is also worth investigating their effects at the regional level and intersectoral level, and analyzing their impact on allocative and ecological efficiency, especially when the river basin or catchment area is more heterogeneous.

It would also be interesting to investigate the performance of weather derivative contracts in recent years. Our analysis is based on weather data from 1976 to 2000, which does not include 2001 to 2007 when a serious drought occurred. If the time period is changed, we may have different conclusions regarding the usefulness of weather contracts in mitigating weather risk and reducing water use. The impact of spatial basis risk, which may reduce the benefits of the index insurance product, can also be investigated.

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APPENDIX A

How ENSO Phases Influence Conditions in Alabama, Florida and Georgia

Phase	Region	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep
El Niño	Peninsular Florida	Wet - cool	Wet-Cool	Slightly Dry	Slightly dry to none
	Panhandle-tri state area	Wet	Wet	Slightly Wet	None
	Western Panhandle	None	Wet	Slightly Dry	None
	Central and North AL, GA	None	None	None	Slightly dry
La Niña	Peninsular Florida	Dry Slightly Warm			
	Panhandle-tri state area	Weak dry	Dry	Dry	None
	Western Panhandle	Slightly Dry	Dry	Dry	None
	Central and North AL, GA	Dry	Dry in South, wet in NW AL	None	Wet in NW AL
Neutral		None	None	None	None

APPENDIX B

The following soil generic information was developed by A.J. Gijsman:

BD was estimated as $BD = 100 / (SOM\% / 0.224 + (100 - SOM\%) / \text{mineral BD})$ (Adams, 1973; Rawls and Brakensiek, 1985). LL and DUL are according to Saxton et al., 1986. SAT was taken as a fraction of porosity (Dalglish and Foale, 1998): 0.93 for soil classes S, SL and LS; 0.95 for soil classes L, SIL, SI, SCL and SC; and 0.97 for soil classes C, CL, SIC and SICL. For this, porosity was estimated as: $POR = 1 - BD / APD$ (in which APD is the adjusted particle density, i.e. corrected for SOM; Baumer and Rice, 1988). The ranges of LL and DUL values were calculated by stepping through the complete texture triangle in steps of 1% sand, 1% silt and 1% clay (>5000 combinations), but with the texture limitations that Saxton set for his method taken into consideration. For SAT, these limitations do not hold, as this was based on POR and not on Saxton. See Gijsman et al., 2002.

The root growth distribution function SRGF was calculated as:

$SRGF = 1 * \text{EXP}(-0.02 * \text{LAYER_CENTER});$ SRGF was set 1 for $\text{LAYER_BOTTOM} \leq 16.$

SOILCLASS	BD	LL	DUL	SAT
C	1.129 - 1.512	0.220 - 0.346	0.330 - 0.467	0.413 - 0.488
CL	1.243 - 1.502	0.156 - 0.218	0.282 - 0.374	0.417 - 0.512
L	1.245 - 1.483	0.083 - 0.156	0.222 - 0.312	0.415 - 0.501
LS	1.353 - 1.629	0.059 - 0.110	0.137 - 0.185	0.355 - 0.416
S	1.446 - 1.574	0.055 - 0.085	0.123 - 0.158	0.374 - 0.400
SC	1.501 - 1.593	0.195 - 0.294	0.276 - 0.389	0.376 - 0.409
SCL	1.475 - 1.636	0.132 - 0.191	0.213 - 0.304	0.360 - 0.418
SI	0.978 - 1.464	0.096 - 0.099	0.299 - 0.307	0.442 - 0.488
SIC	1.307 - 1.446	0.224 - 0.326	0.379 - 0.456	0.455 - 0.489
SICL	1.248 - 1.464	0.155 - 0.219	0.324 - 0.392	0.448 - 0.511
SIL	0.968 - 1.464	0.082 - 0.152	0.240 - 0.333	0.439 - 0.547
SL	1.142 - 1.647	0.066 - 0.133	0.164 - 0.243	0.348 - 0.499

The 12 Generic soils for SOIL.SOL, as estimated by Arjan Gijsman:

- LL, DUL are according to the Nearest Neighbor method (Jagtap et al, 2004)
- Ksat at -99
- BD according to Gijsman et al (2002)
- SAT based on the APSRU manual (Dalglish and Foale, 1998); i.e. 93-97% of porosity depending on the soil type) in which porosity is according to Baumer and Rice (1988).

APPENDIX C

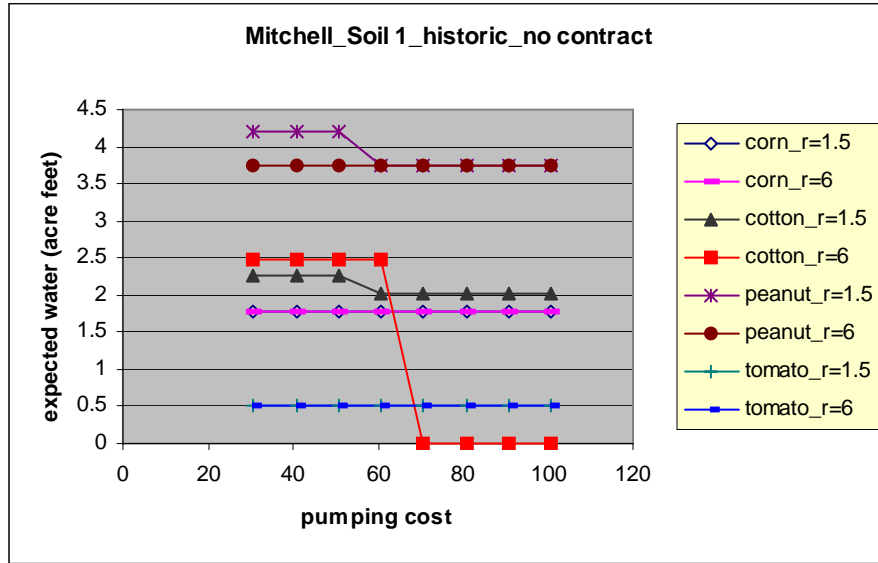


Figure C.1 Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for Mitchell Soil 1

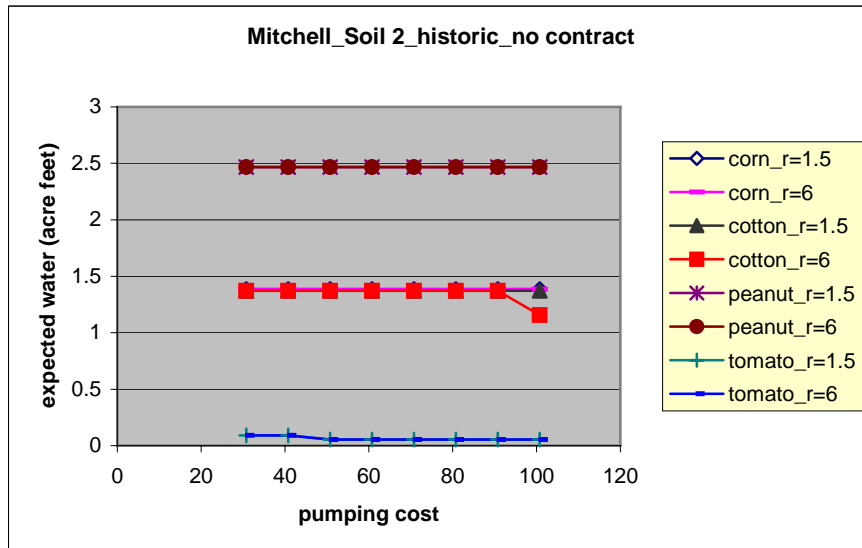


Figure C.2 Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for Mitchell Soil 2

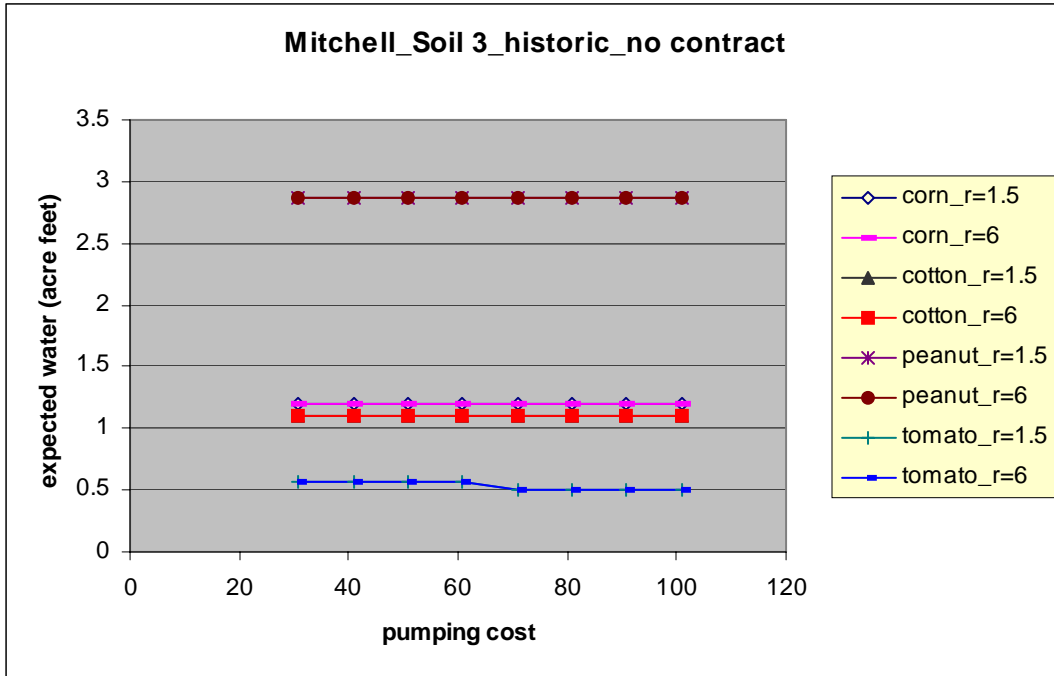


Figure C.3 Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for Mitchell Soil 3

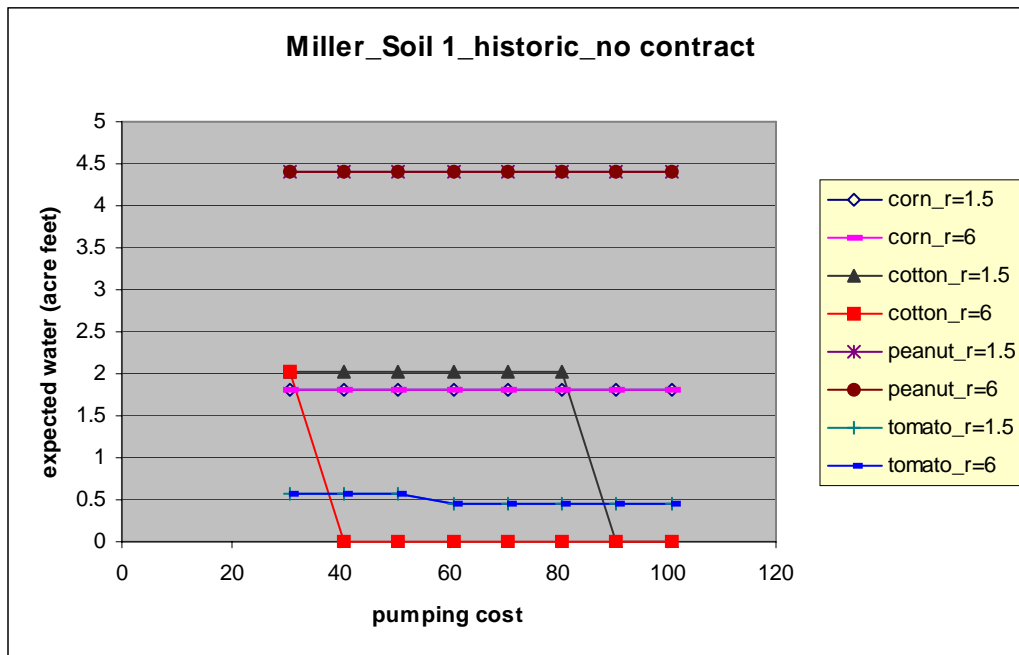


Figure C.4 Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for Miller Soil 1

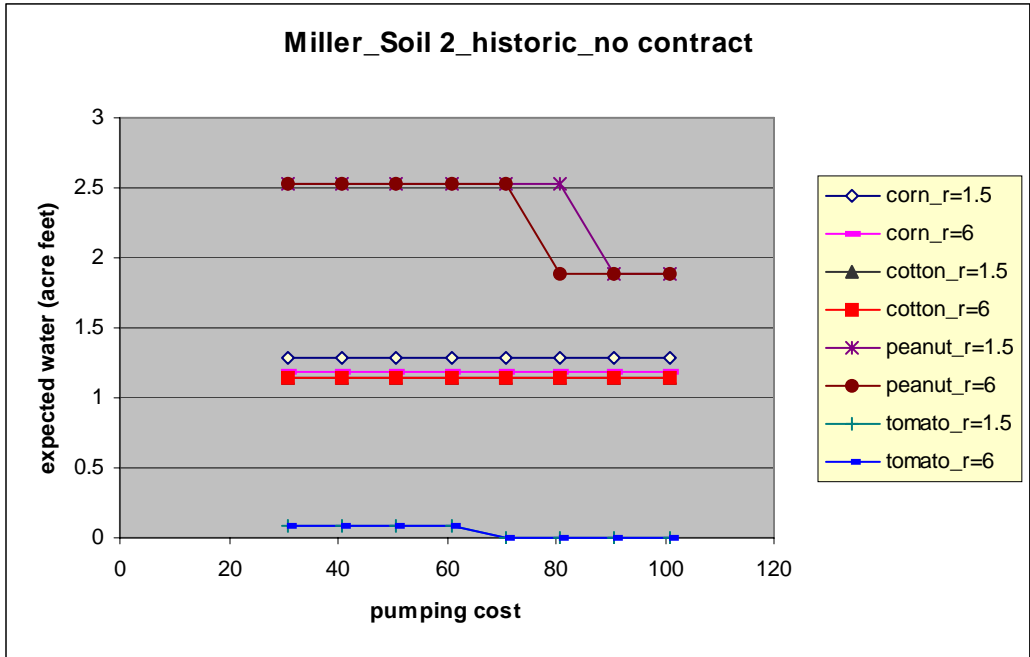


Figure C.5 Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for Miller Soil 2

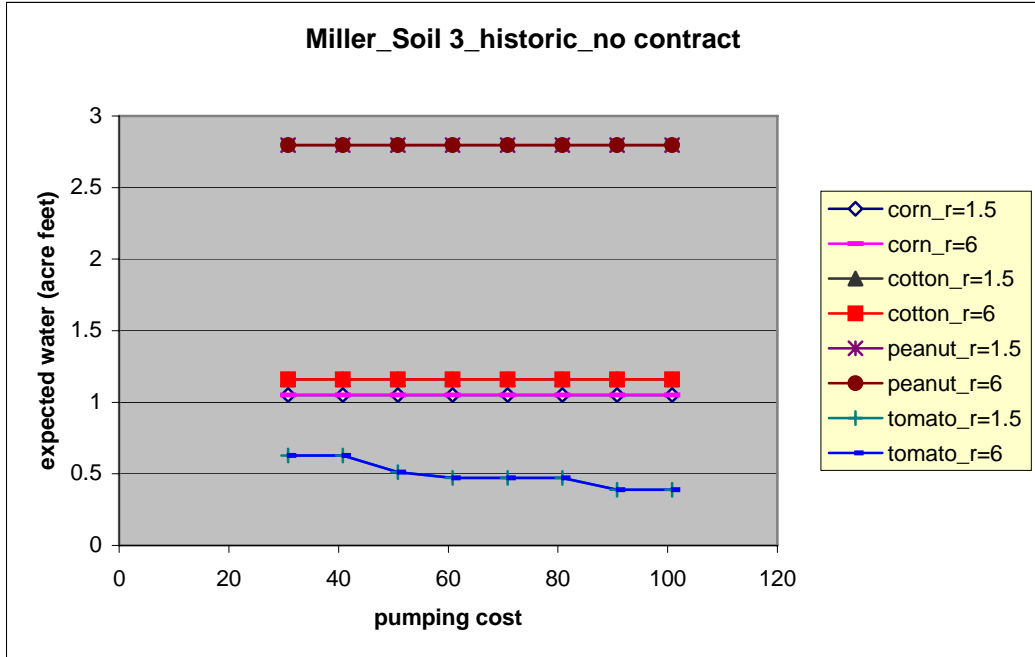


Figure C.6 Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for Miller Soil 3

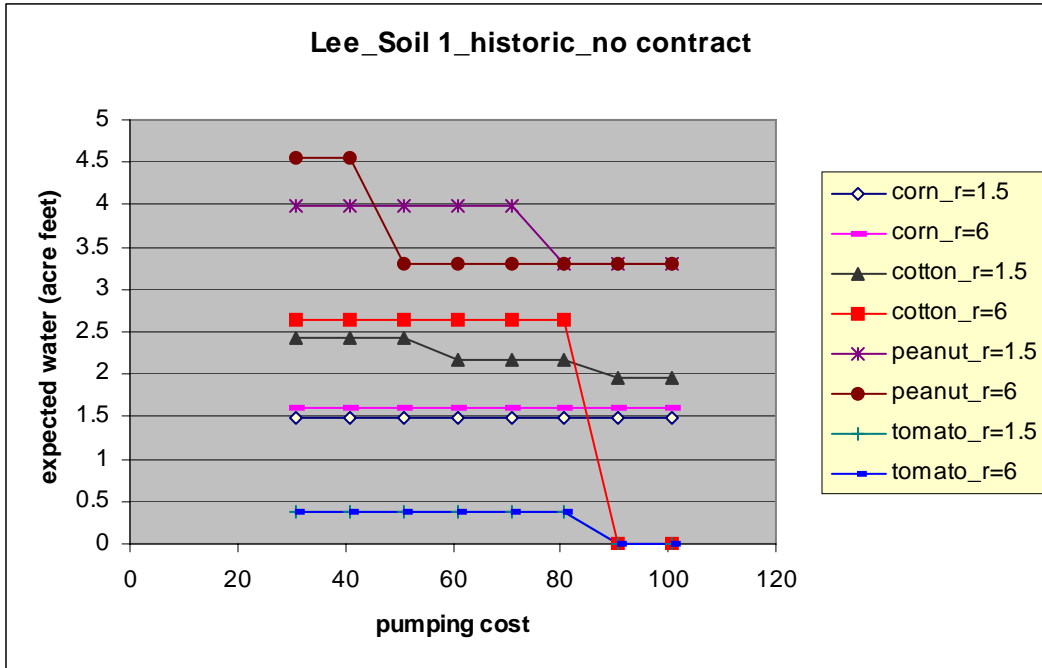


Figure C.7. Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for Lee Soil 1

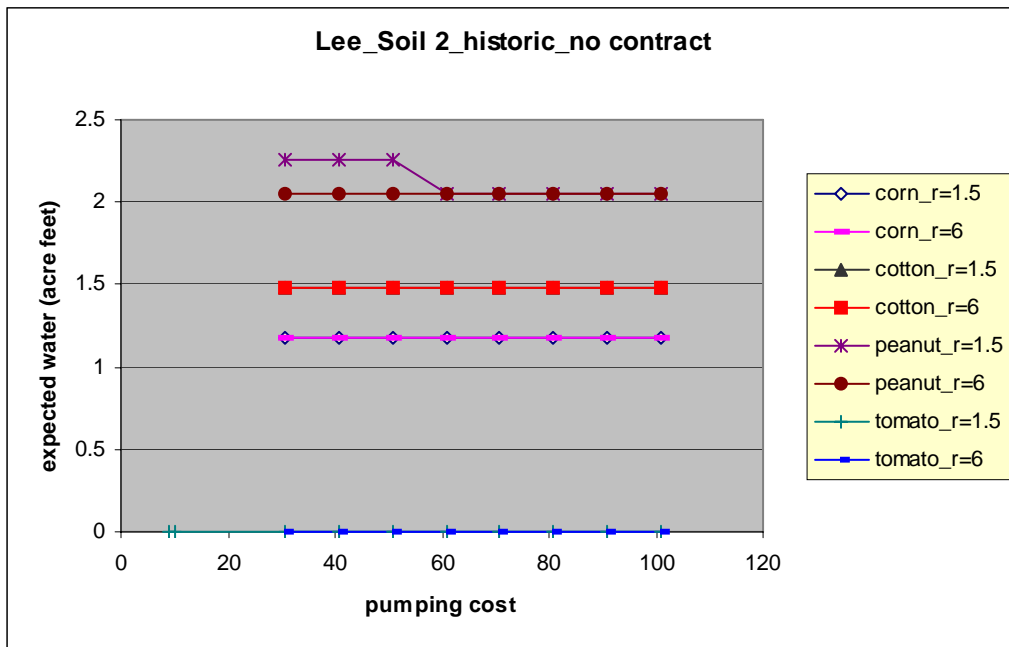


Figure C.8. Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for Lee Soil 2

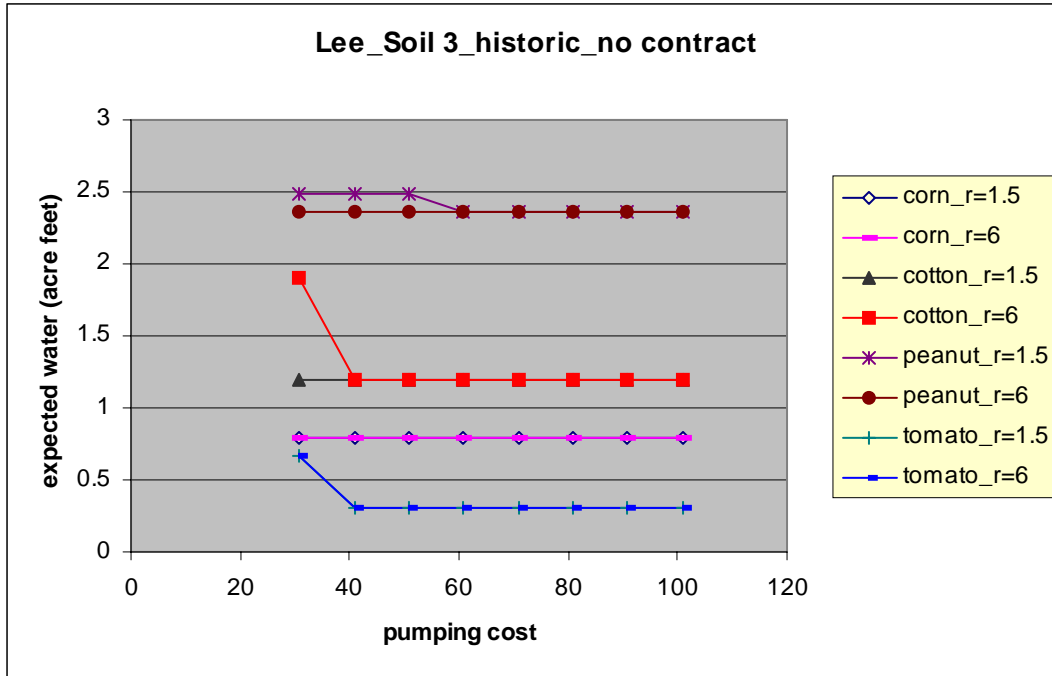


Figure C.9 Impact of Potential Water Pricing Policy on Producers' Optimal Water Use for

Lee Soil 3

APPENDIX D

Table D.1 Contract Parameters for Corn Production in Mitchell County

	soil	R	Max_L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	700	565	132	0.76	7.56	0.01	
	1	6	700	565	132	0.76	7.56	0.01	
	2	1.5	512	565	132	0.84	7.14	0.02	
	2	6	512	565	132	0.84	7.14	0.02	
	3	1.5	472	565	132	0.77	3.78	0.03	
	3	6	472	565	132	0.77	3.94	0.03	
FutureA	1	1.5	691	593	381	0.76	7.56	0.01	
	1	6	691	593	381	0.76	7.56	0.01	
	2	1.5	463	593	381	0.83	7.14	0.02	
	2	6	463	593	381	0.83	7.14	0.02	
	3	1.5	360	593	381	0.75	3.78	0.03	
	3	6	360	593	381	0.76	3.94	0.03	
FutureB	1	1.5	700	631	147	0.76	19.84	0.01	
	1	6	700	631	147	0.76	19.84	0.01	
	2	1.5	512	631	147	0.84	21.76	0.02	
	2	6	512	631	147	0.84	21.76	0.02	
	3	1.5	473	631	147	0.76	13.40	0.02	
	3	6	473	631	147	0.75	12.87	0.02	
FutureC	1	1.5	677	691	448	0.75	6.05	0.01	
	1	6	677	691	448	0.76	6.30	0.01	
	2	1.5	435	691	448	0.81	6.11	0.02	
	2	6	435	691	448	0.83	6.71	0.02	
	3	1.5	346	691	448	0.75	3.09	0.03	
	3	6	346	691	448	0.75	3.09	0.03	

* R: relative risk aversion coefficient

Max_L: maximum liability

Table D.2 Contract Parameters for Cotton Production in Mitchell County

	soil	R	Max L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	1208	1061	618	0.77	8.50	0.01	
	1	6	1208	1061	888	0.75	6.44	0.08	
	2	1.5	637	1060	619	0.82	6.71	0.02	
	2	6	637	1060	619	0.82	6.71	0.02	
	3	1.5	647	1061	629	0.75	4.12	0.02	
	3	6	647	1061	629	0.75	4.12	0.02	
FutureA	1	1.5	1297	1062	616	0.76	8.77	0.01	
	1	6	1297	1062	616	0.76	8.77	0.01	
	2	1.5	739	1060	616	0.8	6.00	0.01	
	2	6	739	1060	616	0.8	6.00	0.01	
	3	1.5	669	1062	616	0.76	4.53	0.01	
	3	6	669	1062	616	0.76	4.53	0.01	
FutureB	1	1.5	1208	1174	682	0.76	7.38	0.01	
	1	6	1208	1174	722	0.91	18.59	0.01	
	2	1.5	620	1173	683	0.83	6.34	0.02	
	2	6	620	1173	683	0.8	4.54	0.02	
	3	1.5	631	1174	694	0.76	3.79	0.02	
	3	6	631	1174	1074	0.98	29.39	0.21	
FutureC	1	1.5	1308	1239	721	0.76	7.56	0.01	
	1	6	1308	1239	721	0.77	7.89	0.01	
	1	6	1308	1239	721	0.77	7.89	0.01	
	2	1.5	709	1238	721	0.79	4.68	0.01	
	2	6	709	1238	721	0.79	4.68	0.01	
	3	1.5	667	1240	721	0.76	3.85	0.01	
	3	6	667	1240	721	0.76	3.85	0.01	

Table D.3 Contract Parameters for Peanut Production in Mitchell County

	soil	R	Max_L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	1060	996	580	0.86	13.06	0.01	
	1	6	1060	996	580	0.85	12.19	0.01	
	2	1.5	586	995	580	0.88	8.42	0.02	
	2	6	586	995	580	0.88	8.42	0.02	
	3	1.5	662	996	580	0.85	7.61	0.02	
	3	6	662	996	580	0.85	7.61	0.02	
FutureA	1	1.5	1072	990	600	0.86	12.77	0.01	
	1	6	1072	990	600	0.86	12.77	0.01	
	2	1.5	667	989	600	0.87	8.53	0.02	
	2	6	667	989	600	0.88	9.24	0.02	
	3	1.5	717	990	600	0.85	7.96	0.01	
	3	6	717	990	600	0.85	7.96	0.01	
FutureB	1	1.5	1047	1105	641	0.86	11.65	0.01	
	1	6	1047	1105	641	0.85	10.88	0.01	
	2	1.5	586	1105	641	0.88	7.62	0.02	
	2	6	586	1105	641	0.88	7.62	0.02	
	3	1.5	660	1106	641	0.85	6.86	0.02	
	3	6	660	1106	641	0.85	6.86	0.02	
FutureC	1	1.5	1030	1155	703	0.86	10.47	0.01	
	1	6	1030	1155	703	0.84	9.16	0.01	
	2	1.5	637	1154	703	0.87	6.96	0.02	
	2	6	637	1154	703	0.88	7.54	0.02	
	3	1.5	688	1156	703	0.85	6.53	0.01	
	3	6	688	1156	703	0.85	6.53	0.01	

Table D.4 Contract Parameters for Tomato Production in Mitchell County

	soil	R	Max L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	537	392	88	0.79	29.06	0.02	
	1	6	537	392	88	0.79	29.06	0.02	
	2	1.5	317	392	328	0.98	48.16	0.18	
	2	6	317	392	328	0.98	48.16	0.18	
	3	1.5	337	392	88	0.81	20.07	0.03	
	3	6	337	392	88	0.81	20.07	0.03	
FutureA	1	1.5	561	397	267	0.81	11.07	0.02	
	1	6	561	397	267	0.81	11.07	0.02	
	2	1.5	330	397	297	0.75	4.44	0.01	
	2	6	330	397	297	0.75	4.44	0.01	
	3	1.5	334	397	267	0.8	6.25	0.03	
	3	6	334	397	267	0.8	6.25	0.03	
FutureB	1	1.5	537	436	99	0.79	26.83	0.02	
	1	6	537	436	99	0.79	26.83	0.02	
	2	1.5	330	436	359	0.98	46.92	0.18	
	2	6	330	436	359	0.98	46.92	0.18	
	3	1.5	337	436	99	0.79	16.14	0.03	
	3	6	337	436	99	0.79	16.14	0.03	
FutureC	1	1.5	496	464	315	0.81	8.29	0.02	
	1	6	496	464	315	0.81	8.29	0.02	
	2	1.5	316	464	345	0.75	3.67	0.01	
	2	6	316	464	345	0.75	3.67	0.01	
	3	1.5	334	464	315	0.8	6.30	0.03	
	3	6	334	464	315	0.8	6.30	0.03	

Table D.5 Contract Parameters for Corn Production in Miller County

	soil	R	Max_L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	714	574	159	0.77	19.51	0.01	
	1	6	714	574	159	0.77	19.51	0.01	
	2	1.5	506	574	159	0.84	19.90	0.02	
	2	6	506	574	159	0.83	18.72	0.02	
	3	1.5	457	574	159	0.76	11.95	0.02	
	3	6	457	574	159	0.76	11.95	0.02	
FutureA	1	1.5	676	588	330	0.77	8.91	0.01	
	1	6	676	588	330	0.75	8.19	0.01	
	2	1.5	436	588	330	0.81	6.94	0.02	
	2	6	436	588	330	0.81	6.94	0.02	
	3	1.5	359	588	330	0.76	4.53	0.03	
	3	6	359	588	330	0.75	4.35	0.03	
FutureB	1	1.5	713	632	177	0.77	17.51	0.01	
	1	6	713	632	177	0.77	17.51	0.01	
	2	1.5	492	632	177	0.84	17.39	0.02	
	2	6	492	632	177	0.84	17.39	0.02	
	3	1.5	427	632	177	0.77	10.49	0.02	
	3	6	427	632	177	0.77	10.49	0.02	
FutureC	1	1.5	677	687	389	0.75	6.95	0.01	
	1	6	677	687	389	0.75	6.95	0.01	
	2	1.5	420	687	389	0.81	6.68	0.02	
	2	6	420	687	389	0.81	6.68	0.02	
	3	1.5	343	687	389	0.75	3.53	0.03	
	3	6	343	687	389	0.75	3.53	0.03	

Table D.6 Contract Parameters for Cotton Production in Miller County

	soil	R	Max L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	1254	1123	705	0.76	7.41	0.01	
	1	6	1254	1123	735	0.75	6.83	0.00	
	2	1.5	649	1123	705	0.8	4.60	0.02	
	2	6	649	1123	705	0.8	4.60	0.02	
	3	1.5	652	1123	705	0.75	3.70	0.02	
	3	6	652	1123	705	0.75	3.70	0.02	
FutureA	1	1.5	1188	1101	777	0.76	6.37	0.01	
	1	6	1188	1101	807	0.75	6.89	0.00	
	2	1.5	634	1100	777	0.81	4.29	0.02	
	2	6	634	1100	777	0.77	3.55	0.02	
	3	1.5	620	1101	777	0.82	4.43	0.02	
	3	6	620	1101	937	0.98	33.06	0.19	
FutureB	1	1.5	1254	1237	778	0.75	6.45	0.01	
	1	6	1254	1237	808	0.75	6.21	0.00	
	2	1.5	647	1237	778	0.82	4.62	0.02	
	2	6	647	1237	778	0.79	3.96	0.02	
	3	1.5	631	1174	694	0.77	3.95	0.02	
	3	6	631	1174	1084	0.98	29.12	0.32	
FutureC	1	1.5	1161	1284	910	0.75	6.11	0.01	
	1	6	1161	1284	940	0.75	4.94	0.00	
	2	1.5	603	1284	922	0.81	3.44	0.02	
	2	6	603	1284	922	0.77	2.84	0.02	
	3	1.5	620	1285	922	0.75	2.69	0.02	
	3	6	620	1285	952	0.75	2.60	0.00	

Table D.7 Contract Parameters for Peanut Production in Miller County

	soil	R	Max L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	1032	1033	690	0.86	10.69	0.01	
	1	6	1032	1033	690	0.86	10.69	0.01	
	2	1.5	567	1034	690	0.88	6.83	0.02	
	2	6	567	1034	690	0.88	6.83	0.02	
	3	1.5	676	1034	690	0.84	6.12	0.01	
	3	6	676	1034	690	0.84	6.12	0.01	
FutureA	1	1.5	994	1005	688	0.86	10.32	0.01	
	1	6	994	1005	688	0.86	10.32	0.01	
	2	1.5	562	1007	688	0.88	6.81	0.02	
	2	6	562	1007	688	0.87	6.29	0.02	
	3	1.5	576	1007	688	0.84	6.23	0.02	
	3	6	576	1007	688	0.84	6.23	0.02	
FutureB	1	1.5	1003	1138	762	0.86	9.41	0.01	
	1	6	1003	1138	762	0.86	9.41	0.01	
	2	1.5	559	1138	762	0.88	6.12	0.02	
	2	6	559	1138	762	0.88	6.12	0.02	
	3	1.5	659	1137	762	0.84	6.41	0.02	
	3	6	659	1137	762	0.84	6.41	0.02	
FutureC	1	1.5	993	1172	806	0.86	8.80	0.01	
	1	6	993	1172	806	0.86	8.80	0.01	
	2	1.5	547	1177	806	0.88	6.65	0.02	
	2	6	547	1177	806	0.87	6.22	0.02	
	3	1.5	548	1176	806	0.85	4.53	0.02	
	3	6	548	1176	806	0.85	4.53	0.02	

Table D.8 Contract Parameters for Tomato Production in Miller County

	soil	R	Max L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	549	410	88	0.81	32.86	0.02	
	1	6	549	410	88	0.81	32.86	0.02	
	2	1.5	331	410	268	0.98	61.69	0.07	
	2	6	331	410	268	0.98	61.69	0.07	
	3	1.5	333	410	88	0.83	22.25	0.03	
	3	6	333	410	88	0.83	22.25	0.03	
FutureA	1	1.5	505	397	185	0.83	16.05	0.02	
	1	6	505	397	185	0.83	16.05	0.02	
	2	1.5	302	397	215	0.75	6.63	0.01	
	2	6	302	397	215	0.75	6.63	0.01	
	3	1.5	306	397	185	0.83	9.74	0.03	
	3	6	306	397	185	0.83	9.74	0.03	
FutureB	1	1.5	535	451	99	0.81	28.42	0.02	
	1	6	535	451	99	0.81	28.42	0.02	
	2	1.5	331	451	299	0.98	56.30	0.07	
	2	6	331	451	299	0.98	56.30	0.07	
	3	1.5	333	451	99	0.84	21.02	0.03	
	3	6	333	451	99	0.84	21.02	0.03	
FutureC	1	1.5	616	384	189	0.78	14.79	0.02	
	1	6	616	384	189	0.78	14.79	0.02	
	2	1.5	447	384	189	0.85	16.76	0.02	
	2	6	447	384	189	0.85	16.76	0.02	
	3	1.5	489	384	189	0.81	13.63	0.02	
	3	6	489	384	189	0.81	13.63	0.02	

Table D.9 Contract Parameters for Corn Production in Lee County

	soil	R	Max L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	709	634	359	0.75	7.90	0.01	
	1	6	709	634	359	0.76	8.23	0.01	
	2	1.5	448	634	359	0.84	7.79	0.02	
	2	6	448	634	359	0.84	7.79	0.02	
	3	1.5	347	634	359	0.75	3.85	0.03	
	3	6	347	634	359	0.75	3.85	0.03	
FutureA	1	1.5	692	623	469	0.75	6.90	0.01	
	1	6	692	623	469	0.75	6.90	0.01	
	2	1.5	434	623	469	0.82	6.14	0.02	
	2	6	434	623	469	0.82	6.14	0.02	
	3	1.5	358	623	469	0.75	3.05	0.03	
	3	6	358	623	469	0.75	3.05	0.03	
FutureB	1	1.5	709	698	398	0.76	7.42	0.01	
	1	6	709	698	398	0.76	7.42	0.01	
	2	1.5	433	698	398	0.83	6.40	0.02	
	2	6	433	698	398	0.84	6.80	0.02	
	3	1.5	345	698	398	0.76	3.61	0.03	
	3	6	345	698	398	0.76	3.61	0.03	
FutureC	1	1.5	692	727	551	0.75	6.02	0.01	
	1	6	692	727	551	0.75	6.02	0.01	
	2	1.5	406	727	551	0.81	3.87	0.02	
	2	6	406	727	551	0.81	3.87	0.02	
	3	1.5	357	727	551	0.75	2.59	0.03	
	3	6	357	727	551	0.75	2.59	0.03	

Table D.10 Contract Parameters for Cotton Production in Lee County

	soil	R	Max_L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	1208	1061	618	0.77	8.50	0.01	
	1	6	1208	1061	618	0.78	8.88	0.01	
	2	1.5	637	1060	619	0.82	6.71	0.02	
	2	6	637	1060	619	0.82	6.71	0.02	
	3	1.5	647	1061	629	0.75	4.12	0.02	
	3	6	647	1061	629	0.82	6.72	0.02	
FutureA	1	1.5	1128	1090	855	0.75	6.28	0.01	
	1	6	1128	1090	855	0.75	6.28	0.01	
	2	1.5	531	1089	855	0.83	3.65	0.02	
	2	6	531	1089	855	0.81	3.27	0.02	
	3	1.5	570	1090	855	0.75	2.66	0.02	
	3	6	570	1090	855	0.78	3.03	0.02	
FutureB	1	1.5	1187	1237	846	0.76	6.84	0.01	
	1	6	1187	1237	846	0.75	6.61	0.01	
	2	1.5	589	1237	846	0.8	3.48	0.02	
	2	6	589	1237	846	0.81	3.66	0.02	
	3	1.5	598	1237	846	0.75	2.83	0.02	
	3	6	598	1237	846	0.75	2.83	0.02	
FutureC	1	1.5	1101	1272	1001	0.75	4.40	0.01	
	1	6	1101	1272	1001	0.76	4.58	0.01	
	2	1.5	529	1271	1001	0.81	2.78	0.02	
	2	6	529	1271	1001	0.8	2.64	0.02	
	3	1.5	540	1272	1031	0.75	2.09	0.00	
	3	6	540	1272	1241	0.98	21.74	0.49	

Table D.11 Contract Parameters for Peanut Production in Lee County

	soil	R	Max L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	959	1048	703	0.86	9.74	0.01	
	1	6	959	1048	703	0.87	10.49	0.01	
	2	1.5	591	1048	703	0.88	7.00	0.02	
	2	6	591	1048	703	0.87	6.47	0.02	
	3	1.5	579	1048	700	0.85	6.52	0.02	
	3	6	579	1048	700	0.84	6.17	0.02	
FutureA	1	1.5	918	1017	805	0.86	8.15	0.01	
	1	6	918	1017	805	0.86	8.15	0.01	
	2	1.5	505	1017	805	0.88	6.22	0.02	
	2	6	505	1017	805	0.87	4.82	0.02	
	3	1.5	474	1017	785	0.85	4.03	0.02	
	3	6	474	1017	785	0.84	3.78	0.02	
FutureB	1	1.5	956	1153	776	0.86	8.80	0.01	
	1	6	956	1153	776	0.85	8.22	0.01	
	2	1.5	577	1153	777	0.88	6.19	0.02	
	2	6	577	1153	777	0.87	6.71	0.02	
	3	1.5	579	1153	772	0.85	6.00	0.02	
	3	6	579	1153	772	0.84	4.69	0.02	
FutureC	1	1.5	891	1187	943	0.86	6.75	0.01	
	1	6	891	1187	943	0.87	7.27	0.01	
	2	1.5	462	1188	943	0.87	3.77	0.02	
	2	6	462	1188	943	0.87	3.77	0.02	
	3	1.5	471	1187	943	0.85	3.33	0.02	
	3	6	471	1187	943	0.84	3.12	0.02	

Table D.12 Contract Parameters for Tomato Production in Lee County

	soil	R	Max	L	E(rain)	strike	limit	tick	premium	rate
historic	1	1.5	509	498	254	0.79	9.54	0.02		
	1	6	509	498	254	0.79	9.54	0.02		
	2	1.5	343	498	284	0.75	4.83	0.01		
	2	6	343	498	284	0.75	4.83	0.01		
	3	1.5	319	498	254	0.84	7.85	0.03		
	3	6	319	498	254	0.84	7.85	0.03		
FutureA	1	1.5	477	465	391	0.98	61.04	0.24		
	1	6	477	465	391	0.98	61.04	0.24		
	2	1.5	288	465	391	0.98	36.82	0.24		
	2	6	288	465	391	0.98	36.82	0.24		
	3	1.5	290	465	291	0.8	4.99	0.03		
	3	6	290	465	291	0.8	4.99	0.03		
FutureB	1	1.5	509	548	281	0.79	8.62	0.02		
	1	6	509	548	281	0.79	8.62	0.02		
	2	1.5	329	548	311	0.75	4.23	0.01		
	2	6	329	548	311	0.75	4.23	0.01		
	3	1.5	319	548	281	0.84	7.09	0.03		
	3	6	319	548	281	0.84	7.09	0.03		
FutureC	1	1.5	463	542	463	0.98	49.99	0.24		
	1	6	463	542	463	0.98	49.99	0.24		
	2	1.5	288	542	463	0.98	31.10	0.24		
	2	6	288	542	463	0.98	31.10	0.24		
	3	1.5	291	542	343	0.8	4.24	0.03		
	3	6	291	542	343	0.8	4.24	0.03		

APPENDIX E

Table E. 1 Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Corn Producers in Mitchell County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change in CER	change in EW
historic	1	1.5	773	1.78	784	1.78	-11	0.00
	1	6	671	1.78	682	1.78	-12	0.00
	2	1.5	956	1.39	967	1.39	-11	0.00
	2	6	723	1.39	736	1.39	-13	0.00
	3	1.5	1397	1.20	1407	1.20	-11	0.00
	3	6	1153	1.20	1167	1.20	-13	0.00
FutureA	1	1.5	820	1.45	831	1.45	-11	0.00
	1	6	676	1.45	688	1.45	-13	0.00
	2	1.5	1103	0.90	1114	0.90	-11	0.00
	2	6	808	0.90	822	0.90	-14	0.00
	3	1.5	1443	0.57	1453	0.57	-11	0.00
	3	6	1188	0.66	1202	0.66	-13	0.00
FutureB	1	1.5	762	1.70	773	1.70	-11	0.00
	1	6	656	1.70	668	1.70	-12	0.00
	2	1.5	988	1.31	999	1.31	-11	0.00
	2	6	767	1.31	780	1.31	-13	0.00
	3	1.5	1407	1.03	1417	1.03	-11	0.00
	3	6	1174	1.01	1187	1.01	-13	0.00
FutureC	1	1.5	757	1.26	767	1.26	-11	0.00
	1	6	623	1.42	636	1.42	-12	0.00
	2	1.5	1130	0.68	1141	0.68	-11	0.00
	2	6	852	0.82	866	0.82	-14	0.00
	3	1.5	1454	0.44	1465	0.44	-11	0.00
	3	6	1212	0.44	1226	0.44	-13	0.00

*CER: Certainty Equivalent Revenue

*EW: Expected Water

Table E.2 Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Cotton Producers in Mitchell County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change CER	change in EW
historic	1	1.5	1990	2.27	2005	2.27	-16	0.00
	1	6	1121	0.00	1113	2.48	7	-2.48
	2	1.5	3458	1.37	3472	1.37	-14	0.00
	2	6	2339	1.37	2351	1.37	-12	0.00
	3	1.5	4443	1.10	4457	1.10	-14	0.00
	3	6	2903	1.10	2917	1.10	-13	0.00
FutureA	1	1.5	2136	1.70	2150	1.70	-14	0.00
	1	6	1307	1.70	1320	1.70	-13	0.00
	2	1.5	3571	0.94	3585	0.94	-14	0.00
	2	6	2354	0.94	2366	0.94	-13	0.00
	3	1.5	4546	0.77	4560	0.77	-14	0.00
	3	6	2961	0.77	2973	0.77	-13	0.00
FutureB	1	1.5	1847	1.94	1861	1.94	-16	0.00
	1	6	1129	0.00	1100	0.00	30	0.00
	2	1.5	3320	1.37	3334	1.37	-14	0.00
	2	6	2227	1.07	2239	1.07	-12	0.00
	3	1.5	4332	1.11	4347	1.11	-14	0.00
	3	6	2923	0.00	2877	1.11	46	-1.11
FutureC	1	1.5	1805	1.55	1819	1.55	-14	0.00
	1	6	1069	1.74	1081	1.74	-13	0.00
	2	1.5	3327	0.71	3339	0.71	-14	0.00
	2	6	2194	0.71	2206	0.71	-12	0.00
	3	1.5	4302	0.62	4317	0.62	-14	0.00
	3	6	2768	0.62	2781	0.62	-13	0.00

Table E.3 Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Peanut Producers in Mitchell County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change in CER	change in EW
historic	1	1.5	934	4.20	1096	4.20	-162	0.00
	1	6	333	3.74	434	3.74	-101	0.00
	2	1.5	987	2.47	1215	2.47	-228	0.00
	2	6	420	2.47	463	2.47	-42	0.00
	3	1.5	1755	2.87	1892	2.87	-138	0.00
	3	6	1102	2.87	1240	2.87	-138	0.00
FutureA	1	1.5	1071	4.01	1087	4.01	-17	0.00
	1	6	314	4.01	334	4.01	-20	0.00
	2	1.5	1148	1.93	1165	1.93	-16	0.00
	2	6	359	2.23	379	2.23	-20	0.00
	3	1.5	1851	2.32	1865	2.32	-13	0.00
	3	6	1207	2.32	1220	2.32	-13	0.00
FutureB	1	1.5	1045	4.14	1061	4.14	-16	0.00
	1	6	449	3.65	467	3.65	-16	0.00
	2	1.5	1060	2.38	1076	2.38	-15	0.00
	2	6	518	2.38	534	2.38	-17	0.00
	3	1.5	1784	2.72	1797	2.72	-13	0.00
	3	6	1161	2.72	1174	2.72	-13	0.00
FutureC	1	1.5	1080	3.96	1096	3.96	-17	0.00
	1	6	417	3.18	434	3.18	-18	0.00
	2	1.5	1199	1.83	1215	1.83	-17	0.00
	2	6	443	2.11	463	2.11	-19	0.00
	3	1.5	1879	2.19	1892	2.19	-13	0.00
	3	6	1226	2.19	1240	2.19	-13	0.00

Table E.4 Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Tomato Producers in Mitchell County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change in CER	change in EW
historic	1	1.5	0	0.52	0	0.52	0	0.00
	1	6	0	0.52	0	0.52	0	0.00
	2	1.5	0	0.00	0	0.09	0	-0.09
	2	6	0	0.00	0	0.09	0	-0.09
	3	1.5	0	0.60	0	0.56	0	0.04
	3	6	0	0.60	0	0.56	0	0.04
FutureA	1	1.5	0	0.82	0	0.82	0	0.00
	1	6	0	0.82	0	0.82	0	0.00
	2	1.5	0	0.00	0	0.04	0	-0.04
	2	6	0	0.00	0	0.04	0	-0.04
	3	1.5	0	0.50	0	0.50	0	0.00
	3	6	0	0.50	0	0.50	0	0.00
FutureB	1	1.5	0	0.54	0	0.54	0	0.00
	1	6	0	0.54	0	0.54	0	0.00
	2	1.5	0	0.00	0	0.09	0	-0.09
	2	6	0	0.00	0	0.09	0	-0.09
	3	1.5	0	0.49	0	0.49	0	0.00
	3	6	0	0.49	0	0.49	0	0.00
FutureC	1	1.5	0	0.83	0	0.83	0	0.00
	1	6	0	0.83	0	0.83	0	0.00
	2	1.5	0	0.00	0	0.04	0	-0.04
	2	6	0	0.00	0	0.04	0	-0.04
	3	1.5	0	0.49	0	0.49	0	0.00
	3	6	0	0.49	0	0.49	0	0.00

Table E.5: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Corn Producers in Miller County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change in CER	change in EW
historic	1	1.5	770	1.81	781	1.81	-11	0.00
	1	6	599	1.81	613	1.81	-14	0.00
	2	1.5	986	1.29	997	1.29	-10	0.00
	2	6	866	1.18	877	1.18	-11	0.00
	3	1.5	1415	1.05	1426	1.05	-10	0.00
	3	6	1300	1.05	1311	1.05	-11	0.00
FutureA	1	1.5	839	1.63	850	1.63	-11	0.00
	1	6	660	1.39	674	1.39	-14	0.00
	2	1.5	1097	0.86	1106	0.86	-10	0.00
	2	6	991	0.86	1002	0.86	-11	0.00
	3	1.5	1441	0.76	1452	0.76	-10	0.00
	3	6	1321	0.74	1333	0.74	-11	0.00
FutureB	1	1.5	732	1.75	743	1.75	-11	0.00
	1	6	540	1.75	555	1.75	-15	0.00
	2	1.5	1003	1.25	1013	1.25	-10	0.00
	2	6	875	1.25	887	1.25	-12	0.00
	3	1.5	1419	1.03	1429	1.03	-10	0.00
	3	6	1304	1.03	1316	1.03	-11	0.00
FutureC	1	1.5	778	1.38	789	1.38	-11	0.00
	1	6	547	1.38	561	1.38	-16	0.00
	2	1.5	1134	0.77	1145	0.77	-10	0.00
	2	6	1024	0.77	1037	0.77	-11	0.00
	3	1.5	1455	0.58	1466	0.58	-10	0.00
	3	6	1332	0.58	1343	0.58	-11	0.00

Table E.6: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Cotton Producers in Miller County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change CER	change in EW
historic	1	1.5	1397	2.03	1417	2.03	-18	0.00
	1	6	567	0.00	577	2.03	-12	-2.03
	2	1.5	2790	1.14	2804	1.14	-14	0.00
	2	6	1647	1.14	1660	1.14	-13	0.00
	3	1.5	3707	1.16	3719	1.16	-13	0.00
	3	6	2423	1.16	2437	1.16	-13	0.00
FutureA	1	1.5	1592	1.69	1608	1.69	-17	0.00
	1	6	764	0.00	767	0.00	-3	0.00
	2	1.5	2964	1.01	2978	1.01	-14	0.00
	2	6	1790	0.69	1803	0.69	-13	0.00
	3	1.5	3884	1.29	3897	1.29	-13	0.00
	3	6	2628	0.00	2584	1.29	44	-1.29
FutureB	1	1.5	1237	1.73	1256	1.73	-20	0.00
	1	6	547	0.00	550	0.00	-2	0.00
	2	1.5	2665	1.26	2679	1.26	-14	0.00
	2	6	1546	0.97	1559	0.97	-13	0.00
	3	1.5	3882	1.23	3895	1.23	-13	0.00
	3	6	2786	0.00	2734	1.23	52	-1.23
FutureC	1	1.5	1359	1.30	1376	1.30	-17	0.00
	1	6	614	0.00	616	0.00	-2	0.00
	2	1.5	2765	0.87	2779	0.87	-14	0.00
	2	6	1632	0.56	1646	0.56	-13	0.00
	3	1.5	3643	0.66	3656	0.66	-13	0.00
	3	6	2390	0.00	2391	0.00	-1	0.00

Table E.7: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Peanut Producers in Miller County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change CER	change in EW
historic	1	1.5	791	4.42	809	4.42	-19	0.00
	1	6	182	4.42	201	4.42	-19	0.00
	2	1.5	844	2.53	859	2.53	-16	0.00
	2	6	287	2.53	307	2.53	-18	0.00
	3	1.5	1504	2.80	1517	2.80	-12	0.00
	3	6	1006	2.80	1021	2.80	-15	0.00
FutureA	1	1.5	904	4.17	918	4.17	-14	0.00
	1	6	417	4.17	435	4.17	-17	0.00
	2	1.5	1026	2.36	1038	2.36	-13	0.00
	2	6	604	2.10	619	2.10	-16	0.00
	3	1.5	1598	2.31	1610	2.31	-12	0.00
	3	6	1206	2.31	1219	2.31	-13	0.00
FutureB	1	1.5	796	4.38	814	4.38	-18	0.00
	1	6	199	4.38	218	4.38	-19	0.00
	2	1.5	868	2.46	883	2.46	-15	0.00
	2	6	349	2.46	366	2.46	-18	0.00
	3	1.5	1517	2.68	1528	2.68	-12	0.00
	3	6	1027	2.68	1042	2.68	-15	0.00
FutureC	1	1.5	922	4.10	936	4.10	-14	0.00
	1	6	458	4.10	474	4.10	-16	0.00
	2	1.5	1064	2.24	1077	2.24	-13	0.00
	2	6	639	2.00	653	2.00	-14	0.00
	3	1.5	1618	2.27	1630	2.27	-12	0.00
	3	6	1204	2.27	1216	2.27	-13	0.00

Table E.8: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Tomato Producers in Miller County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change in CER	change in EW
historic	1	1.5	0	0.78	0	0.78	0	0.00
	1	6	0	0.78	0	0.78	0	0.00
	2	1.5	0	0.00	0	0.09	0	-0.09
	2	6	0	0.00	0	0.09	0	-0.09
	3	1.5	0	0.64	0	0.64	0	0.00
	3	6	0	0.64	0	0.64	0	0.00
FutureA	1	1.5	0	1.12	0	1.12	0	0.00
	1	6	0	1.12	0	1.12	0	0.00
	2	1.5	0	0.00	0	0.00	0	0.00
	2	6	0	0.00	0	0.00	0	0.00
	3	1.5	0	0.66	0	0.66	0	0.00
	3	6	0	0.66	0	0.66	0	0.00
FutureB	1	1.5	0	0.79	0	0.79	0	0.00
	1	6	0	0.79	0	0.79	0	0.00
	2	1.5	0	0.00	0	0.18	0	-0.18
	2	6	0	0.00	0	0.18	0	-0.18
	3	1.5	0	0.81	0	0.81	0	0.00
	3	6	0	0.81	0	0.81	0	0.00
FutureC	1	1.5	0	0.70	0	0.70	0	0.00
	1	6	0	0.70	0	0.70	0	0.00
	2	1.5	0	0.72	0	0.72	0	0.00
	2	6	0	0.72	0	0.72	0	0.00
	3	1.5	0	1.20	0	1.20	0	0.00
	3	6	0	1.20	0	1.20	0	0.00

Table E.9: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Corn Producers in Lee County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change CER	change in EW
historic	1	1.5	631	1.48	644	1.48	-13	0.00
	1	6	366	1.60	382	1.60	-16	0.00
	2	1.5	1136	1.18	1146	1.18	-11	0.00
	2	6	976	1.18	987	1.18	-11	0.00
	3	1.5	1550	0.79	1560	0.79	-11	0.00
	3	6	1397	0.79	1407	0.79	-11	0.00
FutureA	1	1.5	788	1.22	800	1.22	-12	0.00
	1	6	536	1.22	549	1.22	-14	0.00
	2	1.5	1216	0.81	1227	0.81	-11	0.00
	2	6	1068	0.81	1079	0.81	-11	0.00
	3	1.5	1571	0.61	1582	0.61	-11	0.00
	3	6	1409	0.61	1419	0.61	-11	0.00
FutureB	1	1.5	601	1.55	614	1.55	-13	0.00
	1	6	335	1.55	350	1.55	-17	0.00
	2	1.5	1144	1.04	1156	1.04	-11	0.00
	2	6	986	1.13	998	1.13	-11	0.00
	3	1.5	1552	0.74	1563	0.74	-11	0.00
	3	6	1396	0.74	1407	0.74	-11	0.00
FutureC	1	1.5	714	1.15	727	1.15	-12	0.00
	1	6	471	1.15	486	1.15	-14	0.00
	2	1.5	1258	0.64	1269	0.64	-11	0.00
	2	6	1105	0.64	1117	0.64	-11	0.00
	3	1.5	1584	0.41	1595	0.41	-11	0.00
	3	6	1420	0.41	1431	0.41	-11	0.00

Table E.10: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Cotton Producers in Lee County

	Relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change CER	change in EW
historic	1	1.5	1697	2.42	1710	2.42	-13	0
	1	6	1082	2.65	1095	2.65	-13	0
	2	1.5	2937	1.48	2947	1.48	-12	0
	2	6	2254	1.48	2266	1.48	-12	0
	3	1.5	3746	1.19	3757	1.19	-12	0
	3	6	2779	1.91	2791	1.91	-12	0
FutureA	1	1.5	1954	1.32	1966	1.32	-13	0
	1	6	1305	1.32	1318	1.32	-13	0
	2	1.5	2999	0.93	3011	0.93	-12	0
	2	6	2106	0.73	2118	0.73	-13	0
	3	1.5	3778	0.56	3790	0.56	-12	0
	3	6	2790	0.70	2803	0.70	-13	0
FutureB	1	1.5	1648	1.79	1662	1.79	-13	0
	1	6	971	1.57	987	1.57	-15	0
	2	1.5	2718	0.90	2730	0.90	-12	0
	2	6	1911	1.02	1924	1.02	-12	0
	3	1.5	3504	0.83	3517	0.83	-12	0
	3	6	2608	0.83	2620	0.83	-12	0
FutureC	1	1.5	1645	1.14	1658	1.14	-13	0
	1	6	1043	1.36	1057	1.36	-14	0
	2	1.5	2838	0.59	2850	0.59	-12	0
	2	6	2013	0.52	2027	0.52	-13	0
	3	1.5	3659	0.00	3660	0.00	-1	0
	3	6	2753	0.00	2743	0.00	10	0

Table E.11: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Peanut Producers in Lee County

	relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change in CER	change in EW
historic	1	1.5	914	3.99	929	3.99	-16	0.00
	1	6	418	4.55	433	4.55	-15	0.00
	2	1.5	989	2.25	1004	2.25	-16	0.00
	2	6	452	2.05	468	2.05	-17	0.00
	3	1.5	1705	2.48	1718	2.48	-13	0.00
	3	6	1171	2.37	1183	2.37	-13	0.00
FutureA	1	1.5	1031	3.66	1046	3.66	-14	0.00
	1	6	579	3.66	593	3.66	-14	0.00
	2	1.5	1176	1.92	1190	1.92	-14	0.00
	2	6	604	1.70	620	1.70	-17	0.00
	3	1.5	1802	1.94	1816	1.94	-13	0.00
	3	6	1258	1.86	1271	1.86	-12	0.00
FutureB	1	1.5	928	3.93	943	3.93	-16	0.00
	1	6	475	3.55	489	3.55	-14	0.00
	2	1.5	1009	2.21	1024	2.21	-15	0.00
	2	6	473	1.99	489	1.99	-16	0.00
	3	1.5	1720	2.39	1732	2.39	-13	0.00
	3	6	1192	2.31	1205	2.31	-12	0.00
FutureC	1	1.5	1011	3.59	1026	3.59	-14	0.00
	1	6	533	4.20	547	4.20	-14	0.00
	2	1.5	1241	1.55	1254	1.55	-14	0.00
	2	6	714	1.55	729	1.55	-15	0.00
	3	1.5	1827	1.78	1840	1.78	-13	0.00
	3	6	1277	1.62	1288	1.62	-12	0.00

Table E.12: Impact of Weather Derivative Contracts on Irrigation Decisions and Certainty Equivalent Revenues for Tomato Producers in Lee County

	Relative risk aversion	soil coefficient	CER_ with contract	EW_ with contract	CER_ without contract	EW_ without contract	change CER	change in EW
historic	1	1.5	0	0.37	0	0.37	0	0.00
	1	6	0	0.37	0	0.37	0	0.00
	2	1.5	0	0.00	0	0.00	0	0.00
	2	6	0	0.00	0	0.00	0	0.00
	3	1.5	0	0.67	0	0.67	0	0.00
	3	6	0	0.67	0	0.67	0	0.00
FutureA	1	1.5	0	0.00	0	0.66	0	-0.66
	1	6	0	0.00	0	0.66	0	-0.66
	2	1.5	0	0.00	0	0.00	0	0.00
	2	6	0	0.00	0	0.00	0	0.00
	3	1.5	0	0.31	0	0.31	0	0.00
	3	6	0	0.31	0	0.31	0	0.00
FutureB	1	1.5	0	0.39	0	0.39	0	0.00
	1	6	0	0.39	0	0.39	0	0.00
	2	1.5	0	0.00	0	0.00	0	0.00
	2	6	0	0.00	0	0.00	0	0.00
	3	1.5	0	0.64	0	0.64	0	0.00
	3	6	0	0.64	0	0.64	0	0.00
FutureC	1	1.5	0	0.00	0	0.39	0	-0.39
	1	6	0	0.00	0	0.39	0	-0.39
	2	1.5	0	0.00	0	0.00	0	0.00
	2	6	0	0.00	0	0.00	0	0.00
	3	1.5	0	0.30	0	0.30	0	0.00
	3	6	0	0.30	0	0.30	0	0.00