# Irrigation Technology Adoption in the Texas High Plains:

# A Real Options Approach

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## Abstract

Water scarcity has been a significant issue for several decades in the Texas High Plains, with agriculture identified as the main activity contributing to this scarcity. To address this issue, much effort has been devoted to developing and encouraging adoption of sophisticated irrigation systems with high levels of water application efficiency, such as the low energy precision application (LEPA) system, subsurface drip irrigation (SDI), and variable rate irrigation (VRI). In this study, the economic feasibility of these irrigation systems is evaluated in cotton farming in the Texas High Plains using a real options approach. Results find that only the LEPA system is profitable under current conditions. The VRI system is profitable with high cotton prices (above \$0.72/lb), while SDI is not profitable under any conditions explored.

*Key words:* cotton, low energy precision application irrigation, Ogallala aquifer, subsurface drip irrigation, variable rate irrigation.

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Fourteen million acres of irrigated farmland in the United States use water from groundwater aquifers at an unsustainable rate, with four of these fourteen million acres located in Texas (National Research Council). The Texas High Plains is the primary location of these acres in Texas, where the Ogallala aquifer is the only source of groundwater. Over the last three decades, the saturated thickness of the aquifer has decreased so that about one third of the pre-development groundwater resources in the region have been mined (Arabiyat, Segarra, and Willis). Because the depletion rate exceeds the recharge rate, the level of the Ogallala aquifer continues to fall and the resulting water scarcity is a serious issue in the Texas High Plains.

The agricultural sector is considered the leading culprit for aquifer depletion in the Texas High Plains. In this region, cotton is the major crop produced and it uses a significant amount of water. Approximately 54% of all cotton acres in the region were irrigated in 2003, relatively high compared to the state average of about 40% of all cotton acres being irrigated (USDA-NASS). Furthermore, irrigated cotton acreage is increasing in the Texas High Plains, so that agricultural water use continues to increase.

Different irrigation systems have been developed to attempt to balance water use and recharge rates in irrigated regions. Traditionally, furrow irrigation and low pressure sprinkler systems have been the most commonly used irrigation systems in the Texas High Plains. However, with increasing concerns about water scarcity, more efficient irrigation systems are being studied and developed. In recent years, the low energy precision application (LEPA) irrigation system has received significant attention and is being widely adopted. However, subsurface drip irrigation (SDI) is now being considered in this region because of its high efficiency of water use. In addition, variable rate irrigation (VRI) alternatives are currently being tested by a private company and Texas Cooperative Extension in the region (Almas, Amosson, Marek, and Colette). The VRI system has been demonstrated on a representative farm and found to be technically feasible (i.e., the VRI control system can diagnose water content in specific places and deliver the needed water). However, economic feasibility is also pertinent to farmers. Irrigation systems require large initial investments and, once installed, are partially or totally irreversible. Because agricultural production and markets for outputs are uncertain and technology development continues, investors need to consider these and other sources of uncertainty and irreversibility when making investment decisions.

Real options, which applies financial option theory to investment in real assets, is the conceptual framework and empirical methodology commonly used to examine irreversible and uncertain investments (Dixit and Pindyck, p.7). In real options, the investor is assumed to have an option to invest or wait, called investment flexibility. By incorporating this option value, the real options approach provides a better measure of the value of an investment compared to the more traditional net present value (NPV) approach (Trigeorgis, p.15). Specifically, the real options method provides the trigger value of the output price or yield that indicates when the investment should be made.

The purpose of this study is to analyze trigger values for the decision to invest in different irrigation systems currently available in the Texas High Plains and compare the economic advantages among these alternatives. Three cotton irrigation systems (SDI, LEPA, and VRI) are analyzed in this study. This study can help focus research efforts to develop new irrigation systems by identifying systems most likely to be adopted and to aid farmers examining possible investments in new irrigation technologies. In addition, the regional concern to save water may be appeased to some degree by identifying the most efficient irrigation system that could be used. In what follows, we first introduce the alternative irrigation systems used in the Texas High Plains. Next, a conceptual framework for farmer's decision making is established using the real options approach. Finally, the data used for the analysis are described and the results are presented and discussed.

## Irrigation Systems

The three most promising irrigation systems being used or considered in the Texas High Plains to save water are the LEPA, SDI, and VRI systems. Instead of spraying water through the air onto crops, the LEPA system uniformly sprays water onto crops using small water sprayers that are close to the ground. With sprayers close to the ground, evaporation is far less than for traditional irrigation sprinkler system, which increases water application efficiency (the percentage of applied water used by the crop). Water use efficiency with LEPA can reach up to 95% depending on soil conditions (Fipps and New). LEPA is currently widely used in the Texas High Plains.

SDI uses hoses or tapes with drips to uniformly apply water into the soil. Because this system avoids water losses to evaporation, runoff, and wetting the soil below the root zone, it increases water application efficiency to reach even 100%. SDI is very useful where water is scarce or expensive (Shock), which is why it is only now being considered in the Texas High Plains, even though it has been used for a long time elsewhere.

VRI is a precision farming technology because the application of irrigation water depends on variable soil characteristics. As with other precision farming practices, such as variable rate application of fertilizer, VRI diagnoses site-specific water content and varies water application according to its diagnosis. By varying water use spatially, VRI increases water application efficiency (to reach up to 98% depending on soil type). On the other hand, VRI requires sophisticated equipment to diagnose site-specific water content and to control water use spatially. Thus, a cost benefit analysis of this system compared to other systems must be considered before the investment decision is made. This system is currently being tested by a private company and Texas Cooperative Extension, and has found to be technically feasible in the region (Almas, Amosson, Marek, and Colette).

## Conceptual Framework

Capital investments in agriculture change future profit flows which also depend on production and cost relationships as well as the initial investment cost. We derive an investment decision model following the specification of profit and a random yield process to facilitate empirical application. We focus on the farmer's decision of whether to switch from non-irrigated cotton farming to investing in an irrigation system, as opposed to switching from one irrigation system to another. Farmers do not often switch irrigation systems while their current system remains useful—Feng and Segarra report a transition probability less than 2%. Rather, the investment decision they face is, when their current system needs replacement, whether to install a new system, and if so, which system to adopt, or simply to no longer use irrigation. This decision is essentially equivalent to the investment decision we model.

### *Profit and Random Yield Process*

We first define the profit $\pi$ with irrigation system $i$ ($i = 0$: non-irrigation system and $i = 1, 2, 3$ for the three irrigation systems) as the difference between revenue $R_i$ and variable cost $C_i$:

(1) $$\pi_i = R_i - C_i = py_i - w_i x_i,$$

where revenue is the product of the market price $p$ and yield $y_i$ ($R_i = py_i$) and variable cost is the product of the input price $w_i$ and the amount of input $x_i$ ($C_i = w_i x_i$). We assume use of all inputs besides water is the same for each irrigation system $i$ in the model, and so we confine variable input use to groundwater. In addition, we normalize profit by the output price since the output price that farmers realize is relatively stable compared to yield because of government intervention, such as the marketing loan rate, counter cyclical payments, or direct payments. For example, the volatility rate $\sigma$ is 0.101 for the annual market price from 1984 to 2003 when the marketing loan rate creates a price floor at \$0.52/lb (volatility is 0.174 without the program). The comparable volatility rate for yield is 0.267, indicating that yield variability is the primary source of uncertainty. Hence, we ignore price variability and vary output price in the analysis to evaluate the effect of the change in output price. Stochastic per acre yield $y_i$ (lbs/ac) is a function of water use $x_i$ (acre-feet per acre) for irrigation system $i$. We assume a general production function $y_i = f(x_i)$ to derive the optimal level of water use.

No water market exists to govern the use of groundwater in the Texas High Plains. Thus, the input price $w_i$ represents the cost to pump and apply an acre-foot of water, where this cost is for energy and delivery costs, plus equipment maintenance and labor expenses. The marginal cost of pumping and delivering an acre-foot of water is assumed to be the same for all irrigation systems, $w_i = w$ for $i > 0$, while non-irrigated farming has no cost for water, $w_0 = 0$. Though small differences in the marginal cost of water may exist among the irrigation systems, irrigation specialists in the region assume they are constant regardless of the system (Orr).

The profit maximization first order condition $f'(x_i) = w_i$ defines the optimal level of water use $x_i^*$ (the level at which marginal revenue from water use equals its marginal cost), which then defines the optimal yield level $y_i^* = f(x_i^*)$. Non-irrigated yield $y_0$ depends on the same factors as irrigated yield (inputs, pest pressure, hail and wind damage, etc.), except that it receives no irrigation water. To capture this connection, yield without irrigation is proportional to yield with irrigation, a relationship supported by the historical county yields in the region (USDA-NASS). Hence, we use $y_0 = by_i$, where $b < 1$.

Given the optimal water use $x_i^*$, the yield flow $y_i^*$ is assumed to follow a geometric Brownian motion process (Carey and Zilberman; Isik et al.; Price and Wetzstein; Purvis et al.). Dropping the superscript * and the subscript *i* for smooth development of the model, the geometric Brownian motion process is defined as:

$$(2) \qquad dy = \alpha y dt + \sigma y dz,$$

where $\alpha$ is the drift (trend) rate, $\sigma$ is the volatility rate, $dt$ is the small time increment, and $dz$ is the continuous-time stochastic Wiener process defined as $dz = \varepsilon_t \sqrt{dt}$, where $\varepsilon_t \sim N(0,1)$. The expected value of the Wiener process is $E[dz] = 0$ and its variance is $E[(dz)^2] = dt$, where $E[\cdot]$ is the expectation operator (see Dixit and Pindyck for more detail).

*Investment Decision*

The value function of non-irrigated farming $V_0$ is defined as the net present value of the future profit flow with an appropriate discounting factor. The farmer who wishes to invest in an irrigation system has to choose an investment timing $t^*$ that maximizes the net present value of profit subject to the stochastic movement of random yield over time.

$$(3) \qquad V_0(y) = \max \mathrm{E}\left[\int_0^\infty \pi_0 e^{-\rho t} dt\right],$$

subject to equations (1) and (2), where $\rho$ is the risk adjusted discount rate equal to the risk free discount rate $r$ plus the risk premium $\Phi$.

Because the yield $y$ evolves stochastically, equation (3) cannot be solved analytically to produce an investment timing point $t^*$. Instead, a critical value $y^h$ that triggers investment in the irrigation system will be determined following the investment rule that it is optimal to invest only when $y \geq y^h$ (Dixit and Pindyck). Non-irrigated farming produces no benefit from the irrigation system until the investment is undertaken. The only return from the irrigation system is the capital appreciation from holding the option to invest that is affected by the stochastic movement of random yield. Thus, the stochastic dynamic optimization equation (3) can be expressed as the following Bellman equation (Pindyck):

(4) $$\rho V_0(y)dt = \pi_0 + \mathrm{E}[dV_0(y)].$$

Expanding the right hand side of equation (4) using Ito's Lemma gives the following differential equation (Pindyck):

(5) $$\frac{1}{2}\sigma^2 y^2 V_0''(y) + \alpha y V_0'(y) - \rho V_0(y) + \pi_0 = 0,$$

where $V_0'$ and $V_0''$ are the first and second derivative with respect to $y$. Similarly, the differential equation for irrigated farming $V_i$ for $i > 0$ is

(6) $$\frac{1}{2}\sigma^2 y^2 V_i''(y) + \alpha y V_i'(y) - \rho V_i(y) + \pi_i = 0.$$

Both differential equations include linear homogeneous parts so that the general solutions contain a linear combination of any two independent solutions. The solution form of this homogeneous part is $V(y) = Ay^{\beta}$, where $A$ is the constant to be determined as a part of the solution, if $\beta$ satisfies the fundamental quadratic equation

(7) $$\rho - (\rho - \delta)\beta - \frac{1}{2}\sigma^2 \beta(\beta - 1) = 0,$$

where $\delta$ is the risk and growth (trend) adjusted discount rate, $\delta = \rho - \alpha$ (Dixit and Pindyck). The respective positive and negative roots of this quadratic equation are

(8) $$\beta_1 = \frac{1}{2} - \frac{(\rho - \delta)}{\sigma^2} + \sqrt{\left[\frac{(\rho - \delta)}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2\rho}{\sigma^2}} > 1,$$

(9) $$\beta_2 = \frac{1}{2} - \frac{(\rho - \delta)}{\sigma^2} - \sqrt{\left[\frac{(\rho - \delta)}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2\rho}{\sigma^2}} < 0 .$$

Equation (5) also includes a non-homogeneous part that has the solution $\pi_0/\rho$. The general solution of the differential equations can be written as

(10) $$V_0(y) = A_0 y^{\beta_1} + B_0 y^{\beta_2} + \frac{\pi_0}{\rho},$$

(11) $$V_i(y) = A_i y^{\beta_1} + B_i y^{\beta_2} + \frac{\pi_i}{\rho},$$

where $\beta_1$ and $\beta_2$ are the respective positive and negative roots of the fundamental quadratic equation (7) and $A_0$, $B_0$, $A_i$, and $B_i$ are constants to be determined as part of the respective solutions for the value function of non-irrigated farming and irrigated farming. The first two terms in equations (10) and (11) respectively denote the value of the option to invest for the non-irrigating farmer and the value of the option to exit for the farmer with irrigation. The last term in each equation denotes the value of the profit flow from the farming.

At very low yield levels, the probability of investing in an irrigation system is small, so the value of the option to invest in (10) approaches zero ($B_0 = 0$). At very high yield levels, the probability of exiting irrigated farming is also very small, so the value of the option to exit approaches zero ($A_i = 0$). Finally, since the main concern of this study is the investment decision, not the disinvestment decision, we set the value of the option to exit at zero ($B_i = 0$). Thus, the value functions for non-irrigated farming and irrigated farming simplify as follows:

(12) $$V_0(y) = A_0 y^{\beta_1} + \frac{\pi_0}{\rho},$$

(13) $$V_i(y) = \frac{\pi_i}{\rho}.$$

The non-irrigating farmer is willing to pay a lump-sum investment cost $I$ at the investment threshold $y^h$ that triggers the investment in irrigation system as long as the investment is expected to be profitable. By exercising the investment option at a cost $I$, the farmer acquires an irrigation system and loses the value of the option to invest. This relationship can be described by the value matching condition (14) and the smooth pasting condition (15):

(14) $V_0(y^h) = V_i(y^h) - I$,

(15) $V_0^{'}(y^h) = V_i^{'}(y^h)$.

The value-matching condition (14) requires the value of non-irrigated farming to equal the value of irrigated farming at the adoption threshold $y^h$ when the investment cost is paid. The smooth-pasting condition (15) requires the same slopes of the value of the non-irrigated farming and the value of the irrigated farming at the adoption threshold level (Merton).

Substituting equations (12) and (13) into boundary conditions (14) and (15), and replacing revenue and cost functions with $R_i = y_i$ and $C_i = w_i x_i$ gives the optimal yield trigger $y^h$:

(16) $$y^h = \left(\frac{\beta_1}{\beta_1 - 1}\right)\left(I + \frac{\Delta C}{\rho}\right)\frac{\delta}{(1-b)},$$

where the factor $\beta_1/(\beta_1 - 1)$ is called the hurdle rate and exceeds one because $\beta_1 > 1$ (see equation (8)). $\Delta C$ is the cost difference between the non-irrigation system and the irrigation system, $\Delta C = w_i x_i^* - w_0 x_0^*$, and $b$ defines the relationship between non-irrigated yield and irrigated yield, $y_0 = by_i$. The net present value (NPV) criterion requires that, for investment to be triggered, the value of the new investment must exceed the investment cost $I$ plus the discounted net change in cost. In terms of equation (16), the NPV optimal yield trigger is $y^h = \left(I + \frac{\Delta C}{\rho}\right)\frac{\delta}{(1-b)}$, which is simply the real options trigger without the adjustment by the hurdle rate $\beta_1/(\beta_1 - 1)$. Since the hurdle rate exceeds one, equation (16) implies that the real options approach has a higher adoption threshold (trigger yield) than the NPV approach. Hence, the empirical issue is to determine the magnitude of the hurdle rate $\beta_1/(\beta_1 - 1)$.

## Data

For the empirical analysis, we develop a representative farm for Lubbock County, Texas because this county is a major cotton production area in the Texas High Plains and includes both non-irrigated and irrigated farmland with various irrigation systems. Table 1 reports the summary statistics of the data used in the analysis. Initial investment costs per acre are \$300 for LEPA, \$800 for SDI, and \$650 for VRI, respectively, for a representative 120 acre irrigated farm (Segarra, Almas, and Bordovsky; Bronson et al.; Lansford, Segarra, and Bordovsky). The groundwater pumping and delivery cost is assumed to be \$4.00 per acre foot (Orr).

USDA-NASS reports cotton lint yield data Lubbock County, Texas with separate time series for irrigated and non-irrigated yields. For 1984-2003, the average yield is 307.0 lbs/acre for non-irrigated cotton and 507.6 lbs/acre for irrigated cotton. An AR(1) model with a constant term and a time trend with the yield difference as the dependent variable was estimated to test the stability of the irrigated yield time series using the augmented Dickey-Fuller (ADF) unit root test. The ADF test statistic was -2.959, while the 10% critical value for the unit root is -3.276. Hence, we cannot reject the null hypothesis of a unit root, which supports using a geometric Brownian motion process. Regressing non-irrigated yield on irrigated yield series without an intercept gave a slope coefficient of 0.5955 (p value < 0.001). Hence, we use $y_0 = 0.6y_i$ for the proportional relationship between irrigated and non-irrigated yield. Irrigated cotton yields show a positive trend rate ($\alpha$) of 0.054 and a volatility rate ($\sigma$) of 0.267. The trend rate is the average of the log difference of the county yields plus one half the squared volatility rate and the volatility rate is the standard deviation of the log difference of the county yields. We use 10% for the risk adjusted discount rate $\rho$, which is comparable to that used in other studies (Carey and Zilberman; Purvis and Wetzstein). With these parameters, the positive root of the fundamental equation $\beta_1$ is 1.438, implying a hurdle rate of $\beta_1/(\beta_1 - 1) = 3.28$.

The amount of water to produce the county mean irrigated yield level was derived using the CroPMan simulation model (Gerik et al.). CroPMan simulates the interaction of natural resources (e.g., soil, water, climate) and crop management practices to estimate impacts on harvested crop yield, soil properties, soil erosion, profitability, and nutrient/pesticide fate (Gerik et al.). Specifically, CroPMan was used to derive county production function parameters for cotton production. Then, using the most prevalent soil type along with the weather data from weather stations located in Lubbock County, average county yield was obtained from CroPMan with varying water application rates and the economic optimum identified. The optimal water use levels derived were 3.69 acre-feet per acre for LEPA, 3.50 acre-feet per acre for SDI, and 3.32 acre-feet per acre for VRI.

The current cotton marketing loan rate of \$0.52/lb is the minimum price that a participating farmer will receive. In addition, farmers are eligible for counter cyclical payments and direct payments if they have a base for cotton acreage. Hence, we use three prices (\$0.32/lb, \$0.52/lb, and \$0.72/lb) to evaluate the effect of price on the adoption thresholds. These prices are based on the current marketing loan rate of \$0.52/lb and a target price of \$0.72/lb for counter cyclical payment (USDA-FSA 2005a, 2005b). The \$0.32/lb price is intended to evaluate conditions if the marketing loan program were eliminated.

## Results

### *Adoption Thresholds and Economic Feasibilities*

Table 2 shows the adoption thresholds for yield that would trigger investment in each irrigation system using both the NPV and real options approaches. The adoption thresholds under the NPV approach range from 78.4 lbs/acre for LEPA to 354.8 lbs/acre for SDI depending on the price. Compared to the county average yield of 507.6 lbs/acre for the past two decades, the investment in any irrigation system is profitable using a NPV criterion, even if the marketing loan program were eliminated.

Adoption thresholds using the real options criterion range from 257.3 lbs/acre for LEPA to 1,165.1 lbs/acre for SDI depending on the price. The real options thresholds are more than three times higher than those for the NPV approach. This high huddle rate (3.28) is consistent with other empirical studies of agricultural investments using real options (Isik et al.). Price and Wetzstein found a hurdle rate of 2.20 and 4.76 for peach orchard investments in Georgia; Purvis et al. report a hurdle rate of 2.28 in their analysis of free-stall dairy investment in Texas; Carey and Zilberman report hurdle rates ranging 1.52-2.81 in their analysis of irrigated agricultural investment in California. Indeed, if we follow Carey and Zilberman and use a risk adjusted rate of return ($\rho$) of 12%, our hurdle rate is 2.68. Only the adoption thresholds for LEPA with a cotton price of at least \$0.52/lb and VRI with a cotton price of \$0.72/lb are below the county average yield of 507.6 lbs/acre, implying adoption is profitable. The real options threshold for SDI still exceeds the county average yield even with a price of \$0.72/lb.

Given these results, it seems that among these irrigation systems, LEPA is the most plausible irrigation system for adoption by cotton farmers on the Texas High Plains. SDI requires a threshold about twice as high as for LEPA. Compared to the average yield of 507.6

lbs/acre in Lubbock County, only LEPA and VRI are viable candidates for adoption. SDI is not viable except for cases with high prices and yield higher than the county average. These results are consistent with the findings of Amosson et al., who report that SDI is not economically feasible compared to LEPA due to its high investment cost and small gains with respect to water application efficiency.

The NPV criterion ignores the cost of uncertainty due to the potential for large losses if future production or market conditions are worse than expected and the irreversible nature of the investment. Adoption thresholds for the real options approach incorporate the opportunity cost of the investment arising from this uncertainty coupled with irreversibility. Compared to the NPV approach, this irreversibility and uncertainty incorporated by the real options approach delays the investment decision until higher profit is more likely. Ignoring these factors can result in overestimating adoption when introducing a new irrigation system to cotton farming, which has important policy implications. Analyses of the value of new irrigation systems with highly efficient water use may find that the technology is economical based on a NPV criterion. However, once the technology becomes available and is recommended or endorsed by various stakeholders in the region, farmers may still not readily adopt it because the value farmers receive by waiting and maintaining the option to invest was not included in the NPV analysis.

Table 3 reports the break-even investment costs with a county average yield of 507.6 lbs/acre and an output price of $0.32/lb, $0.52/lb, and $0.72/lb. The break-even point is the investment cost that produces zero profit, given the cotton price and county average yield. If the break-even investment cost is higher than the actual investment costs ($300/acre for LEPA, $800/acre for SDI, and $650/acre for VRI), then the scenario is considered profitable. In table 3, as the cotton price increases, the break-even investment cost increases and thus the investment in irrigation systems becomes more favorable. Among the scenarios analyzed, LEPA with a cotton price of \$0.52/lb and \$0.72/lb and VRI with a cotton price of \$0.72/lb have break-even investment costs that exceed the actual investment costs, thus implying profitable scenarios. For cases in which investment is not profitable, the difference between the actual investment cost and the reported break even investment cost indicates the amount of subsidy needed to make adoption profitable. For example, the results in table 3 indicate that at the current marketing loan rate of \$0.52/lb, a farmer with yield equal to the county average yield would need a subsidy of \$285/ac before finding SDI profitable and \$126/ac before finding VRI profitable. Under the same conditions, LEPA would require no subsidy. Given the small decrease in water use for SDI and VRI relative to LEPA (see table 1), subsidies of these amounts seem excessive relative to the small gain in water use efficiency. A possible alternative to a subsidy to facilitate adoption of efficient irrigation systems would be efforts to develop a technology that reduces the unit pumping and application costs.

### *Sensitivity Analysis*

Sensitivity analysis was conducted to evaluate the effects of each parameter on the adoption thresholds. Since table 2 already indicates the effect of the cotton price on the adoption threshold, the cotton price is fixed at \$0.52/lb. Each parameter analyzed was changed by ± 20% from its base value reported in table 1 and the resulting adoption threshold is reported in table 4.

Calculating arc elasticities with the results in table 4 indicates the relative responsiveness of adoption thresholds to each parameter. In all cases in table 4, the thresholds for SDI and VRI are relatively similar and higher than for LEPA. In terms of the elasticities, LEPA only differs from the other systems in responsiveness to the investment cost and variable cost. Arc elasticities for the remaining parameters are essentially equal for all three irrigation systems. Finally, little asymmetry exists between increases and decreases in the parameters.

Increasing the investment cost and variable cost increases the adoption thresholds and thus delays or discourages investment in the irrigation systems. Higher costs require higher benefits to trigger adoption. The adoption threshold for LEPA is less response to the investment cost than for SDI and VRI (arc elasticity of 0.62 versus 0.80 and 0.82) and more responsive to the variable cost (arc elasticity of 0.38 versus 0.18 and 0.20). Hence, developing accurate investment cost estimates is relatively more important for SDI and VRI, while accurate estimates of the variable cost are relatively more important for LEPA.

As the risk adjusted discount rate increases, the adoption thresholds increase because a higher discount rate decreases the value of the future profit flow, having an adverse effect on investment incentives. The arc elasticity for the risk adjusted discount rate is the largest in magnitude for all cases in table 4 (0.87), indicating that using an appropriate risk adjusted discount rate is important for empirical analysis. For example, using a 20% lower risk adjusted discount rate (8% instead of 10%) results in the VRI becoming profitable, since the adoption threshold of 496.0 lbs/acre is less than the county average yield of 507.6 lbs/acre. However, notice that the threshold for the LEPA system (416.7 lbs/acre) is far below the county average yield even when the risk adjusted rate increases by 20%, indicating the more profitable nature of the LEPA irrigation system.

The drift (trend) rate is the yield trend increase due to technological progress. If the rate of technological progress increases, then it lowers adoption thresholds and facilitates investment in irrigation systems. Thus, of all the cases in table 4, the drift rate is the only case with an inverse relationship with the adoption threshold (negative arc elasticity). Furthermore, the absolute magnitude of the arc elasticities is the smallest of all the cases in table 4 (–0.16). Hence a 20% change in the drift rate does not change the general result that LEPA is the most profitable irrigation system and the only system with thresholds likely to trigger adoption. For example, when the drift rate increases by 20%, the adoption thresholds of SDI and VRI are still unprofitable when compared to the county average yield, while LEPA is still profitable even when the drift rate decreases by 20%.

The volatility rate represents the uncertainty of the yield flow. When uncertainty (volatility) increases, the option value of waiting to invest increases, and so the adoption thresholds also increase. However, the arc elasticities are relatively small (around 0.30), so that even when the volatility rate decreases by 20%, the adoption thresholds for the VRI and SDI systems still do not trigger investment relative to the county average yield of 507.6 lbs/acre, while LEPA continues to be profitable even when the volatility rate increases by 20%. Also, the volatility rate's small arc elasticity implies that most of the difference between the real options and NPV adoption thresholds arises from value of the investment flexibility captured by the real options approach.

Overall, the sensitivity analysis shows that these parameters play a weak role in determining farmer investment in irrigation systems. For all cases analyzed, the adoption threshold for LEPA was below the county average yield, the adoption threshold for SDI was above the county average yield, and only in two cases was the adoption threshold for VRI below the county average yield. Hence, we conclude that our general findings are fairly robust to these parameters. Thus, farmers in the Texas High Plains are likely to be more willing to adopt LEPA systems compared to VRI and SDI systems, as long as the marketing loan rate is guaranteed. VRI is potentially economically feasible for some farmers, as we find VRI is a profitable system if its investment cost and risk adjusted discount rate decrease by more than 20%. Finally, under none of the real options scenarios examined did we find SDI to be a profitable investment, even though it has the highest water application efficiency among the evaluated alternatives.

### *Implications*

Our primary finding is that using a net present value (NPV) approach implies that all three of these irrigation technology systems are profitable, while a real options approach, which accounts for the option value created by the flexibility and irreversibility of the investment decision, implies that LEPA is the only profitable irrigation technology under base case conditions. Hence, the implication is that public and private agricultural professionals and policy makers will be most successful at improving the irrigation efficiency of cotton farmers in the Texas High Plains by promoting the adoption of LEPA.

We use non-irrigated farming for comparison when analyzing the irrigation investment decision because it captures the essence of the farmer's problem. Few farmers replace working irrigation systems, since cost savings from increased water use efficiency are small relative to investment costs. Rather, farmers make an investment decision when their existing irrigation system needs replacement. Hence, we focus on non-irrigated farmers considering adoption of an irrigation system, as opposed to switching from one irrigation system to another, since this captures the essence of the problem. Our results imply that as farmers in the region replace worn out sprinkler irrigation systems, they should be adopting LEPA and in some cases possibly VRI.

If the goal is to reduce total agricultural water use in the region, our results do not necessarily imply that policymakers should use subsidies or other incentive mechanisms to lower the investment costs for these irrigation technologies. Profitability encourages adoption by those replacing their worn out irrigation systems, which reduces water use in the region because these systems use groundwater more efficiently. However, profitability also encourages adoption by those currently not using irrigation, so that total acres under irrigation expands, which increases water use in the region. As a result, the net effect on total groundwater use of these two offsetting effects is an empirical issue remaining to be explored. Subsidies or similar mechanisms to reduce initial investment costs would have the same offsetting effects—increased adoption on irrigated acres would reduce water use while increased adoption on non-irrigated acres would increase water use. Potentially, policies targeted to encourage only those with functioning systems to invest in one of these new more water efficient system earlier than is currently optimal may be effective a reducing total water use. Hence, the design of appropriate policies to reduce water use is another issue remaining to be explored.

## Conclusion

Water scarcity is a significant issue in the Texas High Plains, with agriculture identified as the main activity contributing to this scarcity. To address this issue, much effort has devoted to introduce and to develop sophisticated irrigation systems with high levels of water application efficiency. Among the alternatives, we examine the low energy precision application (LEPA) system, subsurface drip irrigation (SDI), and variable rate irrigation (VRI). In this study, the economic feasibility of these irrigation systems is evaluated in cotton farming using a real options approach, which has become more widely utilized as an investment criterion to overcome the shortcomings of the NPV approach. Real options regards the investment decision as an option to be exercised by the investor at any time in the future, thus the decision to invest today has a cost similar to the cost of a call option. For the analysis here, we develop a representative cotton farm for Lubbock County, Texas, a major cotton production area in the Texas High Plains with substantial non-irrigated and irrigated farmland.

Our empirical analysis found that adoption thresholds for yield using the real options approach are 3.28 times higher than thresholds using a NPV approach, with the difference mainly caused by the flexibility of investment timing and irreversibility embodied in the real options approach. Among the irrigation systems analyzed, we found that, under current market and yield conditions, only LEPA is profitable. VRI became profitable under higher price and/or yield scenarios. SDI was found to be the least economical among the alternatives, even though its water use efficiency is the highest among the systems evaluated. SDI was never found to be profitable using a real options approach under any of the conditions we explored. Sensitivity analyses found that the profitability of LEPA was robust to parameter changes ± 20%. Similarly, the non-profitability of SDI was also robust to parameter changes. However, VRI became profitable if its investment cost or the risk adjusted discount rate decrease by more than 20%.

Our analysis is not without limitations.[1] For example, we did not consider the potential for investment reversibility or depreciation of the investment (or aging of the technology), recent additions in the real options literature. Investment reversibility (or partial reversibility) creates more flexibility for the disinvestment decision, which increases the value of the investment and so reduces the adoption threshold, since farmers can disinvest from a bad investment (Abel et al.). However, Kandell and Pearson show that by increasing the future value of an investment, reversibility also makes the option of waiting to invest more valuable, which increases the adoption threshold, so that the net effect of reversibility on the adoption threshold becomes an empirical issue.

Balmann and Musshoff study the effects of asset depreciation and competition using an agent-based approach with firms deriving investment triggers using a genetic algorithm.

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[1] We would like to thank an anonymous reviewer for inspiring the next three paragraphs.

Competition creates a reflective barrier for returns at the trigger level because the resulting stimulation of investment at the trigger increases competition and so reduces returns. Allowing investment depreciation dampens the downward movement of returns because investment depreciation reduces output, which increases returns in a competitive market. Hence, Balmann and Musshoff conclude that depreciation decreases the adoption threshold in a competitive market. Indeed, for a sufficiently high depreciation rate, they find that the real options approach is irrelevant compared to the traditional NPV approach. Though robust, their results are based on simulations, making generalizations beyond the specifics of their simulations difficult.

Another limitation is our use of the geometric Brownian motion (GBM) process. Though our data analysis provided empirical support for the GBM process, other processes may be more appropriate on theoretical grounds. For example, the many argue that U.S. cotton yields have reached a plateau in many areas (Pettigrew; Silvertooth), which would support use of a mean reverting process. Alternatively, the random nature of events such as pest outbreaks or damaging weather events (hail, high winds) could justify use of a jump process. An interesting study would be to compare investment thresholds for these different types of stochastic processes, a topic of recent interest (e.g., Conrad and Kotani). If for example, we had used a mean reverting process, the effect on investment thresholds is not clear (Dixit and Pindyck, pp. 161-173). Mean reversion implies a lower variability for future returns (which decreases the threshold), and an increased probability that returns will fall once they are higher than average (which increases the threshold). These offsetting effects imply that empirical analysis is likely needed to determine which effect dominates. For example, Conrad and Kotani find consistently higher thresholds for a mean reverting process compared to a GBM process, while the Monte Carlo analysis of

Metcalf and Hassett using a geometric mean reverting process indicates that the two offsetting effects can increase or decrease thresholds relative to using a GBM process.

Finally, another limitation of our study concerns the impact on overall groundwater use resulting from policy efforts to develop and/or adapt these more water-efficient irrigation technologies to the Texas High Plains. These technologies increases water use efficiency relative to traditional systems in use, which reduces water use, but the profitability of these technologies also encourages adoption by farmers currently not using irrigation, which increases water use. Hence, the net effect of these technologies on total agricultural water use in the region and appropriate policies to reduce total agricultural water use are empirical issues remaining to be explored.

## Reference

Abel, A.B., A.K. Dixit, J.C. Eberly, and R.S. Pindyck. "Options, the Value of Capital, and Investment." *The Quarterly Journal of Economics* 111(1996):753-777.

Almas, L.K., S.H. Amossono, T. Marek, and W.A. Colette. "Economic Feasibility of Precision Irrigation in the Northern Texas High Plains." Paper presented at the Southern Agricultural Economics Association Annual Meeting, Mobile, Alabama, Feburuary 1-5, 2003.

Amosson, S., L. New, L. Almas, F. Brets, and T. Marek. *Economics of Irrigation Systems*. Bulletin B-6113. College Station, TX: Texas A&M University, Texas Cooperative Extension Service, 2001.

Arabiyat, T.S., E. Segarra, and D.B. Willis. "Sophisticated Irrigation Technology and Biotechnology Adoption: Impact on Groundwater Conservation." *AgBioForum* 2(1999):132-136.

Balmann, A., and O. Musshoff. "Real Options and Competition: The Impact of Depreciation and Reinvestment. 2002. Online. Available at http://www.realoptions.org/papers2002/ BallmanROCompetition.pdf

Bronson, K.F., J.W. Keeling, T. Wheeler, R.J. Lascano, R.K. Boman, E. Segarra, J.D. Booker, and J. Mabry. "Testing of Precision Agriculture Technologies in Irrigated Cotton at AG-CARES." Agricultural Complex for Advanced Research and Extension Systems (AG-CARES) 2000 Annual Report, pp 1-4. Texas Agricultural Experiment Station and Texas Agricultural Extension Service, Texas A&M University, and Lamesa Cotton Growers, Lubbock, Texas.

Carey, J.M., and D. Zilberman. "A Model of Investment under Uncertainty: Modern Irrigation Technology and Emerging Markets in Water." *American Journal of Agricultural Economics* 84(2002):171-183.

Conrad, J. M., and K. Kotani. "When to Drill? Trigger Prices for the Arctic National Wildlife Refuge." *Resource and Energy Economics* 27(2005):273-286.

Dixit, A.K. "Irreversible Investment with Price Ceilings." *Journal of Political Economy* 99(1991):541-557.

Dixit, A.K., and R.S. Pindyck. *Investment under Uncertainty*. Princeton NJ: Princeton University Press, 1994.

Feng, Y., and E. Segarra. Forecasting the Use of Irrigation Systems with Transition Probability in Texas." *Texas Journal of Agricultural and Natural Resources* 5(1992):59-66.

Fipps, G., and L.L. New. “Six Years of LEPA in Texas – Less Water, Higher Yields. Visions of the Future.” *Proceedings of the Third National Irrigation Symposium*, Phoenix, AZ, 1990, pp. 115-120.

Gerik, T. J., and W. L. Harman, M. Magre, E. Steglich, J. Greiner, and L. Francis. “CroPMan (Crop Production and Management model) User's Guide: Version 4.0.” BREC Report 2003-06, Blackland Research and Extension Center, Temple, TX. 2003.

Isik, M., K. H. Coble, D. H. Hudson, and L. O. House. “A Model of Entry-Exit Decisions and Capacity Choice under Demand Uncertainty.” *Agricultural Economics* 28(2003):215-224.

Kandell, E., and N. D. Pearson. “Option Value, Uncertainty, and the Investment Decision.” *Journal of Financial and Quantitative Analysis* 37(2002):341-374.

Lansford, V., E. Segarra, and J. Bordovsky. “The Dollars and Cents of Subsurface Drip Irrigation (SDI) for Cotton in the Southern High Plains of Texas.” *Proceedings of the 2004 Beltwide Cotton Conferences*, Cotton Economics and Marketing Conference Section, CD-ROM, 2004.

Metcalf, G. e., and K. A. Hassett. “Investment under Alternative Return Assumptions: Comparing Random Walks and Mean Reversion.” *Journal of Economic Dynamics and Control* 19(1995):1471-1488.

Merton, R.C. “Theory of Rational Option Pricing.” *Bell Journal of Economics and Management Science* 4(1973):143-183.

Myer, S.C. “Finance Theory and Financial Strategy.” *Interfaces*. Reprinted in *Midland Corporate Finance Journal* 5(1987):6-13.

National Research Council. *A New Era for Irrigation*. Washington DC: National Academy Press, 1996.

Orr, Scott. Personal Communication. Cost of Irrigation in the Texas High Plains – Certified Agricultural Irrigation Specialist. High Plains Undergroundwater Conservation District Number 1, Lubbock, Texas, 2005.

Pettigrew, W. T. “Improved Yield Potential with an Early Planting Cotton Production System.” *Agronomy Journal* 94(2002):997-1003.

Pindyck, R.S. “Irreversibility, Uncertainty, and Investment.” *Journal of Economic Literature* 29 (1991):1110-1148.

Price, T.J., and M.E. Wetzstein. “Irreversible Investment Decisions in Perennial Crops with Yield and Price Uncertainty.” *Journal of Agricultural and Resource Economics* 24(1999):173-185.

Purvis, A., W. G. Boggess, C. B. Moss, and J. Holt. "Technology Adoption Decisions under Irreversibility and Uncertainty: An *Ex Ante* Approach." *American Journal of Agricultural Economics* 77(1995):541-551.

Segarra, E., L.K. Almas, and J. Bordovsky. "Adoption of Advanced Irrigation Technology: LEPA vs. Drip in the Texas High Plains." *Proceedings of the 1999 Beltwide Cotton Conference*. 1999:324-328.

Shock, C. C. "An Introduction to Drip Irrigation." Malheur Experiment Station. Oregon State University. Online. Available at http://www.cropinfo.net/drip.htm.

Silvertooth, J. C. "Recent Yield and Fiber Micronaire Tendencies for Upland Cotton in Arizona." 2001 Arizona Cotton Report, University of Arizona College of Agriculture and Life Sciences, 2001. Online. Available at http://ag.arizona.edu/pubs/crops/az1224/.

Trigeorgis, C.G. *Real Options: Managerial Flexibility and Strategy in Resource Allocation*. Cambridge MA: MIT Press, 1996.

United States Department of Agriculture, Farm Service Agency. "2005 Crop Years National Averages." 2005a. Online. Available at http://www.fsa.usda.gov/dafp/psd/2005CropYearsNationAverages.pdf.

United States Department of Agriculture, Farm Service Agency. "Fact Sheet." 2005b. Online. Available at http://www.fsa.usda.gov/pas/publications/facts/html/dcp03.htm.

United States Department of Agriculture, National Agricultural Statistics Service. "Quick Stats: Agricultural Statistics Data Base." 2005. Online. Available at http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/index.asp.

**Table 1.** Summary of Parameters Used in Real Options Calculation of the Value of Different Irrigation Systems in Lubbock County, Texas

| | Low Energy Application (LEPA) | Subsurface Drip Irrigation (SDI) | Variable Rate Irrigation (VRI) |
|---|---|---|---|
| Investment Cost ($/acre) | 300 | 800 | 650 |
| Pumping Cost ($/acre-feet) | 4.00 | 4.00 | 4.00 |
| Optimal Water Use (acre-fee/acre) | 3.69 | 3.50 | 3.32 |
| | ----------- All Irrigation Systems ----------- | | |
| Average Yield (lbs/acre) | 507.6 | | |
| Yield Drift (Trend) Rate* ($\alpha$) | 0.054 | | |
| Yield Volatility Rate* ($\sigma$) | 0.267 | | |
| Risk Adjusted Discount Rate* ($\rho$) | 0.10 | | |
| Risk and Trend Adjusted Rate* ($\delta$) | 0.046 | | |
| Fundamental Equation Positive Root ($\beta_1$) | 1.438 | | |

*Units for rates are percentages as decimals (e.g., 0.05 = 5%).

**Table 2.** Adoption Thresholds for Net Present Value (NPV) and Real Options Approaches[a]

| Irrigation System | Cotton Price Level ($/lb) | | |
|---|---|---|---|
| | 0.32 | 0.52 | 0.72 |
| | Real Options Adoption Threshold (lbs/acre) | | |
| Low Energy Precision Application (LEPA) | 579.0 | 356.3 | 257.3 |
| Subsurface Drip Irrigation (SDI) | 1,165.1 | 717.0 | 517.8 |
| Variable Rate Irrigation (VRI) | 975.1 | 600.1 | 433.4 |
| | NPV Adoption Threshold (lbs/acre) | | |
| Low Energy Precision Application (LEPA) | 176.3 | 108.5 | 78.4 |
| Subsurface Drip Irrigation (SDI) | 354.8 | 218.4 | 157.7 |
| Variable Rate Irrigation (VRI) | 297.0 | 182.7 | 132.0 |

[a] Adoption threshold is the level of the current yield flow triggering adoption of the indicated irrigation system.

**Table 3.** Break-Even Investment Costs under Real Options at the County Average Yield[a]

| Irrigation Systems | Cotton Price Level ($/lb) | | |
|---|---|---|---|
| | 0.32 | 0.52 | 0.72 |
| | ------- Investment Cost ($/acre)[b] ------- | | |
| Low Energy Precision Application (LEPA) | 240 | 506* | 771* |
| Subsurface Drip Irrigation (SDI) | 250 | 515 | 781 |
| Variable Rate Irrigation (VRI) | 259 | 524 | 790* |

[a] 507.6 lbs/acre.

[b] Parameters for each system reported in Table 1.

* Break-even investment cost less than actual investment cost, implying profitable investment.

**Table 4.** Adoption Thresholds (lbs/ac) for Each Irrigation System and Their Sensitivity to Selected Parameters

| Parameter | Change | LEPA[a] | SDI[a] | VRI[a] | LEPA[a] | SDI[a] | VRI[a] |
|---|---|---|---|---|---|---|---|
| | | Adoption Threshold[b] (lbs/ac) | | | Arc Elasticity | | |
| Base Case[c] | none | 356.3 | 717.0 | 600.1 | | | |
| Investment Cost $I$ | -20% | 312.2 | 599.3 | 504.5 | 0.619 | 0.821 | 0.797 |
| | 20% | 400.4 | 834.6 | 695.7 | 0.619 | 0.820 | 0.797 |
| Variable Cost $w_i$ | -20% | 329.2 | 691.3 | 575.7 | 0.380 | 0.179 | 0.203 |
| | 20% | 383.4 | 742.7 | 624.5 | 0.380 | 0.179 | 0.203 |
| Risk Adjusted Rate $\rho$ | -20% | 294.5 | 592.6 | 496.0 | 0.867 | 0.868 | 0.867 |
| | 20% | 416.7 | 838.6 | 701.9 | 0.848 | 0.848 | 0.848 |
| Drift (Trend) Rate $\alpha$ | -20% | 367.6 | 739.8 | 619.2 | -0.159 | -0.159 | -0.159 |
| | 20% | 346.1 | 696.4 | 582.8 | -0.143 | -0.144 | -0.144 |
| Volatility Rate $\sigma$ | -20% | 335.0 | 674.1 | 564.2 | 0.299 | 0.299 | 0.299 |
| | 20% | 377.0 | 758.6 | 634.9 | 0.290 | 0.290 | 0.290 |

[a] LEPA is low energy precision application, SDI is subsurface drip irrigation, and VRI is variable rate irrigation.

[b] Adoption thresholds are the levels of current yield flow triggering adoption of the indicated irrigation system when evaluated at cotton price of $0.52/lb.

[c] Base parameters values reported in Table 1.