Uncertainty and Technology Adoption with Imperfect Property Rights: Lessons from the Arkansas River Valley

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Introduction

Water resources in the arid west and other parts of the world are becomingly increasingly scarce as population growth and water quality impairment puts new demands on this limited resource. With those increasing demands comes an increasing urgency to conserve water and to consume the resource more efficiently throughout the myriad of uses. Indeed, much of the conservation pressure comes down to agriculture, as this sector is allocated as much as 80% of the water available in states like Colorado; water is often over-appropriated and yet population is projected to double by the year 2050. Complicating this resource management problem is a very complex institutional rights structure, which can vary from basin to basin. In this study, we examine how agricultural producer technology adoption decisions with uncertain water supplies are influenced by existing water rights systems, including prior appropriation and the ubiquitous "Beneficial Use Doctrine." We find that imperfect property rights and uncertainty over water availability decrease the incentive to adopt water-saving technology.

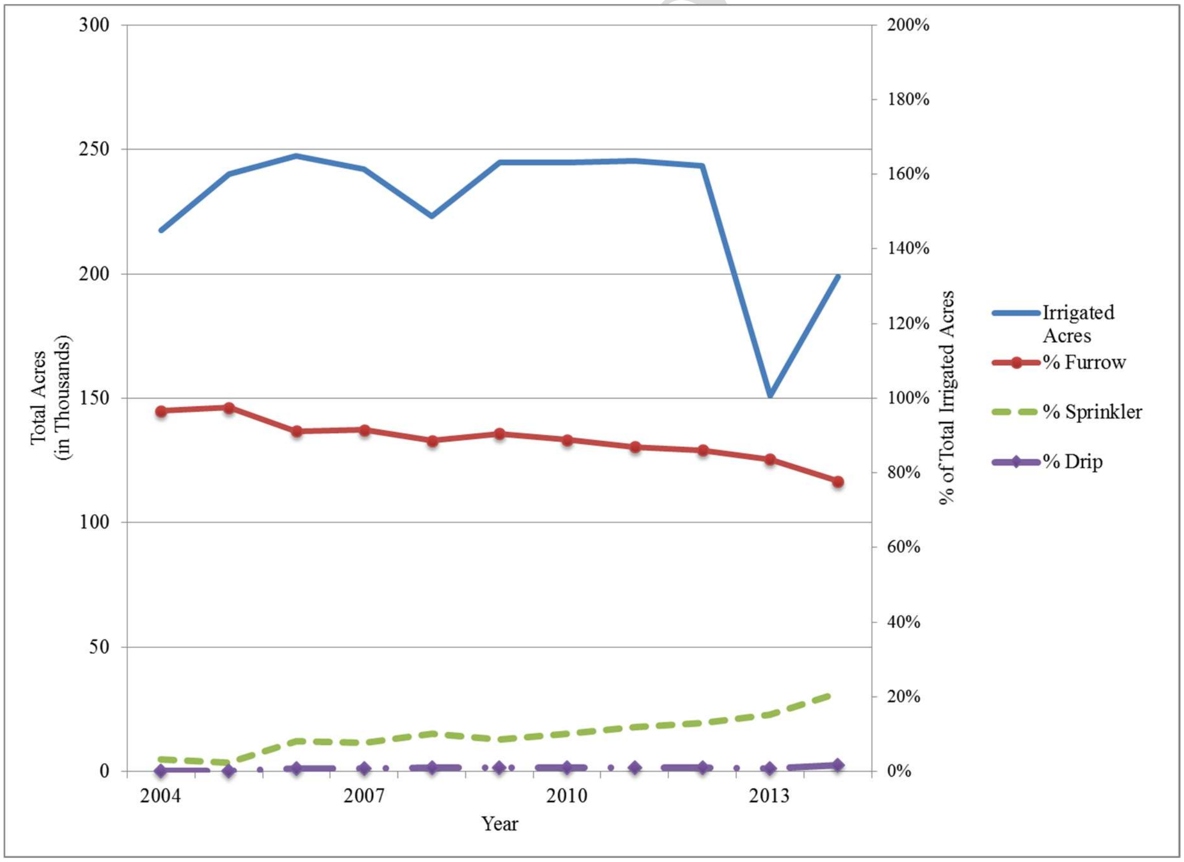
For one water constrained basin in Colorado, the Arkansas River Valley, almost 90% of irrigation technology is flood irrigation, rather than a more efficient system such as sprinkler or drip irrigation. The low rates of sprinkler adoption indicate a potential opportunity to increase the efficiency of water use through technology adoption. However, because return flows are allocated to downstream users on a historical basis through interstate water compacts, farmers implementing new technology may only maintain consumptive use of their water allocation. The implication of this is that upon adoption of new technology, they lose a portion of their water right in application. This water loss combined with a system of seniority in water allocation serve to make water availability uncertain over future time periods.

To account for uncertainty and irreversibility in conservation technology adoption decision making under use-based property rights, this study utilizes a framework developed by Dixit and Pindyck that incorporates the option value a producer holds to wait to invest until new information arrives (Dixit and Pindyck 1994). Using data from the Arkansas River Basin to parameterize a producer's problem, this approach allows researchers to quantify the impact of the inefficient property rights regime and explore policy options to overcome delays in conservation technology adoption.

Colorado Water Policy Background

Colorado's rapidly growing population has pushed leaders in the state to begin to discuss discuss methods of meeting a pending water "gap" caused by a projected doubling of the population by 2050. While new supply initiatives are included in these discussions, policy makers are looking to water conservation efforts to meet much of the state's projected water needs (Colorado Water Conservation Board 2010). Often conservation in agriculture is geared towards using water more efficiently both through the adoption of more efficient irrigation systems and through better water management practices. In the western states, 51.5 percent of water applied in irrigated agriculture was by conservation irrigation technology (sprinkler or drip) (Schaible and Aillery 2012). Yet, the Arkansas River Basin lags behind this average significantly indicating that there must be some institutional barriers to adoption. Furrow irrigation has historically been over 80% of total irrigated acreage with recent gains taking place for sprinkler irrigation (figure 1).

Figure 1: Lower Arkansas River Valley Irrigated Acres by Technology (2004-2014)



Source: Colorado Division of Water Resources, based on the H-I model.

In the western U.S. where every drop of water is used several times, there is a large difference between water conservation and water savings. In particular, if one changes their irrigation technology but does not reduce the amount of water that they draw from the river or ditch, then they are most likely increasing consumptive use of the water and thus reducing the total amount of water available in the basin (Anderson 2013, 271). Colorado policy defines a water right as the "actual historical, beneficial consumptive use" which implies the amount of water evapotranspired by the plant over a period of time (Waskom, et al. 2016). By strict definition of the water right, changes in irrigation technology that increase consumptive use should necessarily decrease the amount of water diverted by the farmer as less water is required to meet historical consumptive use. This policy is meant to care for the needs of all water users in the basin through maintaining on-farm productivity and meeting downstream users' needs.

One of the driving forces affecting water use, and by extension water rights, is the Arkansas River Compact. The compact was ratified in 1948 to "settle existing disputes and removes causes of future controversy between the states of Colorado and Kansas" (Arkansas River Compact: Kansas-Colorado 1949). Accordingly, at least 40 percent of water in Arkansas River must flow into Kansas. The compact resulted in serious constraints on farmers' ability to make adjustments in their irrigation systems, as the compact does not permit development to materially deplete the river's flow to the state line. For example, a producer that upgrades an irrigation system from flood (with an efficiency typically around 50%) to center pivot sprinkler (with an efficiency closer to 90%), will have to prove that the change does not decrease surface return and/or deep percolation flows.

In 2011, the state of Colorado created its own rules for the basin to assure that the compact is upheld (Colorado Division of Water Resources 2016). Rule 8 requires an application the details of any improvements in irrigation systems. The rule also allows for the optional submission of information pertinent to leaching and consumptive use. Recognizing the high cost of acquiring such information, Rule 10 adds a provision for multiple growers to act as a single party in filing an application to improve an irrigation system. Rule 10 provides relief in the costs of determining the impact of irrigation changes on return flows and administrative burden. Importantly, producers can purchase water to maintain historical flows to restore any damages their upgrade may cause, which is commonly called augmentation. The upshot of these rules is that upon adoption of new irrigation technology, farmers must lose a portion of their water right or pay to maintain the same water level.

Literature Review and Contribution

Often when looking at investment, it is important to determine if a decision has a positive net present value (NPV) indicating that the net benefits over the life of the project exceed the net benefits of the next best alternative. If the NPV is negative, then we should not observe investment as farmers are worse off and therefore would not undertake the project. However, there are occurrences where the NPV is positive and yet we do not observe farmers investing in the conservation practice/project. Emerging from this puzzle is a concept known as option value that suggests that when investment decisions are irreversible and can be delayed that traditional NPV analysis inaccurately predicts adoption as decision makers hold on the option to wait and see how economic variables change in the next time period (Dixit and Pindyck 1994). In the case of irrigation investment under western water institutions, undergoing a change in irrigation system is irreversible. This is because the water right available to the farmer is reduced because of rules on technology associated with interstate compacts. Additionally, the seniority of the water right a farmer holds may influence the decision making environment; if the farmer is regularly water stressed (junior water right holder), then a reduction in his water right could be even more detrimental to his profits.

The option value method has been applied to various problems of environmental conservation, particularly for forecasting purposes to predict *ex ante* how agents might respond to a new policy. Purvis et al (1995) look at how uncertainty regarding the design of environmental policies can impact investment decisions for dairy producers. They use simulation for their empirical analysis and find that uncertainty about policies that change overtime will decrease experimentation and postpone investments (Purvis, et al. 1995). Similarly, Carey and Zilberman (2002) explore how creation of water markets might impact investments in modern irrigation technology. Their key finding is that creation of water markets will result in a farmers avoiding investment until the expected present value exceeds the investment cost by a large hurdle rate due to the new opportunity cost of their water resources created by the water market (Carey and Zilberman 2002). Seo, et al. (2008) find the problem of irrigation technology adoption (and entry and exit of irrigated agriculture) to be influenced by stochastic crop output price. They empirically determine the switching points that trigger entry into irrigated agriculture (sprinkler system adoption) and exit (dryland agriculture). Additionally, they find that policies that encourage new irrigation systems do not actually result in water savings because of the low exit threshold—farmers continue to farm extensively after sprinkler adoption even if it is not profitable (Seo, et al. 2008). Another article looks at supply uncertainty and storage to find that when farmers have an option to store water on site, they are more likely to invest in better irrigation technology (Bhaduri and Manna 2014).

The contribution of this study is twofold. First, we model an uncertain water supply in a dynamic framework, indicating an option value associated with waiting to adopt water-saving irrigation technology. Second, we develop a model that reflects the institutional reality of water use under use based property rights. Specifically, consumptive use of water cannot increase and any reduction in return flows must be paid for by the farmer. Because of the beneficial use doctrine and interstate compacts, any water privately saved is gained by downstream users rather than the conservationist. The dynamic model developed here explores how uncertainty in water supplies due to institutions impact adoption decisions.

Methods

While adoption of water conserving technology is on the forefront of policy maker's minds, farmers are more motivated by private returns to investment both in the short and long term. Their decision to adopt technology depends greatly on how it impacts their profits within a given growing season, considering also the impacts of this investment on longer-term profitability. Their decision making environment is often complicated by uncertainty, both in terms of the weather as well as the allocation/availability of their scarce, yet necessary, water resources. It is under this framework that we develop a decision making model for farmers that captures the motivations of farmers as well as the institutional environment under which they operate.

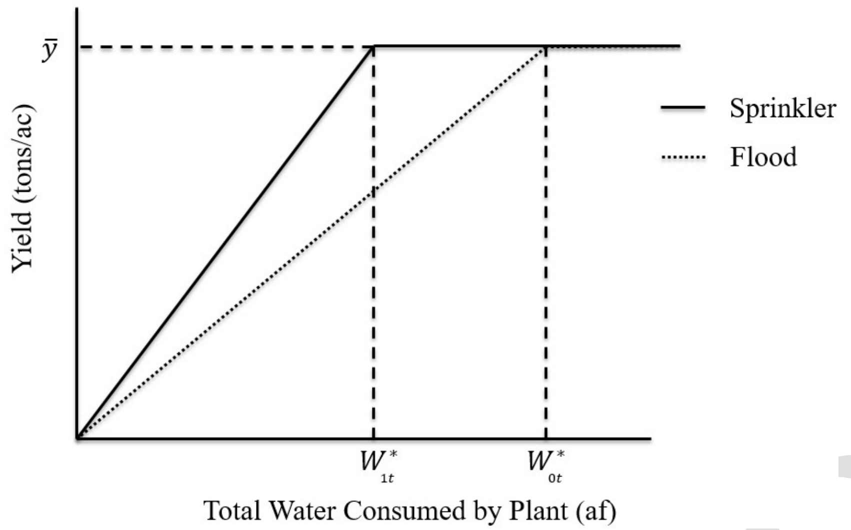
This paper uses a dynamic programming approach to explore the option value associated with undertaking an irrigation technology adoption decision with an inefficient property rights regime. The option value approach developed in this paper is based on the idea that when firms make an irreversible investment decision they give up the "option" to wait to invest until a future time period when more information arrives—in other words, investment comes at an opportunity cost which can significantly impact the expected benefits and the timing of investment. The following sections set up the theoretical model. To begin, the threshold level of water at which a farmer would invest under a NPV rule is derived. Next, dynamic programming is used to solve for the value of the project as a function of the two profit curves under each irrigation types. After this, the value of the option to invest is derived in order to obtain the critical level of water availability at which a farmer would adopt sprinkler irrigation over flood irrigation. Finally, an empirical application for a representative farm in the Arkansas River Basin will serve as an example of how property rights regimes can impact investment decision making; this application serves to quantify the impact of uncertainty and inefficient property rights on the timing of conservation technology adoption.

Theoretical Model

In order to determine the value of the project, the theoretical model must begin by assessing how an investment would be made under a traditional net present value analysis. The key to investment is that the difference between the two irrigation methods be positive. The two irrigation systems available to this model are assumed to be flood irrigation $(i = 0)$ and sprinkler irrigation $(i = 1)$. Both producers face a Von Leibig production function such that input of water in any given time period $(W_{i,t})$ increases output $(y_{i,t})$ linearly until a maximum level of production $(\bar{y})$ (following Carey and Zilberman, 2002). The slope of the production function (b_i) under sprinkler irrigation is steeper than under flood irrigation achieving maximum production with less water application with a sprinkler system implying greater water productivity under a sprinkler system $(b_1 > b_0)$. The production function is shown in (1), with figure 2 as a graphical display of the output associated with input use under sprinkler and flood irrigation. Often, water is limiting in our model so exposition may be simplified to $b_i * W_{i,t}$.

$$Y = \begin{cases} Y_0 = \min\left(\bar{y}, b_0 * W_{i,t}\right), & i = 0 \\ Y_1 = \min(\bar{y}, b_1 * W_{i,t}), & i = 1 \end{cases} \tag{1}$$

Figure 2: Von-Leibig Production under Flood and Sprinkler Irrigation



Water availability $(W_{i,t})$ is the main source of uncertainty in this model. Water availability is assumed to be stochastic and follows a Geometric Brownian Motion (GBM) stochastic process (2). This functional form assumes that a small change in water within a time period (dW) is determined by a drift parameter (α_w) and a volatility parameter (σ), with dt as the time increment and dz is the increment of the Weiner stochastic process (Dixit and Pindyck 1994). The drift rate is the amount that the expected quantity of water changes each year. The last term of the GBM has an expected value of zero; dz is distributed normal with mean 0 and a variance of 1 $(dz \sim n(0,1))$. The GGM is appropriate here as results can be easily compared to those in Carey and Zilberman (2002) and Seo et, al (2008) and water is projected to follow a trend overtime[1]. In order to simulate the current property rights regime, the amount of water available to a farmer is constrained in any given time period by a parameter α (3) which is assumed to be the fraction that reflects the increase in consumptive use from an improved irrigation system.

$$dW = \alpha_w W dt + \sigma W dz \tag{2}$$

$$\alpha * W_{i,t} \; with \; 0 < \alpha < 1 \tag{3}$$

All prices in this model are exogenous and constant. Adoption of sprinkler technology comes at a sunk cost (K) and the cost of irrigating (c_i) under a sprinkler system are higher than under flood irrigation $(c_1 > c_0)$. Fixed costs of sprinkler irrigation are less than fixed costs for

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[1] Under climate change projections, water levels in Southern Colorado are expected to decrease over time (Colorado Water Conservation Board 2010).

flood irrigation ($f_1 < f_0$). Prices for outputs (p) do not differ for the two technologies. Based on this information, the profit functions to be compared are (4) and (5). Using the traditional NPV, if the expected net present value of these two projects less the upfront costs (K) of investments are greater than zero, then the farmer should invest (6).

$$\Pi_{0,t} = \int_0^\infty e^{-\rho t}[\,(p * b - c_o)W_{it} - f_0] \tag{4}$$

$$\Pi_{1,t} = \int_0^\infty e^{-\rho t}[\,(p * b - c_o)\alpha W_{it} - f_0] \tag{5}$$

$$\Pi_{1,t} - \Pi_{0,t} = \int_0^\infty [p(\alpha b_1 - b_0) - (\alpha c_1 - c_0)]W_t * e^{-\rho t}dt + \int_0^\infty (f_0 - f_1)\, e^{-rt}dt - K \tag{6}$$

Net Present Value

After making substitutions (7a), (7b) and (7c) into (6), we find that the water level $(\widetilde{W})$ the farmer would choose to switch from flood to sprinkler irrigation under a traditional NPV analysis depends on the expected net benefits of investment and on interest rates (8). Comparative statics quickly reveal that as fixed costs of sprinkler irrigation grows, the water level required to switch increases $\left(\frac{d\widetilde{W}}{df}, \frac{d\widetilde{W}}{dK} > 0\right)$. Conversely, as the marginal net benefit of switching increases, the water level required to switch decreases $\left(\frac{d\widetilde{W}}{dA} < 0\right)$. The impact of the water rights institution (modeled here as the α parameter) depends on the net marginal benefit of switching, which will be explored further in the empirical application.

$$Let\ p(\alpha b_1 - b_0) - (\alpha c_1 - c_0) \stackrel{\text{def}}{=} A \tag{7a}$$

$$Let\ (f_1 - f_0) \stackrel{\text{def}}{=} f \tag{7b}$$

$$Let\ \rho - \alpha_w \stackrel{\text{def}}{=} \delta \tag{7c}$$

$$\widetilde{W} = \delta\left[\frac{f + rK}{rA}\right] \tag{8}$$

The Value of the Project

This level of water suggested by the NPV analysis ignores the option value associated with waiting to invest. In order to derive the threshold level of water at which a farmer would invest given the uncertain and irreversible setting of adopting new irrigation technology, first the value of the project $(V(w))$ must be solved for, followed by the option to invest $(F(w))$ (Pindyck 1991). Using the notation above, it is easy to see that our Bellman (9) is made up of the current benefit from investing ($[AW_t - f]dt$) and the continuation or future value of the project ($E[V(W + dW)e^{-\rho dt}]$) wherein W follows a GBM stochastic process (2). Following Dixit and

Pindyck (1994), substituting (2) into (9) and using Ito's Lemma, results in (10); simplification results in the ordinary differential equation (11).

$$V(W) = \max E \int_0^{\infty} [AW_t - f]dt + \ [V(W + dW)e^{-\rho dt}] \ s.t. dW = \alpha_w W dt + \sigma W dz \tag{9}$$

$$V(W) = [AW_t - f]dt + \ E\left[\alpha_w W V'(w) + \frac{1}{2}\sigma_w^2 W^2 V''(W)\right]dt + (1 - \rho dt)V(w) + 0dt \tag{10}$$

$$\frac{1}{2}\sigma^2 W^2 V''(W) + \alpha_w W V'(W) - \rho V(W) + AW - f = 0 \tag{11}$$

In order to solve the differential equation for V(W), we utilize four boundary conditions (12a-12d). These boundary conditions state that as water level equals zero, the value of the project equals zero (12a). This is an implication of the stochastic process because once the value arrives at 0, it will stay there. Conditions (12b) and (12c) require that the value function be continuous and differentiable functions of fixed costs because the value function cannot change abruptly across AW as it is a stochastic process that moves freely across the states. These "smooth pasting" conditions are generally required for an optimum; if the functions were not smooth at the point when the investment option is exercised, it would be better to exercise at a different point. And lastly, as W becomes very large, the probability that the value of the project will remain positive becomes very large. This is the "value matching" condition because if the investment is made, the producer gets the value of the project immediately (Dixit and Pindyck 1994, 188).

$$V(0) = 0 \tag{12a}$$

$$V(f^+) = V(f^-) \tag{12b}$$

$$V_W(f^+) = V_W(f^-) \tag{12c}$$

$$\lim_{W \to \infty} V = \frac{WA}{\delta} - \frac{f}{r} \tag{12d}$$

Since the second order ODE is linear in V and its derivatives, the general solution can be expressed as a linear combination of any two independent solutions. Using the boundary conditions (12a-12d), we can guess at a functional form and see if it works by substitution. A functional form often used is the quadratic function (13) as it meets the conditions above. However, the non-homogenous part of our ODE $(AW - f)$ is defined differently when $AW < f$ and when $AW > f$ so we must solve the equation separately for the two scenarios then stitch the solution together at the point $AW = f$. When $AW < f$, profits are zero and only the homogenous parts of the quadratic function remain. Therefore, the general solution is a linear combination of the two proper solutions corresponding to the two roots (13) where D_1 and D_2 are constants to be determined. As AW becomes very small, the event of it's rising above f becomes unlikely meaning the expected PV goes to zero. However, with β_2 as the negative root, $D_2W^{\beta_2}$ goes to infinity as w goes to zero. Therefore, the constant multiplying this terms should be zero (first part of (14)). In this case, the value of project is only the value of the option to produce in the future. When $AW \geq f$, we have the homogenous part as well as the particular solution. This solution implies that profits will accrue during this time and when AW becomes very large, the suspension option $D_1W^{\beta_1}$ is very unlikely to be invoked so its value is zero implying the second part of equation 14. In this case, value is made up of the value of the option to stop producing and the present value of the future flows of profit. Lastly, when $AW = f$, the two regions meet and it is included in the second component of (14) because we still have the value of the option to stop producing and the present value of the future flows of profits. We utilize conditions (12b) and (12c) to solve for the remaining parts of our solution (15) and (16).

$$V(W) = D_1W^{\beta_1} + D_2W^{\beta_2} \tag{13}$$

$$V(W) = \begin{cases} D_1W^{\beta_1}, \; AW < f \\ D_2W^{\beta_2} + \frac{AW}{\delta} - \frac{f}{r}, \; AW \geq f \end{cases} \tag{14}$$

$$\beta_1 = \frac{1}{2} - \frac{\rho-\delta}{\sigma^2} + \sqrt{\left[\frac{\rho-\delta}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2\rho}{\sigma^2}} > 1 \tag{15a}$$

$$\beta_2 = \frac{1}{2} - \frac{\rho-\delta}{\sigma^2} - \sqrt{\left[\frac{\rho-\delta}{\sigma^2} - \frac{1}{2}\right]^2 + \frac{2\rho}{\sigma^2}} < 0 \tag{15b}$$

$$D_1 = \frac{r-\beta_2(r-\delta)}{r\delta(\beta_1-\beta_2)} f^{(1-\beta_1)} \tag{16a}$$

$$D_2 = \frac{r-\beta_1(r-\delta)}{r\delta(\beta_1-\beta_2)} f^{(1-\beta_2)} \tag{16b}$$

The Value of the Option to Invest

Having acquired the value of the project, it is now possible to find the value of the option to invest $F(W)$ as well as the optimal investment rule (W^*). The steps to find $F(W)$ are the same as for $V(W)$ with W still being the stochastic component. The option value approach maximizes the expected present value of the project derived above $(V(W))$ less the investment cost of that endeavor (K), collectively known as the option to invest (equation (14)). The associated Bellman equation sets equal the expected return on the investment $(\rho F dt)$ and the expected rate of capital appreciation $(E[dF(W)])$ (15). From this Bellman, we derive a differential equation (16) that can be solved using the boundary conditions (17a-17c)[2]. We can confirm that the value of the option to invest takes the quadratic form as before (18). Recall from before that the solution for the value of the project ($V(W)$) took on different values depending on if net benefits were non-negative ($AW \geq f$). In the case of option value, there is no need to undertake the investment at cost K only to keep the project idle. As such, the solution for the option value ($F(V)$) is only for the operating region. Using the boundary conditions (17a-17c), the solution for the investment threshold (19) can be solved numerically.

$$F(V) = \max E\left[(V(W) - K)e^{-\rho t}\right] \; s.t. \; dW = \alpha_w W dt + \sigma W dz \tag{14}$$

$$\rho F dt = E(dF(W)) \tag{15}$$

$$\frac{1}{2}\sigma^2 W^2 F_{WW} + (r - \delta)W F_W - rF = 0 \tag{16}$$

$$F(0) = 0 \tag{17a}$$

$$F(W^*) = V(W^*) - K \tag{17b}$$

$$F_W(W^*) = V_W(W^*) \tag{17c}$$

$$F(V) = E_1 W^{\beta_1} + E_2 W^{\beta_2} \tag{18}$$

$$(\beta_1 + \beta_2)D_2(W^*)^{\beta_2} + \frac{(\beta_1 - 1)W^*}{\delta} - \beta_1\left(\frac{f}{r} + K\right) = 0 \tag{19}$$

Data and Model Parameterization

For simplicity, this study utilizes a 1-acre sized representative field grown in alfalfa—a crop that takes up roughly 36% of irrigated agriculture in the Arkansas River Basin. The two types of irrigation technology are flood and mid-elevation sprinkler application center pivot both utilizing surface water flows. Bauder, et al. estimate the water use efficiency of alfalfa in the Intermountain West to be 0.177*acre-inch (Bauder, et al. n.d.). Additional production data for alfalfa came from local extension reports (Davidson, Bartolo and Tanabe 2013). Using irrigation technology efficiency data and production data, the slopes of the two irrigation methods were calculated (Table 1). Cost data came from USDA data (USDA 2016), Texas A&M irrigation cost data (Amosson, et al. 2011), and from a USDA report on irrigation (Schaible and Aillery 2012). Table 2 defines parameter values used in this study. Some of these parameters are varied for sensitivity analysis. For example, the parameter for the institutional restriction on water supply

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[2] The second and third conditions (17b and 17c) are again the value-matching condition and smooth-pasting condition respectively. The value matching condition implies that upon investing the firm receives a net payoff. The smooth pasting condition states that $F(V)$ is continuous and smooth at the critical exercise value (W^*).

(α) is set to 0.7 to reflect an increase in productivity from 65% to 95% efficiency; yet the value of that parameter is important to the results so we look closely and how the optimal water level changes with this parameter. We also take a closer look at the drift parameter (α_w) to see the impact of decreasing water supplies on the critical value of water (W^*).

Table 1: Exogenous Model Parameters

Description	Name	Value
Price for output[1]	p	\$200.00
Maximum production[2]	$\bar{y}$	8
Fixed cost of conventional[3]	f_0	\$51.50
Fixed cost of sprinkler[3]	f_1	\$22.34
Variable cost of conventional[3]	c_0	\$0.00
Variable cost of sprinkler[3]	c_1	\$0.99
Slopes of production functions[4]		
Slope for conventional	b_0	0.1062
Slope for sprinkler	b_1	0.1682
Investment Costs	K	\$998.83
1 Data from USDA 2016		
2 Data from Davidson, Bartolo, and Tanabe 2013		
3 Calculated for local environment with data from Schaible and Aillery 2012 and Amosson, et al. 2011		
4 Slopes calculated based on irrigation efficiency information in Amosson, et al., 2001 and alfalfa production data in Bauder, et al., n.d.		

Table 2: Parameter Values

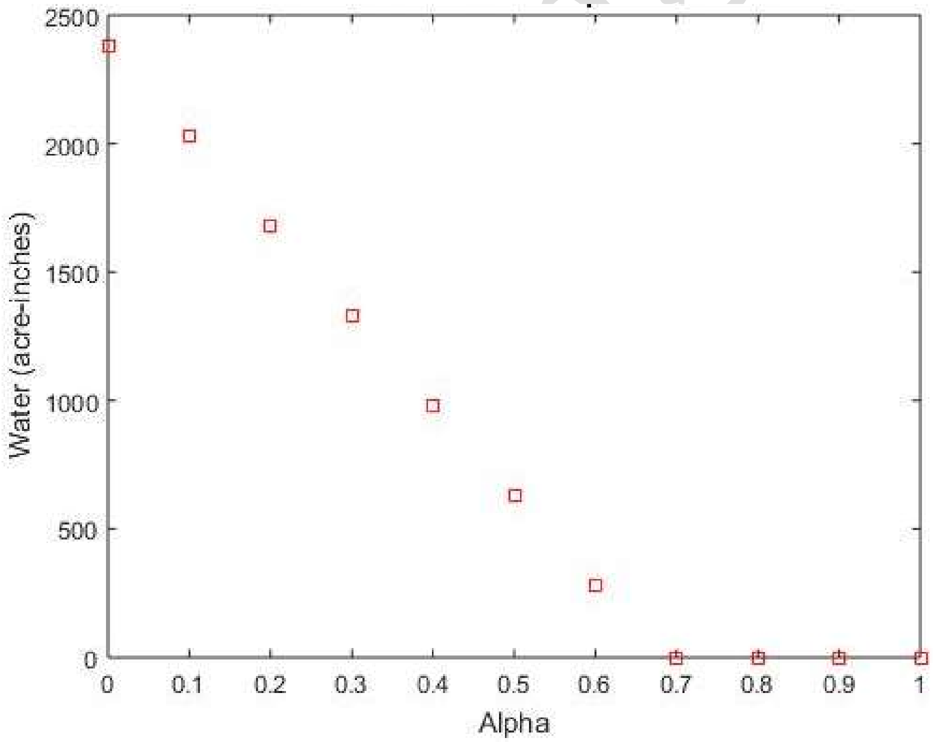
$r = 0.04$	$\rho = 0.10$	$\alpha_w = -0.03$	$\delta = \rho - \alpha_w = 0.13$
$\sigma = 0.15$	$\sigma^2 = 0.0225$	$W_0 = 48$	$\alpha = 0.7$

Discussion

This study utilizes Matlab (2015, student edition) to solve for the net present value water level at which one would switch to sprinkler irrigation ($\widetilde{W}$) and the critical value of water using the option value analysis (W^*). Preliminary results suggest that the net present value of sprinkler adoption is positive, such that for any water level, farmers should be adopting sprinkler irrigation. However, the loss in water right due to irrigation improvement rules increases the amount of water required in order to make the switch to sprinkler irrigation. Additionally, the option to wait to adopt and downward trends in water availability impede farmers from making the investment decision[3].

Explore the impacts of the water rights institutions, its simplest to look at the NPV rule. If a farmer adopts sprinkler irrigation and is able to keep the entirety of his water right ($\alpha = 1$), then he would be better off sprinkler irrigation for any level of water. However, under the irrigation improvement rules, it is certain that a farmer will lose a portion their water right as they can only maintain consumptive use. If a farmer increases the consumptive use from 65% to 95%, the appropriate α level would be 0.7 (1-0.3). This implies that for any α level above 0.7, the farmer will at least maintain yield if not increase it. The function of our water level at which we would switch irrigation technologies is shown graphically in Figure 3. As α exceeds 0.7, the farmer requires a much greater water level in order to switch irrigation technologies.

Figure 3: Water Level Required for Farmers to Switch Irrigation Practices



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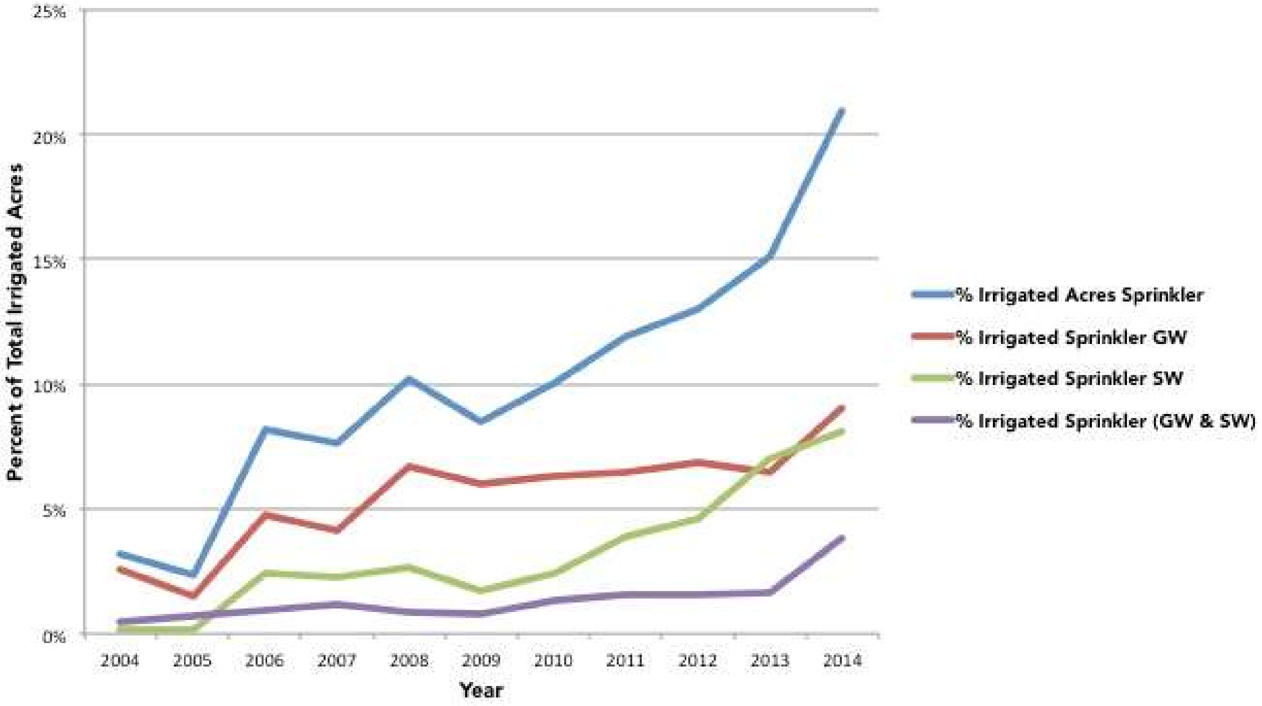
[3] The results from the option value analysis are still too preliminary to report in this paper. They will be updated as the research progresses.

In the basin, there has been an up-tick in farmers collectively filing Rule 10 plans to change irrigation practices compared to historical adoption rates. In 2016, three Rule 10 plans were submitted for renewal. Based on the publically available applications, roughly 165 fields, covering close to 26,600 acres will be irrigated with Rule 10 plan sprinklers. These values represent cumulative acreage totals since the inception of the Irrigation Improvement Rules (2011). Total sprinkler acreage growth for the 2016 is about 15% over 2015 acreage. Figure 4 illustrates the growth in sprinkler acreage by water source.

Figure 4: Lower Arkansas River Basin Percentage of Sprinkler Irrigated Acres by Water Source (2004-2014)



Source: Colorado Division of Water Resources, based on the H-I model.

Conclusions

As policy makers target water conservation as a way to meet pending demands on water quantity in the west, there must be consideration of existing property rights systems that impact conservation decision making. The private benefits of adopting conservation technology are eroded by rules on irrigation that serve to maintain return flows at the expense of current agricultural water users in the Arkansas River Basin. Temporary supply agreements, like the recently passed HB 1228, serve to get water to urban users in times of great need while maintaining water in agriculture. However, since these policies require farmers only lease 50% of their water, the impact of this policy is again to push farmers away from more efficient irrigation technologies. Additionally, the option of a farmer to wait and see how irrigation rules, new water transfer policies and water markets emerge further impact a farmers decision making on irrigation technology adoption.

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