

## How probability weighting affects participation in water markets

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[1] The behavioral tendency to overestimate probabilities of loss can affect a farmer's participation in water markets. We examine this issue with a theoretical model of a nonexpected utility maximizing farmer who places subjective weights on the actual probabilities of loss of water rights due to market transactions. The farmer bargains over sharing of surpluses with the buyer of water. The farmer then incorporates the bargaining outcome in his intertemporal expected benefit maximization problem that accounts for the possible loss of water rights due to its sale out of agriculture. Three key results emerge. First, subjective weighting of probabilities leads to discounting of resources when farmers overestimate probabilities of loss. Second, if farmers have idiosyncratic time preferences, total water supply in the market would depend on the level of heterogeneity in the population. Third, considering the case of two farmers, we find that the farmer with lower endowments bears the burden of risk reduction, whereas the one with higher endowments sells more water for profits. As the level of risk increases, however, the relative difference in risk sharing declines.

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### 1. Introduction

[2] Despite a growing disparity between the value of water in agriculture and urban uses in the United States, few regions exchange water through markets to capture these potential gains from trade. The key factors responsible for this low success rate of water markets can be classified as either institutional or behavioral [Ranjan, 2006]. Institutional factors comprise political, legal, physical, and financial matters. Behavioral factors involve how an individual owner of water perceives the risks associated with water transfers and how this affects his water sales [Goodman and Howe, 1997].

[3] Political bottlenecks to water trade include disregard for policy objectives defined in terms of economic efficiency, such as the efficient allocation and redefinition of water rights to facilitate the transfer of water to its higher valued uses [Gaffney, 1997]. Legal factors include the ambiguity over definition of water rights that fails to account for third-party impacts and promotes uncertainty over the future water rights for market participants [Colby, 1990]. Physical and financial bottlenecks refer to the lack of transferring and storage facilities and financial instruments that would help participants hedge risks from water trade created by uncertainties over water supply and water rights.

[4] While institutional factors are crucial, behavioral responses of the water rights owners will ultimately determine the success or failure of water markets. Institutional

factors will shape behavioral responses of farmers. However, in the absence of fully developed institutions, farmers' personal subjective evaluations of risks become critical. Farmers are well aware of the risk to their water rights when considering the pros and cons of participating in water markets. This risk, which is well documented in the literature, stems from the unstable nature of water rights [Howitt, 1995]. Howitt [1995] describes the evolution of property rights as an endogenous process determined by the evolution of water demand, the uncertainty of future water supply, and the institutional costs of redefining water rights. The water rights, according to Howitt [1995], are malleable, with economic pressure being the primary force acting on it. In selling his water out of agricultural uses, the farmer must weigh the benefits of a current transfer against the probability of losing future water rights. While risk is acknowledged as one of the most significant forces affecting the use of water markets, few studies exist that have closely scrutinized the behavioral underpinnings of risk on water markets.

[5] Following insight from behavioral economics on how people respond to risky choices, we consider how a farmer chooses to participate in risky water markets. We explore this issue through a Nash bargaining framework wherein buyers and sellers maximize the joint product of their surpluses. The farmer considers the impact of his current water sales on future probabilities of water rights loss. On the basis of prospect theory, we suppose that this farmer assigns higher weights to low probabilities of water rights loss and lower weights to high probabilities of loss [see, e.g., Starmer, 2000]. We further use Prelec's [1998] probability weighting scheme to examine how these weights affect the farmer's willingness to sell water to urban users. At this stage, there is little empirical work available to guide us through the nature of risk perception of water sellers in

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the water markets. Consequently, we rely heavily on empirical evidence for risk perception available from psychological experiments in controlled environments to derive analytical insights.

[6] On the basis of a set of empirically confirmed parameters, our findings make strikingly different behavioral predictions, more in line with observed behavior, as compared with those predicted by expected utility maximization theory. Three key results emerge. First, subjective weighting of probabilities leads to discounting of resources if the probabilities fall in the zone of overestimation. The conventional assumption about the shape of the weighting function is that it follows an inverse S-shaped pattern. This weighting scheme is characterized by (1) the inflection (reference) point at which a person switches from overestimating low-probability events to underestimating high-probability events, i.e., the degree of over and underestimation; and (2) the curvature, which captures the idea that people become less sensitive to changes in probability the farther they are from the inflection point [Tversky and Kahneman, 1992; Gonzales and Wu, 1999].

[7] Second, if farmers vary in their time preferences, it is not straightforward to predict their behavior related to water sales since they act differentially depending on whether the subjective weighting of their probabilities takes them beyond the point of inflection or not. Consequently, total water supply in the market is a function of the degree of heterogeneity in the time preference of the participants. In addition to time preferences, the nature and level of risks associated with water sales also influence whether farmers' subjective perceptions fall on one side of the inflection point or the other.

[8] Third, the analysis reinforces the importance of water sellers' institutional organization, their voting schemes, and their level of endowments in determining total water supply. In the case of heterogeneity among water sellers, the farmer with lower endowments bears a larger burden for risk reduction, while the one with higher endowments sells more water for profits. As the level of risk increases, though, this relative difference in risk sharing becomes small.

[9] Before presenting the model, we briefly review the state of the water rights in the United States in order to highlight some of the key factors that create uncertainty about the security of rights to water.

## 2. Water Rights in the United States

[10] There are primarily two types of surface water rights in the United States: riparian and prior appropriation. Riparian rights came into force in regions with abundant water and are water rights associated with land ownership bordering water sources. Water was regarded as a public property, however, under this form of ownership. If the riparian rights owners failed to put water to "reasonable uses," they could lose their rights. These rights were further subject to government interpretation and were usually nontransferable.

[11] The second type of water right, primarily found in the West, is the prior appropriation right that allocates water ownership based upon "beneficial uses." While beneficial uses have mostly been classified as agricultural, municipal, and industrial, environmental uses have been increasingly asserting their claims [Council of State Governments, 2003].

These rights are mostly hierarchical and could be appropriated by the government if it could demonstrate higher beneficial use from the water. Because of the uncertainty associated with the "beneficial use" clause, water sold out of agricultural uses might be deemed as not being used for beneficial purposes and could face appropriation. Even though farmers support water markets, they are wary of the fact that in absence of well-defined property rights over water, they might lose such rights by trading in water no matter how beneficial the trade is (see <http://www.techcentralstation.com/011503B.html>).

[12] The evolving nature of water rights creates uncertainty for water trade. There have been recent instances of water rights being temporarily lost by farmers. In September of 2005 a federal judge rejected the compensation claim of irrigation farmers from the Klamath basin who had contractual rights for water that was diverted by the government for salmon protection in 2001 [U.S. Water News Online, 2005a]. The irrigators complained that this decision overturned hundred years of reclamation law, whereas the government argued that paying farmers for their property rights could make the endangered species act very costly to enforce. In another judgment, the U.S. Supreme Court ruled that farmers in California's central valley district could not sue the federal government for compensation even as the Bureau of Reclamation diverted water to protect threatened fish [U.S. Water News Online, 2005b].

[13] While there have been no known instances of farmers losing water rights due to water trading, the possibility is real, as suggested by the growing number of court battles over water rights. Historically, three ways for water reallocation have been applied: voluntary transactions, administrative or legislative mandates, and litigation [Smith, 1994]. Howitt and Hansen [2005, p. 60] note, "When appropriative rights were codified into state laws in the late 19th and early 20th centuries, state lawmakers did not envision widespread leasing and permanent transfers of water rights. As a result, western rights holders have historically been reluctant to lease water out, for fear of losing their right to the water in the longer term." In the absence of well-defined rules for voluntary transactions, legislative and litigation methods might be increasingly used to settle such disputes, which could result in loss of water rights.

## 3. Model

[14] Consider a water market with two participants, a farmer and an urban buyer. If the farmer decides to sell water out of agricultural uses, the farmer risks losing his water rights. The risk of loss is a function of level of water transactions and other exogenous parameters (e.g., institutional factors, environmental needs, water scarcity, and the possibility of future redefinition of beneficial use).

[15] We assume that the loss in water rights is confined to the amount of water transferred. The amount of water used in agriculture would still be available to the farmer. A farmer profits from the sale of water to the urban buyer and from the sale of agricultural output. His objective is to maximize expected utility over time under the constraint of continuously evolving risk from water trading. For simplicity, we assume that the farmer's utility function is linear in his profits. Further, current and future urban water demand

and the cost of obtaining water from an alternate source to the urban buyer are given and known to both.

[16] Formally, let  $x$  be the amount of water sold to the urban buyer by the farmer out of his total endowment of one unit, i.e.,  $0 < x < 1$ . Output in agriculture is a function of water applied  $(1 - x)$  and available land  $(I)$ , and is assumed to be Cobb-Douglas in form.

[17] The risk of water loss in this system is modeled as a Poisson process, based upon the work of *Clarke and Reed* [1994], *Reed* [1988], and *Reed and Heras* [1992]. In each time period, assume that the water rights owner faces an instantaneous probability of losing these rights denoted as  $p$ . The timing of water rights loss is defined as a random variable, and for tractability we assume that this variable has a Poisson distribution. The cumulative risk of water rights loss  $\lambda(t)$  is then governed by

$$\lambda(t) = \int_0^t p(s, x, \theta) ds, \quad (1)$$

where  $p(s, x, \theta)$  is the instantaneous probability (or hazard rate) of loss of water right at time  $s$  given that water rights were not lost up to that time, and is a function of the amount of water sold  $x$  and an exogenous parameter  $\theta$ , which is beyond the farmer's control. In this model we do not focus on the risks arising from changing institutional structures, although they may have some role to play in the perception of risk regarding water sales. Our emphasis is on risks that are idiosyncratic and directly related to the farmer's actions. Institutional risks from ill-defined water rights may too be perceived differentially based upon the farmer's type. For instance, more resourceful farmers would be better able to fend off threats to water rights arising from third-party litigations. Next, the cumulative risk  $\lambda(t)$  evolves as

$$\frac{\partial \lambda(t)}{\partial t} = p(t, x, \theta). \quad (2)$$

When the farmer engages in a water trade and loses his water rights, his benefits are simply the output from agriculture using the remaining water. Assuming agriculture prices are fixed at unity for all periods, the value of agricultural output is given by

$$Q = (1 - x)^\alpha I^\beta, \quad (3)$$

which summed to infinity and discounted at  $\rho$  is

$$Q = \frac{(1 - x)^\alpha I^\beta}{\rho}. \quad (4)$$

Until the time the farmer retains his water rights, his profits in each period are

$$\pi x + (1 - x)^\alpha I^\beta, \quad (5)$$

where  $\pi x$  is the profit to the farmer from selling his water to the urban buyer at a price  $\pi$ .

[18] Assuming that the farmer maximizes his expected profits, discounted sum of profits to the farmer from water trade and agriculture can be written as

$$J = \int_0^\infty e^{-\rho t - \lambda(t)} \left( \pi x + (1 - x)^\alpha I^\beta + p(t, x, \theta) \frac{(1 - x)^\alpha I^\beta}{\rho} \right) dt. \quad (6)$$

This formulation of the expected profit function is based upon that of *Clarke and Reed* [1994]. The farmer's problem is to maximize (6) subject to (2). Since  $x$  is indirectly determined through bargaining between the urban buyer and the farmer over the price of water, the problem is (assuming a Nash bargaining game)

$$\max_\pi (\pi x - (1 - (1 - x)^\alpha) I^\beta) (Bx - \pi x), \quad (7)$$

where the first term represents the farmer's surplus from trade and the second term represents the urban buyer's surplus from avoiding a costly alternative source of water, at a price  $B$ . Notice that in absence of trade, the farmer's output in agriculture would be  $I^\beta$  and with trade his output would be  $(1 - x)^\alpha I^\beta$ . Therefore the opportunity cost of water sold to the buyer is  $(1 - (1 - x)^\alpha) I^\beta$ . It is unnecessary that the bargaining surplus for the farmer would always be positive. If the price of water offered by the buyer does not meet the opportunity cost of water, the surplus may become negative, thus discouraging any trade. The possibility that this would happen in the United States, however, is extremely rare as the urban value for water far exceeds its value in agriculture. ("Farmers in Imperial [Valley] currently get their water for about \$15 an acre-foot (about 326,000 gallons), and San Diego was offering to pay \$258 for that water. Of course, that \$258 gets watered down pretty quickly (it would cost money to move the water, and much of the payment would be dispersed throughout the community by local politicians), but it still sounds like an attractive offer—especially since the alternative to selling the water was simply to have it taken away by the Interior Department" (<http://www.techcentralstation.com/011503B.html>)). Maximizing (7) with respect to water price gives us  $\pi$  in terms of  $x$  as

$$\pi(x) = \frac{B}{2} + \frac{(1 - (1 - x)^\alpha) I^\beta}{2x}. \quad (8)$$

[19] This form of bargaining assumes that the total amount of water,  $x$ , sold to the urban buyer is decided in advance by the farmer through his intertemporal objective maximization. The bargaining is over the settlement of the price of water in each period. Plugging (8) back into (6) we get

$$J = \max_x \int_0^\infty e^{-\rho t - \lambda(t)} \left( \pi(x)x + (1 - x)^\alpha I^\beta + p(t, x, \theta) \frac{(1 - x)^\alpha I^\beta}{\rho} \right) dt. \quad (9)$$

The current value Hamiltonian is

$$e^{-\lambda(t)} (\pi(x)x + (1-x)^\alpha l^\beta) + p(t, x, \theta) \frac{(1-x)^\alpha l^\beta}{\rho} + \mu p(t, x, \theta). \tag{10}$$

Taking the first-order condition with respect to  $x$  yields

$$e^{-\lambda(t)} \left( \pi_x(x)x + \pi(x) - (1-x)^{\alpha-1} l^\beta + p_x(t, x, \theta) \frac{(1-x)^\alpha l^\beta}{\rho} - p(t, x, \theta) \frac{(1-x)^{\alpha-1} l^\beta}{\rho} \right) + \mu p_x(t, x, \theta) = 0 \tag{11}$$

The costate variable  $\mu$  evolves as

$$\frac{d\mu}{dt} = e^{-\lambda(t)} \left( \pi(x)x + (1-x)^\alpha l^\beta + p(t, x, \theta) \frac{(1-x)^\alpha l^\beta}{\rho} \right) + \rho \mu. \tag{12}$$

In steady state expression (12) reduces to

$$\rho \mu + e^{-\lambda(t)} \left( \pi(x)x + (1-x)^\alpha l^\beta + p(t, x, \theta) \frac{(1-x)^\alpha l^\beta}{\rho} \right) = 0 \tag{13}$$

Substituting for the value of  $\mu$  from (11) we get:

$$-\rho \frac{\left\{ e^{-\lambda(t)} \left( \pi_x(x)x + \pi(x) - (1-x)^{\alpha-1} l^\beta + p_x(t, x, \theta) \frac{(1-x)^\alpha l^\beta}{\rho} - p(t, x, \theta) \frac{(1-x)^{\alpha-1} l^\beta}{\rho} \right) \right\}}{p_x(x)} + e^{-\lambda(t)} (\pi(x)x + (1-x)^\alpha l^\beta) + p(t, x, \theta) \frac{(1-x)^\alpha l^\beta}{\rho} = 0. \tag{14}$$

Rewriting (14) yields the optimality condition

$$\left\{ e^{-\lambda(t)} \left( \pi_x(x)x + \pi(x) - (1-x)^{\alpha-1} l^\beta + p_x(t, x, \theta) \frac{(1-x)^\alpha l^\beta}{\rho} - p(t, x, \theta) \frac{(1-x)^{\alpha-1} l^\beta}{\rho} \right) \right\} = \frac{\left\{ e^{-\lambda(t)} (\pi(x)x + (1-x)^\alpha l^\beta) + p(t, x, \theta) \frac{(1-x)^\alpha l^\beta}{\rho} \right\} p_x(x)}{\rho} \tag{15}$$

In equation (15), the left-hand side represents the change in expected instantaneous profits from an incremental sale of water to the urban buyer. This includes changes in the bargaining profits and changes in future agricultural returns from loss of water rights. The right-hand side is the opportunity cost of altering the expected profits from an incremental sale of water and is interpreted as the discounted sum of future returns that could be had from not selling that water.

[20] We now add the behavioral economics element into the model. On the basis of accumulated evidence in

economics and psychology literature (see summary by *Hurley and Shogren [2005]*), assume that the farmer assigns higher weights to low probabilities of water rights loss and lower weights to high probabilities of loss [also see *Starmar, 2000*]. We add these weights to the hazard rate  $p(x)$ , which represents the probability of the water right loss at time  $t$ , given that it did not happen previously. Let the weighting function follow an inverse S-shape. Following *Prelec [1998]*, we use a two-parameter weighting function as

$$w(p) = e^{-\theta(-\ln p)^\gamma} \tag{16}$$

where  $\theta$  is the parameter that primarily determines elevation, and  $\gamma$  is the parameter that primarily determines curvature. Elevation reflects the inflection (reference) point at which a person switches from overestimating low-probability events to underestimating high-probability events, i.e., the degree of overestimation and underestimation; curvature captures the idea that people become less sensitive to changes in probability the farther they are from the inflection point [*Tversky and Kahneman, 1992; Gonzales and Wu, 1999*].

[21] The inflection point of the inverted S-shaped curve is critical and can only be determined empirically. Weighting of hazard rates implies that predominance is given to the probability of the rights being lost at time  $t$ , given that they would survive until then. In an exponential distribution, this hazard rate is constant (but could be endogenous). To gain additional insight, we now consider a numerical simulation of the model.

#### 4. Details of Numerical Simulation

[22] Define the instantaneous hazard rate  $p$  as  $p(x) = p_0 x(t)^2$  where,  $p_0$  is exogenous and referred to as the policy-independent risk component as characterized by *Clarke and Reed [1994]*. Tables 1 and 2 presents a hypothetical but empirically consistent set of parameters used for numerical simulation, which was preformed using GAMS. For the base case we initially presume that the farmer is concerned that he will lose his water rights given that he participates in the water market, but he does not assign subjective weights to this risk (i.e.,  $\theta = 1$  and  $\gamma = 1$ ); he is an expected profit

**Table 1.** Baseline Parameters for One-Farmer Case

Parameter	Value
$\rho$	0.01
$\alpha$	0.5
$\beta$	0.5
$\gamma$	1
$p0$	1
$\delta$	0.003
$L$	2
$B$	100
$\theta$	1
$\lambda_0$	0.00001
$Z$	1

maximizing type farmer. A time horizon of 200 years mimics the infinite horizon problem, and the steady state for the problem is found to exist. Consider now the simulation results.

[23] We examine probability weighting scenarios that create two distinct farmer types, apart from the base case type, to explore how subjective risk weighting behavior affects farmer participation in a water market. First, the base case farmer type represents our traditional rational choice benchmark behavior. Here, there is no over or under weighting of probabilities, i.e.,  $w(p) = p$  given ( $\theta = 1$ ;  $\gamma = 1$ ). In Figure 1 the unweighted type is represented by the 45 degree line in  $w(p)$  and  $p$  space. Second, we have farmer type A ( $\theta = 0.99$ ;  $\gamma = 0.79$ ), who serves as the “overestimates low probabilities/underestimates high probabilities” benchmark. This weighting scheme leads to a crossing over point of 0.385, which is consistent with *Tversky and Kahneman’s* [1992] estimates of 0.38 for losses. Figure 1 shows farmer A as biasing his perceptions of risk but remaining relatively sensitive to changes in probabilities away from the inflection point.

[24] Third, we consider a farmer type (type B) to explore the sensitivity of the overestimation/underestimation results by changing the sensitivity to changes in probability, or changes in the degree of overestimation. We have farmer type B ( $\theta = 0.99$ ;  $\gamma = 0.69$ ), who overestimates/underestimates probabilities with the same inflection point as farmer A, but now is less sensitive to changes in probabilities relative to farmer A (see Figure 1). Consider now farmer A and his reaction to the risk in water markets relative to the baseline case of unweighted probabilities. Figure 2 shows that the unweighted probability base case leads to low water sales all throughout. In comparison, farmer A increases his sale of water in all periods. Figure 2 and subsequent figures depict time period on the X axis. Now if we decrease the relative sensitivity to a change in probability (farmer B), we see a further increase in the amount of water sold to the urban buyer. The sale of higher

amounts by farmer A and B reflects the discounting of water as a resource due to an increased risk of its loss. Both farmer types are operating in the regions where they tend to overestimate the probabilities of water right loss, consequently selling larger quantities of it.

**4.1. Summary Result 1**

[25] When a farmer overestimates low probabilities and underestimates high probabilities of water rights loss, it has an effect similar to discounting of resources faced with risk of loss. Greater perceived probability of a water rights loss increases current water sales (farmer A). If the farmer type is less sensitive to probability changes and overestimates low probabilities (farmer B), water sales increase even further.

[26] So far, the risk perception of the farmers has allowed them to overestimate their probabilities; however, the risk has never increased so much that it may cross the point of inflection beyond which probabilities are under-weighted. We now consider the robustness of these results to changes in a key parameter: the discount rate or the time preference of the farmers. First, how robust are these results to a change in the discount rate? If a farmer puts less weight on the future, it is tantamount to having a higher risk perception as described above. Therefore, if a farmer uses a high discount rate for future returns from water sales, his risk perception can be considered to be high. Consequently, it may happen that the risk lies beyond the point of inflection, beyond which it is underestimated. If probabilities actually get underestimated subjectively due to higher time discounting, the implications for water sales become complicated. To test this intuition, Figure 3 compares the water sales for farmers A and B. Observe in Figure 2 that when the discount rate is low ( $\rho = 0.01$ ), farmer B sells more water (overestimates low probabilities compared to farmer A). In Figure 3, however, as discounting increases to  $\rho = 0.5$ , the behavior of the two farmer types switches: Farmer B underestimates more high probabilities of loss relative to A. While 50% is indeed a very high level of discounting, the same results could be attained for a much lower level of discounting by changing other parameters in the model. In fact, in the above case, the point of inflection is crossed for the two farmers at a discount rate of 30%. Any increase in discounting above this level would lead to switching in their relative patterns of water sales. Farmer A now sells more water than B.

[27] To compare the subjective weights placed by the farmers on their hazard rates, consider Figure 4. When the time discounting is higher, the weighted hazard rate for farmer A exceeds farmer B, unlike the case when time discounting is lower. This occurs because with greater time discounting farmer A weighs risk of loss more than B,

**Table 2.** Probability Weighting by Farmer Types

Probability Weighting Parameters	Farmer Type		
	Unweighted: Farmer Who Neither Overestimates Nor Underestimates Probabilities, $w(p) = p$	A: Benchmark Farmer Who Overestimates Low Probabilities and Underestimates High Probabilities	B: Farmer Who Is Less Sensitive to Changes in Probabilities Relative to Farmer A
$\gamma$	1	0.79	0.69
$\theta$	1	0.99	0.99

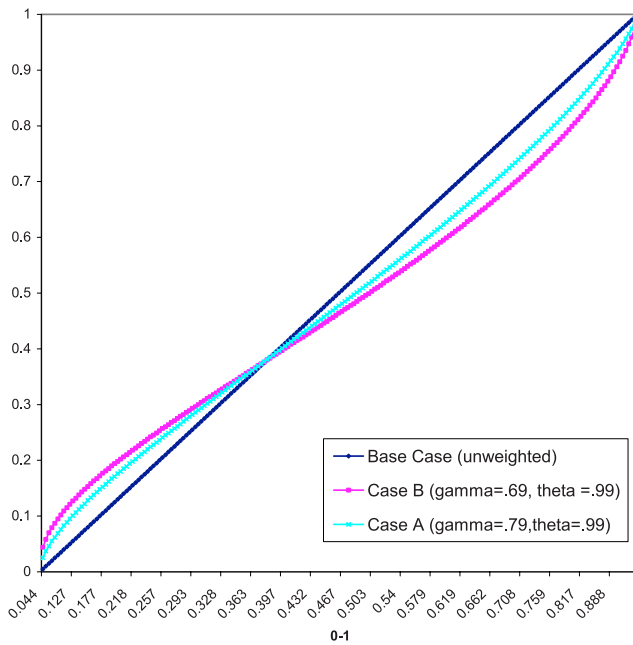


Figure 1. Weighted and unweighted hazard rates.

although being more sensitive to changes in probabilities. To further confirm this notion, we increase the hazard rate of water right loss from  $p(x) = p_0 x(t)^2$  to  $p(x) = p_0 x(t)$ . Notice that as water sales are represented in fractions of total available water supply of 1, the later equation represents a higher risk from water sales. Figure 5 below now shows water sales under a time discounting of 1 and 20%. For the discount rate of 1%, farmer B is the dominant seller as he weighs the probability of loss more than A. However, as the discount rate is increased to 20% (as compared with 30% in the above case), farmer A becomes the dominant seller as the point of inflection has been crossed and accordingly he is the one weighting probability higher than the other. The point is that it is not only the time preference, but also the nature of risks associated with water sales that might decide whether farmers dwell on one side of the inflection point or the other.

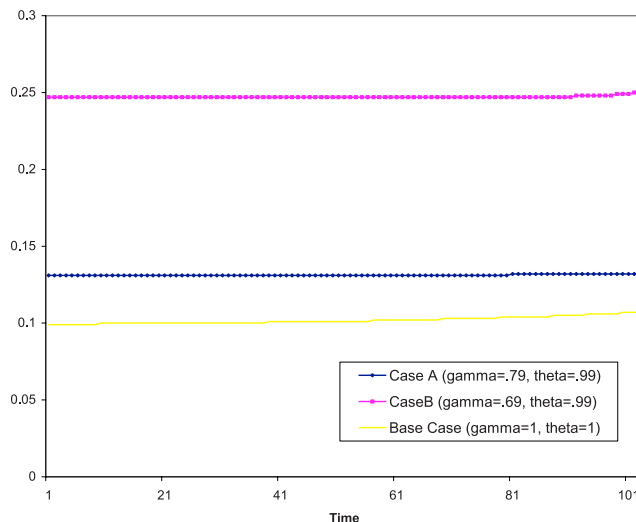


Figure 2. Water sales: under probability weighting.

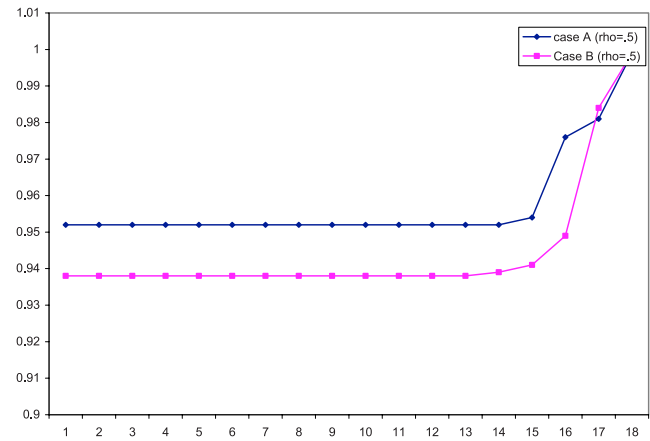


Figure 3. Water sales with higher time preference ( $\rho = 0.5$ ).

4.2. Summary Result 2

[28] We find under a weighted probability model, farmer A's and farmer B's participation in the water market is significantly affected by their time preferences. Those farmers who weigh probability of loss less as compared with others at low discount rates end up weighting it relatively more at high discount rates, and vice versa. As a consequence, knowledge of subjective weighting alone may not be sufficient for predicting water sales. For instance, a farmer who places high weights on probabilities but also has a low discount rate may behave the same way as the one who places relatively lower weights on probability but also has a higher discount rate.

[29] One crucial factor that may make this issue significant is the point of inflection of the inverted S-shaped probability weighting scheme. If the point of inflection beyond which farmers switch to underweighting of probabilities lies to the extreme right and the farmers do not differ a lot in their time preferences, the above anomaly may not show up. This is more likely to be evident among a

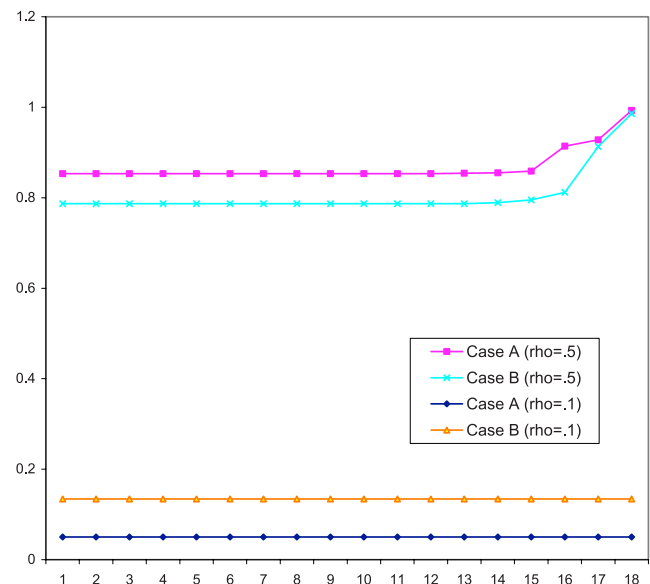
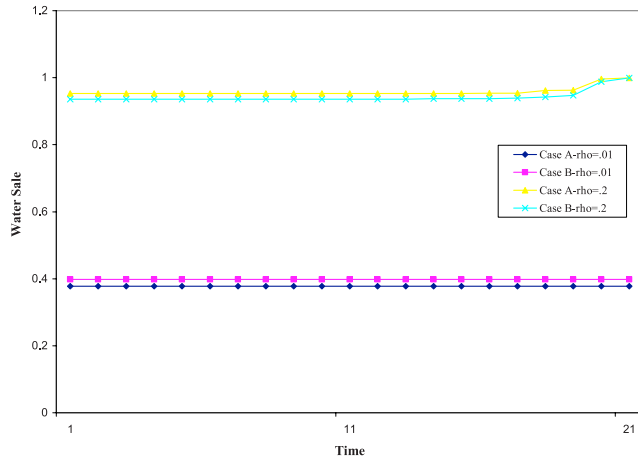


Figure 4. Weighted and unweighted hazard rates.



**Figure 5.** Water sales under higher probability of loss and varying time preferences.

homogenous group of farmers. Whereas when the time preferences of the farmers differ significantly from each other due to their heterogeneity, the above complexity of predicting water sales may crop up. Whether or not the actual situation in the United States is reflected in either of the two scenarios could be a matter of practical relevance and can be only determined through farmer surveys.

[30] Now consider the impact on total water offered for sale as the market size increases. A typical water market is characterized by farmers with idiosyncratic probability weights and unique water endowments, which will affect the total water supplied into a market. Most water owners tend to form cooperatives or hire managers who represent their interests. The way an individual farmer influences these organizations affects the outcome of the market as well. We now explore these issues for a water organization owned by two farmers with different endowments for water rights and different subjective perception of the probabilities.

## 5. A Case of Two Farmers

[31] We have purposefully restricted our analysis up to this point to a single farmer to understand the role of probability weighting on decision of individual farmers. Since water sales decisions in a geographical region are interlinked, one farmer's decision to sell water can affect the supply of water to the downstream users. As a result, despite well-defined water allocations, probabilities of water rights loss might be interdependent. Such risks are further reinforced in the presence of third-party impacts. Joint sale of water could influence water risks in either direction. For instance, when water sellers are able to exercise clout over political processes relating to future water rights decisions, the larger their group, the stronger will be the rewards from coalition formation. Since in most cases federal incentives too are geared toward promoting markets, such effects are likely to be stronger. When uncertainties are large, farmers may choose to err on the cautious side and act as if the more water that is sold, the larger are the probabilities of loss of water rights. In such cases, joint sale of water must incorporate the ensuing probabilities, and therefore a mech-

anism must be designed to share profits from water sales. In cases when water markets exist, farmers form cooperatives to share profits. The manager who runs the operations is guided in his sales decisions by how the voting rights are allocated among participants. We now apply a cooperative decision-making process to the bargaining game to explore joint water sale decisions given a probability of water rights loss.

[32] Consider two farmers, 1 and 2. Farmer 1 has twice the water as farmer 2, i.e., two units versus one unit. The allocation decision is made in the following fashion. The manager of the cooperative owned by these two farmers maximizes the weighted sum of their profits over an infinite horizon. The weighting is either (1) equal-weighting wherein both farmers receive equal profits, or (2) weighted by their water endowments (farmer 1 gets 66% weighting, 2 gets 33%). During the bargaining phase with the buyer, the weighted surplus from water sales is maximized to derive the price of water. The bargaining stage involves maximizing the product of surpluses as before:

$$\max_{\pi} \left\{ w \left\{ \pi x_1 - (2^\alpha - (2 - x_1)^\alpha) l^\beta \right\} + (1 - w) \left\{ \pi x_2 - (1 - (1 - x_2)^\alpha) l^\beta \right\} \right\} (B(x_1 + x_2) - \pi(x_1 + x_2)), \quad (17)$$

which yields

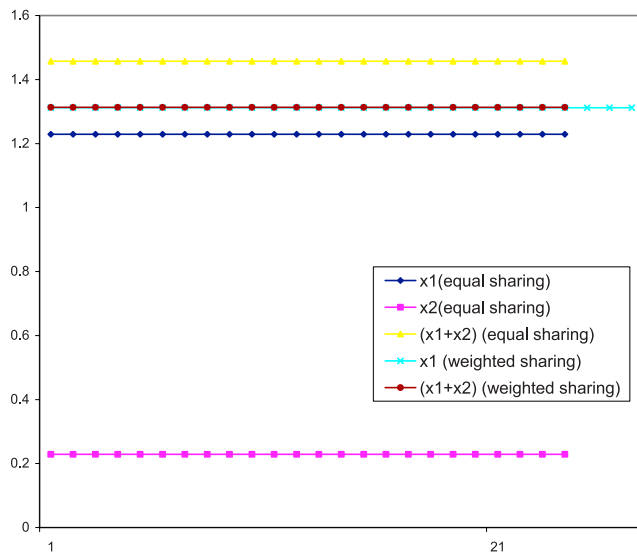
$$\pi = \frac{B}{2} + \frac{w \left\{ (2^\alpha - (2 - x_1)^\alpha) l^\beta \right\} + \left\{ (1 - (1 - x_2)^\alpha) l^\beta \right\} (1 - w)}{2(w x_1 + (1 - w) x_2)}. \quad (18)$$

This relationship between price and water sales is fed back into the weighted profit maximization problem of the manager similar to equation (9) as

$$J = \max_x \int_0^\infty e^{-\rho t - \lambda(t)} \left\{ \begin{aligned} & w \left\{ \left( \pi(x) x_1 + (2 - x_1)^\alpha l^\beta + p(t, x, \theta) \frac{(2 - x_1)^\alpha l^\beta}{\rho} \right) \right\} + \\ & (1 - w) \left\{ \left( \pi(x) x_2 + (1 - x_2)^\alpha l^\beta + p(t, x, \theta) \frac{(1 - x_2)^\alpha l^\beta}{\rho} \right) \right\} \end{aligned} \right\} dt. \quad (19)$$

[33] We simulate three cases to explore how probability weighting affects water sales in a cooperative game. All parameters remain the same as before except for the exogenous component of the hazard rate, which is reduced to  $p0 = 0.1$ . Note that risk or risk perception of water rights loss would depend upon several factors including the size of the sellers, their political clout, etc. We reduce the policy-independent component of risk here for practical purposes of solving the nonlinear programming problem.

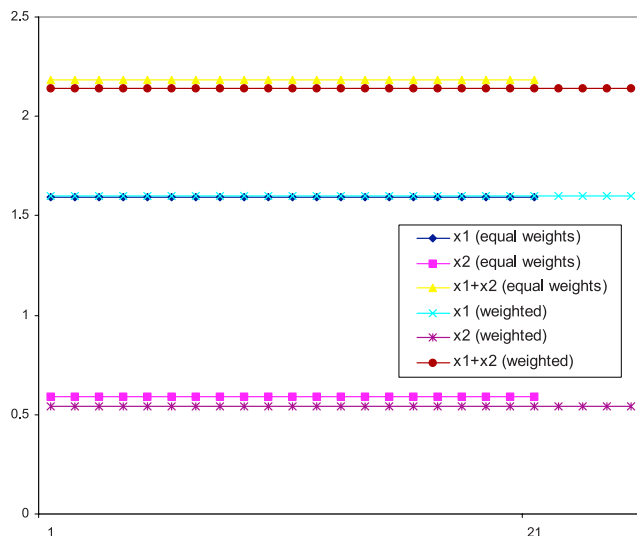
[34] Figure 6 shows a situation in which both the farmers place low subjective weights on risk of water right loss ( $\gamma_1 = 0.25$ ,  $\gamma_2 = 0.25$ ,  $\theta_1 = 0.45$ ,  $\theta_2 = 0.45$ ). Farmer 1 sells more water than farmer 2. When the weighting of profits is water ownership based, farmer 2 bears most of the burden for risk avoidance, i.e., his water sales are minimal. Farmer 2's sales



**Figure 6.** Water sales, two-farmer case, high probabilities ( $\gamma_1 = \gamma_2 = 0.25, \theta_1 = \theta_2 = 0.45$ ).

improve in the equal weighting scenario, while farmer 1's fall marginally.

[35] These results suggest that when overestimation of probabilities is not significant, and farmers have differential endowments, the less endowed farmer bears a higher share of burden for reducing risks under water endowment weighting scheme. Farmer 2 also has a lower opportunity cost of water in terms of forgone agricultural output. As a consequence, increase in water sale from farmer 2 may not increase the weighted profits (for the manager maximizing their joint weighted profits) as much as it would add to the probability of water rights loss. The net impact of water-weighted profits allocation is then to reduce the supply of water in the market, as the concerns of the farmer with higher water endowments are weighted over those of the farmer with the lesser endowment. Note that this is in sharp



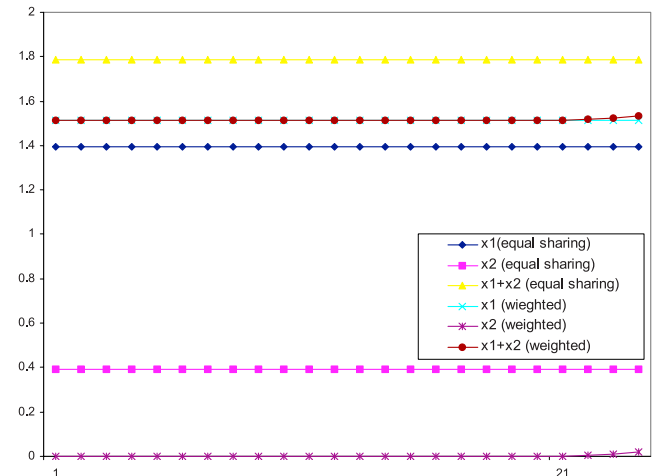
**Figure 7.** Water sales, two-farmer case, low probabilities ( $\gamma_1 = \gamma_2 = 0.025, \theta_1 = \theta_2 = 0.45$ ).

contrast to earlier simulation results involving decisions of individual farmers, where the impact of an increased risk was to invariably raise the supply of water. In the case when there is a multitude of farmers, and not all of them are treated equally, joint benefit maximization may involve risk reduction at the cost of those farmers with lower weights assigned by the manager. Equal weighting increases total water supply as the water sale of farmer 1 falls under this scheme to compensate for the increase in risk caused by high water sales from farmer 2.

[36] The second case of high probabilities ( $\gamma_1 = 0.025, \gamma_2 = 0.025, \theta_1 = 0.45, \theta_2 = 0.45$ ), as shown in Figure 7, reveals that water sales of farmer 1 and 2 both increase significantly from the previous case under either weighting scheme. Further note that the supply of water in this case is not influenced much by the nature of the weighting scheme. This scenario shows that as the subjective weighting of probabilities increases, the less endowed farmer suffers less disproportionately the burden to reduce risks. This is because as risk increases, the benefits from keeping water for use in agriculture diminish rapidly, thus prompting higher sale from both farmers in the water markets.

[37] Finally, in Figure 8, we consider two heterogeneous farmers, with farmer 1 having a higher subjective evaluation of the probabilities ( $\gamma_1 = 0.025, \gamma_2 = 0.25, \theta_1 = 0.45, \theta_2 = 0.45$ ). Under the water-weighted profits sharing scheme, farmer 1 still manages to sell more water, while farmer 2 bears all the burden of reducing risks. Under an equal sharing of water, however, water sale by farmer 2 becomes positive. However, notice that the total water sold in this case is lower than the previous case as the sum of probabilities of the two farmers is still lower than before.

[38] The main conclusions from the two-farmer case are that the amount of water sold in the water market would depend upon the relative probability weighting of the participants and the nature of profit sharing scheme between the farmers. A farmer with a lower endowment of water may end up bearing a higher burden of the risk of water right loss under an equal profits sharing scheme. While our analysis does not extend beyond the two-farmer case, it is



**Figure 8.** Water sales, two-farmer case, differential probabilities ( $\gamma_1 = 0.025, \gamma_2 = 0.25, \theta_1 = \theta_2 = 0.45$ ).



possible that with an increase in the size of the markets, the outcome with respect to relative water sale and risk sharing among participants would resemble that of a competitive market. Under such a situation it is possible for poorly endowed participants to make relatively larger gains from water sale. However, a farmer with higher endowments would always end up selling more water than the farmer with lesser endowments, irrespective of the level of probability weighting or the nature of the profit sharing. Also, a farmer with higher endowments would always sell more water under water-weighted profit sharing as compared with equal weights on profit sharing. Finally, total water sale under equal sharing is always higher than that under weighted sharing for any given level of subjective weights assigned by the water right owners.

## 6. Conclusion

[39] Water markets are considered to be an important factor for the successful transfer of water among its most productive uses. The functioning of water markets, however, is constrained by several factors that hinder the participation of the sellers of water. One important factor is the security of retaining water rights for future uses in agriculture, which farmers fear could be compromised from sale of water to nonagricultural uses. Historical circumstances, which have been biased in favor of allocating water rights to the most beneficial uses, coupled with the absence of any comprehensive and clear-cut policy related to long-term ownership of water rights have vastly contributed to this fear of water right loss. While such probabilities of water right losses are real, farmers can attach their own subjective weighting of the probability of losing water rights due to trade. These probability weights can be unique to the water right owner and are shaped by his water and land endowments, his political clout in the water right community, and his perception of the government's long-term policies related to water rights.

[40] This subjective weighting of probabilities may be crucial in determining the success of water markets. Overestimating the probability of loss invariably leads to discounting of the future value of water for an individual owner, thus prompting its sale in the water markets. Our results indicate that the total amount of water sold in the market is a complex function of the composition of the participants who may vary in their subjective weighting of probabilities. Higher weighting of probabilities by farmers may not necessarily increase total water sale, since the organization of the farmers and their say over risk sharing plays a crucial role in determining water supply. Further, the time preferences of the water rights owner matters in determining his sale of water. Our results suggest that predicting water supply in a market with a heterogeneous mix of farmers will be a challenge. For the case of two farmers, our findings confirm the importance of water sellers' organization, their voting schemes, and their level of endowments in determining the total water supply. Unlike the individual farmer case, in which greater risk invariably leads to discounting of resources, for the two-farmer case, the farmer with lower endowments bears a larger burden of risk reduction, whereas the one with higher endowments sells more water for profits. As the

level of risk increases, though, this relative difference in risk sharing decreases.

[41] We have not addressed alternative uses of water for the farmer apart from agriculture. The value of water, however, increases with greater demand due to urbanization, which is reflected in rising land prices. This raises an additional aspect of time preference for the water rights owners. The possibility that the farmers use water rights for future hedging cannot be denied, especially when the value of their land is tied to the amount of their water endowments. Now, an increase in probability of water rights loss may not be enough to increase its sale in the water market, as the farmers would be more inclined to save it for future appreciation in its value. Such concerns pose significant modeling challenges, and provide avenues for future research in this area.

[42] A final caveat: While we presented a theoretical model of probability weighting in water markets, an empirical validation of the results would be highly desirable. As *Gonzalez and Wu* [1999] admit, however, it may not be easy to estimate probability weights and the functional form of the weighting function simultaneously using econometric methods. In the case of water markets, the paucity of data due to nascent nature of water markets would make it even harder. Further, as *Gonzalez and Wu* note, functional forms might vary at individual levels. *Gonzalez and Wu* have used nonparametric method of estimation by eliciting responses from participants in controlled psychological experiments using computer-assisted surveys. This might be one way to understand probability weighting for participants in water markets too, and could be an interesting avenue for future research in this field. The parameters selected in this paper confirm to the empirical findings over probability weighting; however, further work is required to assess water market specific parameters.

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