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LOSS AVERSION IN WATER MARKETS

By

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Loss Aversion in Water Markets

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Abstract

This paper looks at the role of risk aversion in determining participation of agricultural farmers holding water rights in the water markets. Risk aversion is of the non-expected utility maximizing type that allows for subjective weighing of the actual risks emanating from water transactions. The analysis involves design of a theoretical model that involves bargaining over sharing of surpluses between the buyer and the seller of water. The seller of water incorporates the bargaining outcome in his inter-temporal expected benefit maximization problem that accounts for the possibility of loss of water rights due to its sale out of agriculture. The analysis is also extended to more than one farmer case and explores the impact of time preferences and relative risk aversion between participants on outcome in the water market. Results are predominantly derived through numerical simulations.

Introduction

The rate of introduction of water markets in the USA, despite a growing disparity between its value in agriculture and urban use, has been low with success showing only in a few regions. The several factors responsible for this low success rate have been classified into institutional and behavioral (Ranjan et al. 2003). The institutional factors can be classified into political, legal, physical, and financial. Political bottlenecks include disregard for economic efficiency driven policies such as efficient allocation and re-definition of water rights to facilitate transfer of water to its higher valued uses (Gaffney 1997). Legal factors include the ambiguity over the 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 include the lack of transferring and storage facilities and financial instruments that help the participants hedge risks from water trade created by water supply and water rights driven uncertainties. Behavioral factors involve the water owner's response to the nature of risks associated with water transfers and its role in affecting water transactions (Goodman and Howe 1997).

The role of risks has been acknowledged as one of the most significant forces affecting the water markets. Yet, few studies exist that have closely scrutinized this aspect of the water markets. Further, in general, the traditional ways of dealing with risks have been found to be inadequate in explaining the behavioral responses of participants to risk (Starmer 2000). For instance, the expected utility maximization theory fails to capture the fact that risk averse participants may show more aversion to losses than a desire for gains involving same payoffs. Loss of water rights resulting from trade in water is a real fear that the farmers face while considering the pros and cons of participating in the water markets. This fear has been substantiated by the evolving nature of water rights that has been geared towards facilitating the provision of water to its most beneficial uses (Howitt 1995). In selling his water out of agricultural uses, the farmer must weigh the benefits of current transfer to the costs of loosing the water rights in future. An expected utility maximizing farmer would weigh the tradeoffs between the marginal value from the sale of current water and its marginal impact on prospects of future benefits from retaining the water rights. However, if the farmer assigns higher weights to low risks of water rights loss and lower weights to high risks of loss, a phenomenon confirmed through several experiments in behavioral economics, he may display strikingly different behavior as compared to the one predicted by expected utility maximization theory (List 2003).

In this paper we apply the insights from behavioral economics to understand the response of farmers who participate in the water markets. This is achieved through a Nash bargaining framework wherein the buyer and the seller maximize the product of their surpluses. The farmer while putting water for sale also considers the impact of his current sales on future risks of water rights loss. Several weighing schemes are used to consider the impact of his nature of risk aversion on water sales (Prelec 1998).

Model

There are two participants in the water market, a farmer and an urban buyer. The farmer runs the risk of losing his water rights over time if he decides to sell that water out of agricultural use. The risk of loss may be a function of level of water transactions and some other exogenous parameters beyond the farmer's control (for instance environmental needs, increasing water scarcity, redefinition of 'beneficial use', etc.). Let us assume that the amount of loss of water rights would be confined only to the amount of water transferred. The amount of water used in agriculture may still be available to the farmer.

Farmer's profits comprise the sale of water to the urban buyer and sale of agricultural output. His objective is to maximize the expected profits over time under the constraint of continuously evolving risk from water trade. The 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. A mathematical sketch of the model is presented below.

Let x be amount of water sold to the urban buyer by the farmer out of his total endowments of one unit, i.e. $0 < x < 1$. Let $C(x)$ be the transaction cost of selling that water. Output in agriculture is a function of amount of water applied $(1-x)$, and land (l) and is Cobb-Douglas in form.

The risk of loss of water rights is a Poisson event governed by:

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

where $p(s, x, \theta)$ is the instantaneous probability (or hazard rate) of loss of water rights at time s and is a function of the amount of water sold x and some exogenous parameter θ beyond the farmer's control. Consequently $\lambda(t)$ evolves as:

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

When the farmer looses his water rights, his benefits are simply the output from agriculture given by (assuming agriculture prices are 1 for all periods):

(3) $Q = (1-x)^{\alpha} l^{\beta}$, which summed to infinity and discounted at ρ would be:

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

Until the time the farmer retains his water rights his profits in each period would be:

(5) $$\pi x + (1-x)^{\alpha} l^{\beta}$$

where πx is the profit to the farmer from selling his water to the urban buyer at a price π . Therefore the expected discounted sum of profits to the farmer from water trade and agriculture can be written as:

(6) $$J = \int_{0}^{\infty} e^{-\rho t - \lambda(t)} (\pi x + (1-x)^{\alpha} l^{\beta} - C(x) + p(t,x,\theta) \frac{(1-x)^{\alpha} l^{\beta}}{\rho}) dt$$

The farmer's problem is to maximize (6) subject to (2). However, x is indirectly determined through bargaining between the urban buyer and the farmer over the price of water. Therefore, assuming a Nash bargaining game, the problem could be set up as:

(7) $$Max_{\pi}\ (\pi\ x - (1-(1-x)^{\alpha}) l^{\beta}) * (Bx - \pi x)$$

where the first bracket 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 *B*. Maximizing (7) gives us π in terms of *x* as:

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

This form of bargaining assumes that the total amount of water *x* to be sold to the urban buyer is decided in advance by the farmer through his objective maximization. The bargaining is only over the settlement of the price of water. Plugging (8) back into (6) we get:

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

The current value Hamiltonian can be written as:

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

Taking the first order condition with respect to *x* yields:

(11)

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

The costate variable μ evolves as:

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

In steady state equation (12) reduces to:

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

Substituting for the value of μ from (11) we get:

(14)

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

Rewriting (14) we get:

(15)

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

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

In equation (14) the left hand side represents the change in the instantaneous value function from an incremental sale of water to the urban buyer. This includes changes in the bargaining profits and the changes in future agricultural returns from loss of water rights. The right hand side of the above equation is the discounted sum of all future benefits from the current instantaneous expected returns brought in by the effect of an increased hazard rate from the sale of incremental water.

More insights could be drawn from a numerical simulation of the above model through a hypothetical set of parameters. We now turn to role of subjective weights on the probabilities of loss of water rights in determining the farmer's supply of water to the urban buyer. These weights will be placed on the hazard rate $p(x)$, which is the probability of the loss of water right at time *t*, given that it did not happen before. Let the weighing function follow an inverse S-shape as is generally agreed upon in the literature. This captures the relatively high weight that farmers may put on low chances of losses and low weight on high chances of losses. Following Prelec (1998) we use:

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

The actual path of the hazard rate which is determined by the optimal allocation problem may now look different from before. Intuitively, when the hazard rate is high, farmers may have the incentive to reduce it by selling less water. However, with a subjective weighing that discounts high risks, they would not care about loss any more and put more water on the table. Similarly, when the initial hazard rate is low, they would have placed more water on the table in absence of subjective weighing. However, with subjective weighing they may not. In this analysis the inflexion point of the inverted s-shaped curve is critical and can only be determined empirically. There is no theoretical basis for weighing the hazard rates either (as compared to weighing instantaneous probability). Weighing of hazard rates implies that the predominance is given to the probability of the rights being lost at time *t*, given that they would survive until that time. In an exponential distribution, this hazard rate is constant. Whereas, when weightage is put solely on the instantaneous probability, which for an exponential distribution is given by $p(x)e^{-\lambda(t)}$, it is inevitable that future probabilities would be lower, therefore introducing a bias towards higher sale in future due to the reduced risks.

Details of the Numerical Simulation

The instantaneous hazard rate p has been defined as:

$$p(x) = p_0 x(t)^2$$

Transaction cost $c(x)$ has been ignored for now to understand the basic issues first. The parameters used in numerical simulation are presented below in Table 1.

INSERT TABLE 1 HERE

Numerical simulations were preformed using GAMS. A time horizon of 200 years mimics the infinite horizon problem and the steady state is found to exist. The results of the simulations are presented in the figures below.

Figure 1 depicts the comparison between a no-risk case and a constant risk case. When there are no risks the optimum response of the farmers is to put most all of his water for sale, reflecting the lower returns in agriculture. In a constant risk case, the response is to sell a lower amount of water for a certain period of time and no water afterwards. Risk of water right loss lowers the incentives to sell water and raises the incentives to use it in agriculture.

Next we look at the behavioral responses of the farmers. This is done through five cases depicted in Table 2. Besides, the base case is the one involving unweighted risks. Case A, as shown in figure 2, puts the least weights on the hazard rates below the inflexion point. Case B has higher weightage compared to case A implying its higher risk aversion for low values of hazard rate. Also, note that the weights beyond the inflexion point are higher too for case B than A, implying B's risk aversion is lower than that of A once the hazard rate crosses a certain threshold. Case C monotonically assigns higher weights to all hazard rates as compared to cases A and B. The pattern of water sales is shown in figure 3. The base case leads to low water sales all throughout until the end when they are spiked[1].

In case A, the perceived risk is higher compared to the base case. This leads to a higher sale of water all throughout as future benefits are discounted at a larger rate. In case B, the subjective risks lead to still larger perceptions of a high hazard rate compared to case A) thus, pushing water sales to later stages. In the initial periods all the water is dedicated towards agricultural production as the future gains in terms of avoided water rights loss outweigh the instantaneous benefits from water sales. However, as future benefits are also discounted, the optimal time to start allocating some water for outside of agricultural uses is decided by the point where the expected benefits from allocating water jointly between agricultural and non-agricultural uses equals the sure profits from allocating all the water to agriculture. As the subjective weights are raised still higher in

[1] The spike in water sales at the end is due to the end of time horizon effect.

Case C, it leads to an interesting discontinuity in the pattern of water sales. While high risk makes it optimum to postpone current sales until the future risk of water loss is mitigated by the high discount factor, it is feasible to sell some water in the beginning stages and still keep the risk low[2]. One can interpret this discontinuity as being introduced by the non-linear nature of the weighing function. The point of inflexion may play a crucial role in deciding whether the optimal policy should be to risk a low amount of water for all periods through water sales or risk a higher amount but only in the later stages. This tradeoff favors a sale of low water for all periods in the base case and case A and a high amount of water in later stage in cases B and C. The weighing becomes even more stronger in cases D and E, where very high weights are placed on lower risks with the point of inflexion pushed beyond the planners scope of risks. These weights are depicted in figure 4. The effect on water sales is shown in figure 5. Note that high risks make it suboptimal to postpone water sales as future gains are highly discounted. This prompts the sale of high levels of water in the early stages. Note that in figure 5, water sale is higher in the relatively lower risk case D and lower in the higher risk case E. This may seem counter intuitive at first, but also note that as the expected profits from water sale fall due to high discounting, the profits from its use in agriculture rise. As a consequence, even though more water is sold in case E compared to cases A, B and C, it does not exceed that of case D.

Proposition 1: An inverted S-shaped weighing of the hazard rate has a similar effect as the discounting of resources facing risk of loss. The increase in risk perception of water rights loss leads to an increase in water sales. However, when the weights are relatively low (low risk aversion), an increase in marginal weights on the hazard rate leads to a

[2] This break in water sales response presents interesting venues to analyze for policy purposes.

higher sale of water for all time periods (compare Case A and Base Case). When weights are relatively large, a marginal increase in weights leads to reduced sale of water (Cases D and E). There is an intermediate set of weights which leads to discontinuity in water sales that ranges from water sale being relegated to later stages to water sale occurring only towards the beginning and the end.

So far we have looked at the impact of high subjective weights on lower levels of hazard rate. However, due to the nature of weighing scheme used, it is also possible that farmers switch their roles when risks become relatively large. Note that an inverted S-shaped weighing function is uniform, when the farmer who assigns higher weights to lower risks also assigns lower weights to the higher risks, i.e., becomes less risk averse at high levels of risks. Alternatively, the uniformly inverted s-shaped weighing allows wider fluctuations in either direction allowing the higher risk averse farmer to turn into a lower risk averse farmer beyond the inflexion point. It is possible that when time preferences are altered so that farmers heavily discount the future, they would be operating in the realms of high risks. In such a case the more risk averse farmer of the previous case may also become the less risk averse farmer under a higher discounting. This intuition is tested through further simulations wherein we raise the discount rates to 10 percent. Figure 6 compares the water sales for cases A and B in the two discount rate cases of 1 percent and 10 percent. Observe that when the discount rate is low, Case B is the more risk averse guy (assigns higher weights to lower risks) thus selling water only in the final stages. Case A is the low risk averse guy, who sells less water but consistently all throughout. This is consistent with proposition 1 that says, below a threshold level of hazard rates higher risk farmer would sell more water. However, as the level of discounting is raised to 10 percent, Case B becomes the less risk averse person and Case A is the more risk averse person. This is evident from the weighing scheme of figure 2. As a consequence, following proposition 1, Case A sells less water than Case B. Figure 7 compares their hazard rates.

Proposition 2: Under an inverted S-shaped weighing of risks, risk aversion of farmers is significantly affected by their time preferences. Farmers who are less risk averse at low levels of discount rate turn more risk averse at high levels of discount rate and vice versa. As a consequence, risk aversion alone may not be sufficient in predicting water sale behavior. For instance, a farmer who places high weights on his risks but also has a low discount rate may behave the same way as the one who places lower weights on risks but also has a higher discount rate.

Next we look at the roles played by transaction costs and external factors that affect the risk of water rights loss. The instantaneous hazard rate p is now defined as:

$$p(x) = p_0 x(t)^2 \exp(-.05t)$$

The exponential element in the hazard rate reflects the effect of exogenous factors that reduce the risks over time. This is only one of the several possibilities that exist with respect to exogenous effects. For instance risk might as well be increasing over time. Transaction cost $c(x)$ has been defined as:

$$c(x) = x(t)\delta \exp(-.02\int_0^t x(t)dt)$$

A simulation of the base case is shown in figure 8. Note that, the reduction in transactions costs and the hazard rates over time make it possible to attain a much higher level of steady state water sales. However, as mentioned before such interpretations are subject to the assumptions over the nature of future costs and risks.

Two Farmers Case

The above analysis was restricted to a single farmer case. In reality, water sale decisions in a given geographical region are interlinked, as one farmer's decision to sell water may affect the supply of water to the downstream users. In such cases, despite well defined water allocations, risks to water rights may be interdependent. Such risks are further reinforced in presence of third party impacts. Joint sale of water may affect water risks in both directions. 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 the rewards from coalition formation. Since, in most cases federal incentives too are geared towards promoting markets, such effects are likely to be stronger. However, when uncertainties are large, farmers may choose to err on the low side and act as if the more water that is sold, the larger are the risks of loss of water rights. In such cases joint sale of water must incorporate the ensuing risks and therefore, a mechanism must be designed to share profits from water sales. In cases where water markets exist, farmers often form cooperatives to share profits. Though, a manger is in charge of running the operations of such profits, his economic decisions are predominantly guided by the way voting rights are shared amongst participants. In case each participant has equal voting right irrespective of his endowments, the managers incentives may be to maximize joint profits. In cases when voting rights are weighed by participants' endowments, manager's goal would be maximize the weighted profits. We apply a cooperative decision making process to the bargaining game presented previously in order to explore joint water sale decisions in presence of risks.

Consider two farmers, I and II, with farmer one having twice as much water as farmer two. Specifically, farmer I has two units of water he could use for agricultural purposes or sell to the buyer and farmer II has one unit of water which he could allocate similarly. 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 weighing is either equal-weighing wherein both farmers receive equal profits or it is weighed by their water endowments in which case farmers I gets 66 percent weighing and farmer II gets 33 percent. During the bargaining phase with the buyer, the weighted surplus from water sales is maximized in order to derive the price of water[3]. More specifically, the bargaining stage involves:

$$Max_{\pi}\ \left(w\left\{\pi x_1-(1-(1-x_1)^{\alpha})l^{\beta})\right\}+(1-w)\left\{\pi x_2-(1-(1-x_2)^{\alpha})l^{\beta})\right\}\right)*(B(x_1+x_2)-\pi(x_1+x_2))$$

Which yields:

$$\pi=\frac{B}{2}+\frac{w\left\{1-(1-x_1)^{\alpha})l^{\beta}\right\}+\left\{(1-(1-x_2)^{\alpha})l^{\beta}\right\}(1-w)}{2(wx_1+(1-w)x_2)}$$

This relationship between price and water sales is fed back into the weighed profit maximization problem of the manager similar to equation (9) before. We consider three specific cases to study the impact of risk aversion on water sales in a cooperative game. These cases are depicted through figures 10-12. Figure 9 shows a situation in which both

[3] This is a very simple bargaining game. Another game could be one in which the product of the individual farmer's surpluses is maximized. Such a game would however complicate the analysis in second stage of the game when farmers decide upon a mechanism to allocate water sales over the infinite horizon considering its impact on risks.

the farmers have low risk aversion to water loss. Farmer I being the more endowed one in this case gets to sell more water than farmer II. In fact, when the weighing is water ownership based (with farmer I getting 66 percent of weights), farmer II bears most of the weights of risk avoidance. That is, his water sales are minimal. Farmer II’s sales improve in the equal weighing scenario, whereas those of farmer I fall marginally. One can conclude from above that when risks are low and farmers differentially endowed, the less endowed farmer bears a higher share of such risks under either weighing scheme. Notice that the farmer with less water also has a lower opportunity cost of water in terms of forgone agricultural output. As a consequence, increase in water sale from farmer II may not raise the weighted profits (for the manager maximizing their joint weighted profits) as much as they would add to the risks of water rights loss. The implication of water-weighted profits allocation is then to reduce the supply of water in the market. Equal weighing increases total water supply only marginally as the water sale of farmer I falls under this scheme. The second case, that of high risks, as shown in figure 10, reveals that water sales of farmer I increase marginally from the previous case, whereas those of farmer II rise significantly under water-weighted profit sharing. Total supply of water in the market in this case, however, is higher compared to the low risks case as current benefits from higher water sales exceed the opportunity costs of water rights. This scenario shows that as the risks increase, the less endowed farmer suffers less disproportionately. This is primarily due to the fact that weighted profits of farmer II from increased sale of water are higher than the reduction in benefits from increased risks. Finally, in figure 11, farmer I is also the one with relatively higher risks. Under water weighed profits sharing he still manages to sell more water, with farmer II bearing the burden of reducing risks. However under an equal sharing of water, total water sales fall. This is due to the fact that high risks of farmer I are discounted as compared to the water-weighted case. As a consequence, sales from farmer I decrease and from II increase.

Proposition: The amount of water sold in the water market would depend upon the relative risk aversion 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 sharing scheme.

While the above analysis does not extend beyond a two farmers case, it is possible that with an increase in the size of the markets, the outcome with respect to relative water sale and consequently risk sharing amongst participants would resemble that of a competitive market. Under such a situation it is possible for less endowed participants to make larger gains from water sale.

Conclusion

Little empirical evidence exists to test the validity of the inverted-S shaped weighing scheme in the water markets. However, the above exercise throws valuable insights into the nature of water sale from water owners faced with the threat of loosing their water rights. The analysis involves putting the risk from water sale in a dynamic infinite horizon context wherein the expected benefits from water sale are maximized for water sellers by a manger. The manager may choose between an equal sharing or water endowment-weighted scheme to decide allocation water sales amongst its participants.

The price of water is determined through a bargaining scheme that maximizes the product of surpluses of the farmers and the water buyer.

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Table 1

Parameters	ρ	α	β	γ	$p0$	δ	L	B	θ	Z
Values	.01	.5	.5	.05	1	.003	2	100	.5	1

Table 2

Parameters	Case A	Case B	Case C	Case D	Case E
γ	.79	.6	.8	.05	.05
θ	.99	.99	.68	.5	.9

Figure 1: Comparison of a No-Risk Case With a Constant Risk Case

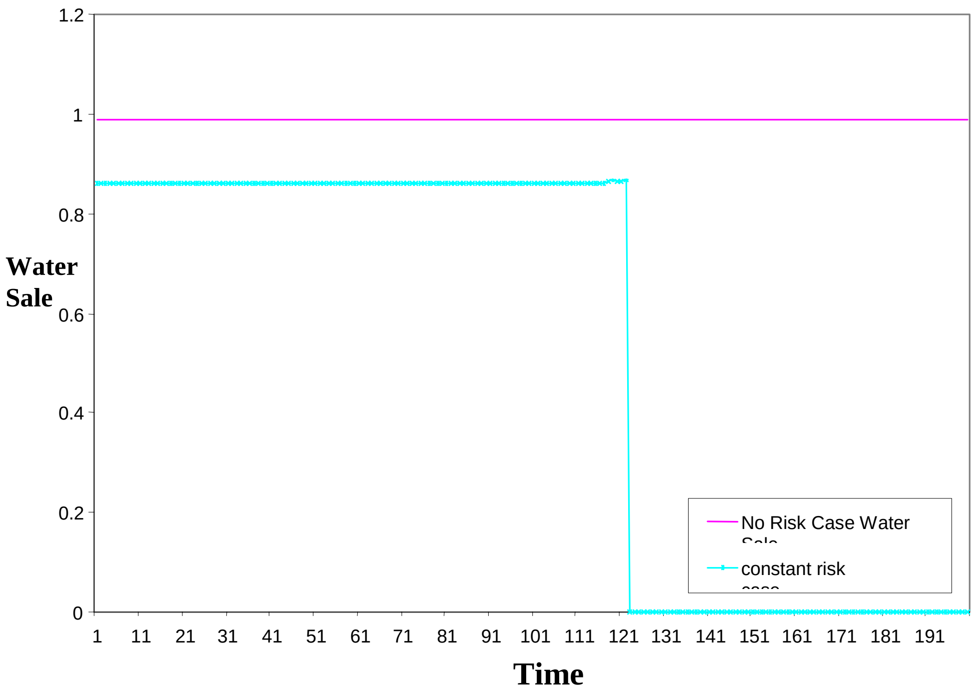


Figure 2: Weighing of the Hazard Rate

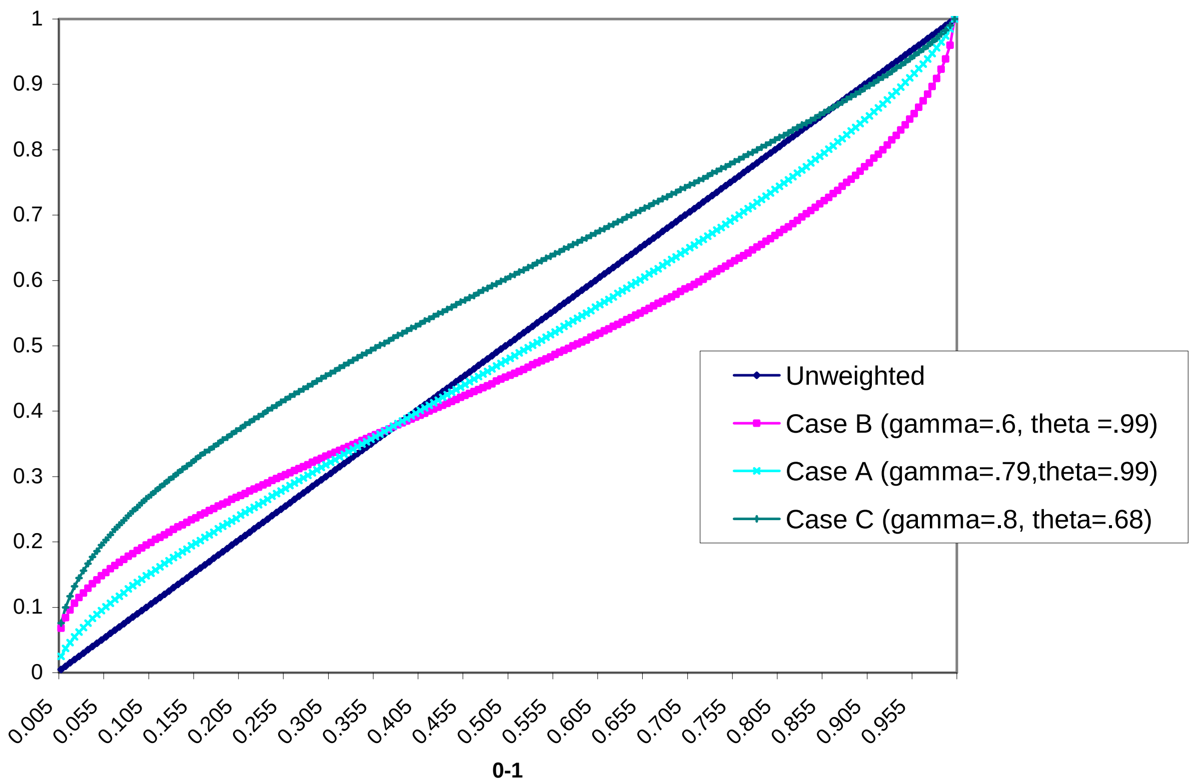


Figure 3: Water Sale

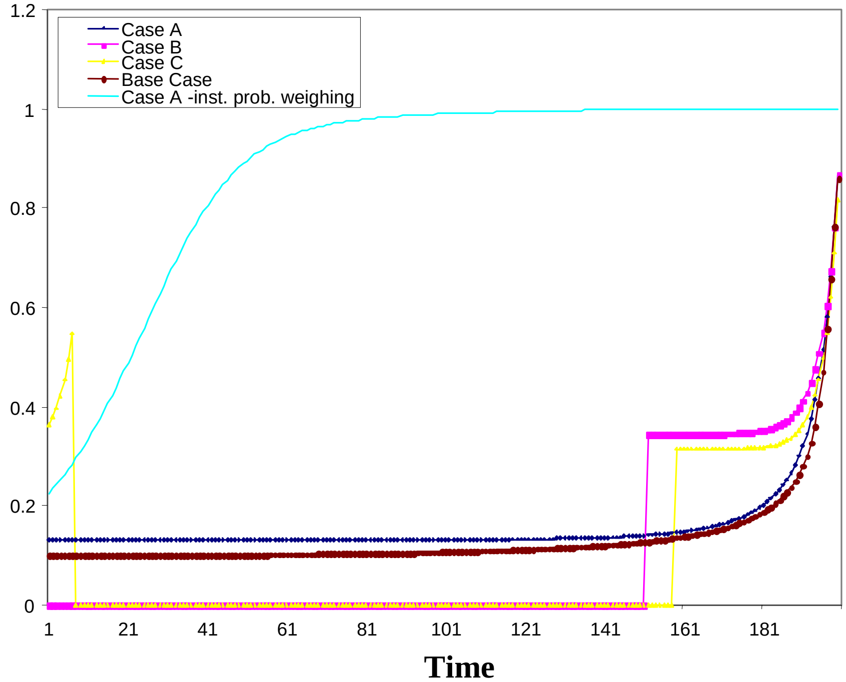


Figure 4: Weights

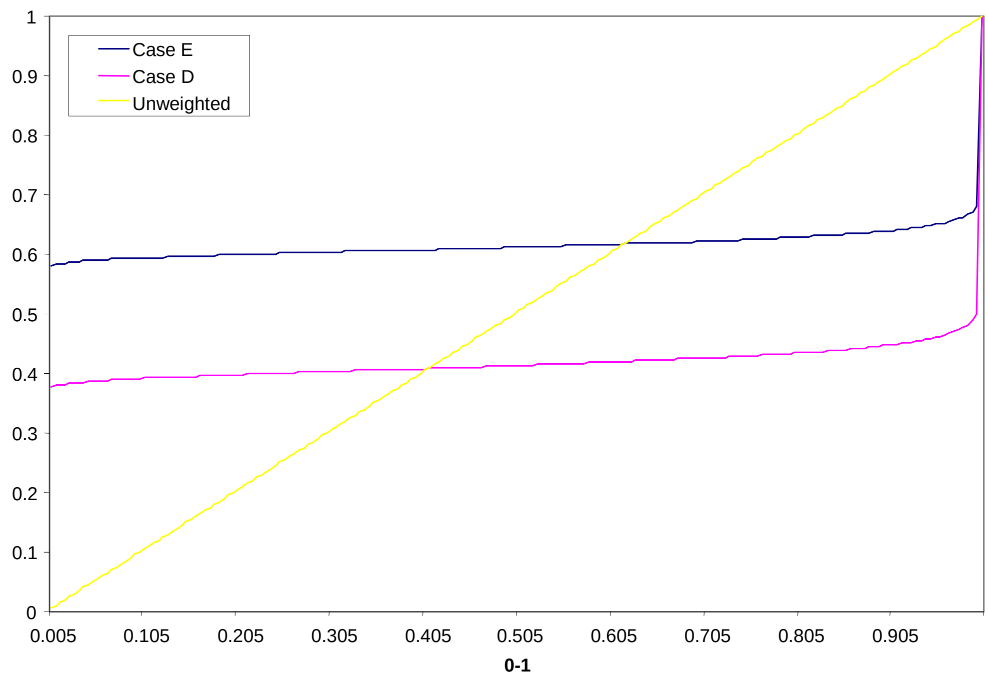


Figure 5: Water Sale

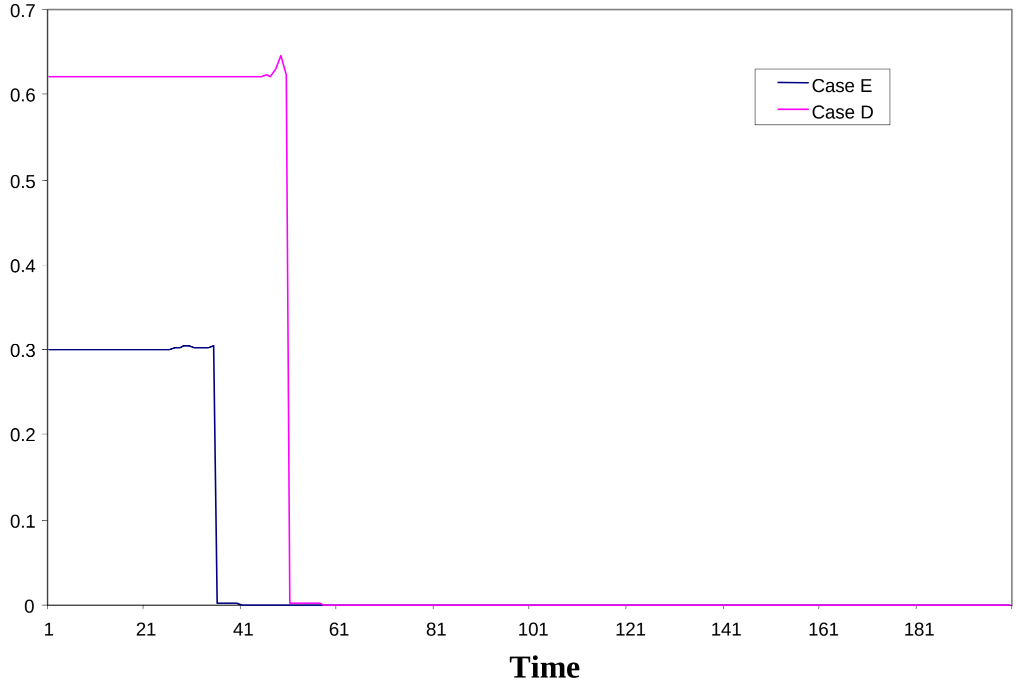


Figure 6: Water Sale under Varying Time Preference

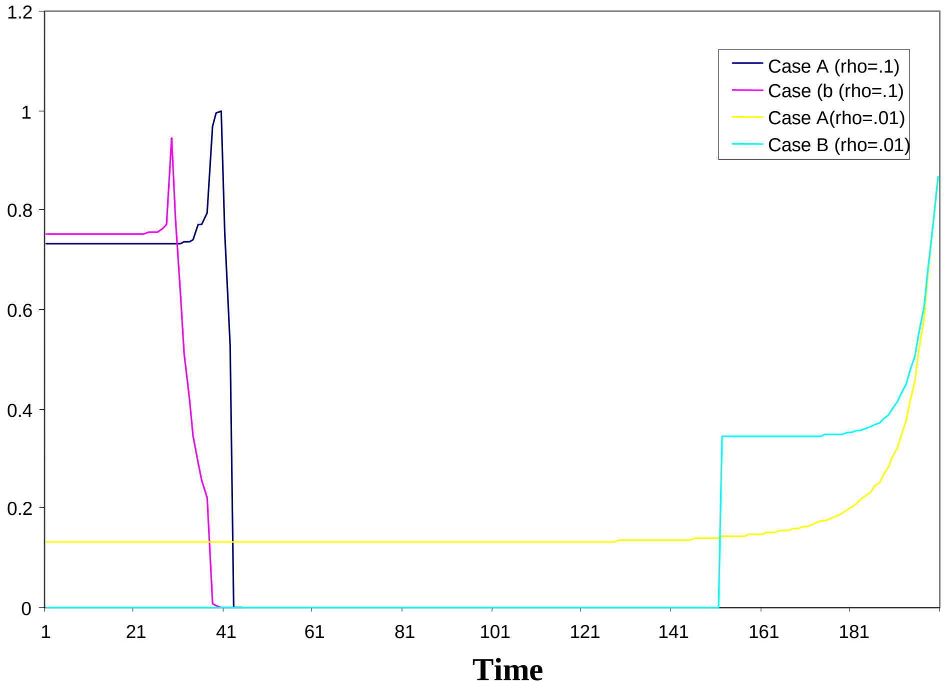


Figure 7: Hazard Rate under Varying Time Preference

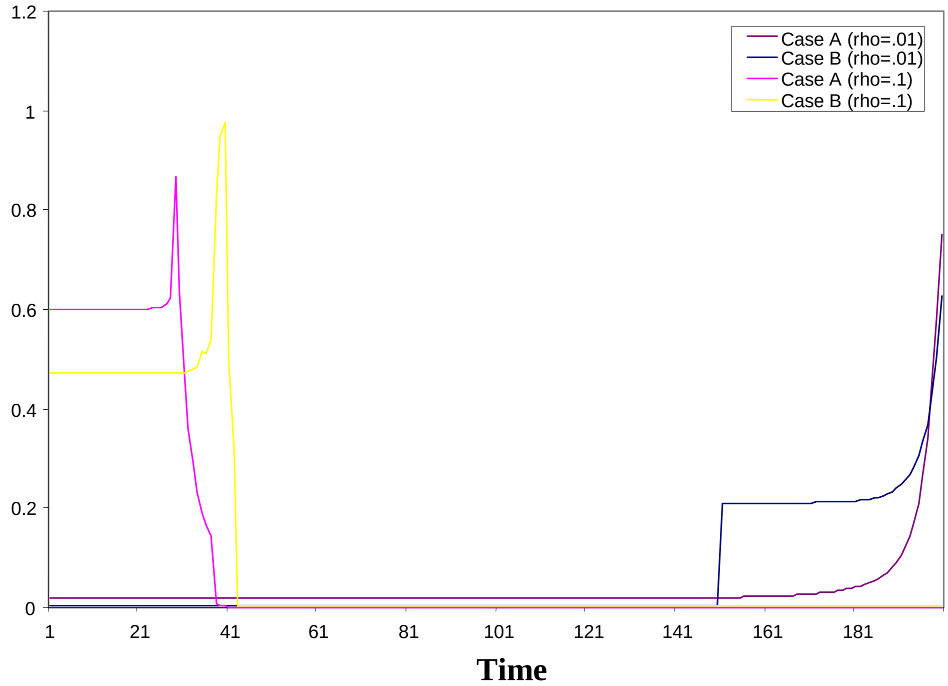


Figure 8: Water sale with transaction costs and time-dependant hazard rates

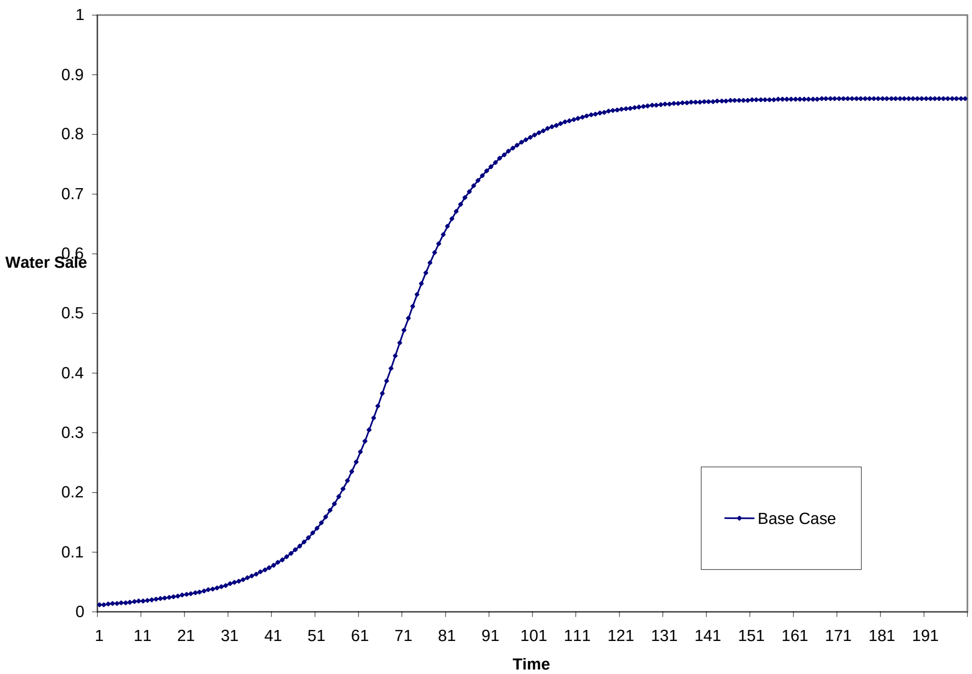
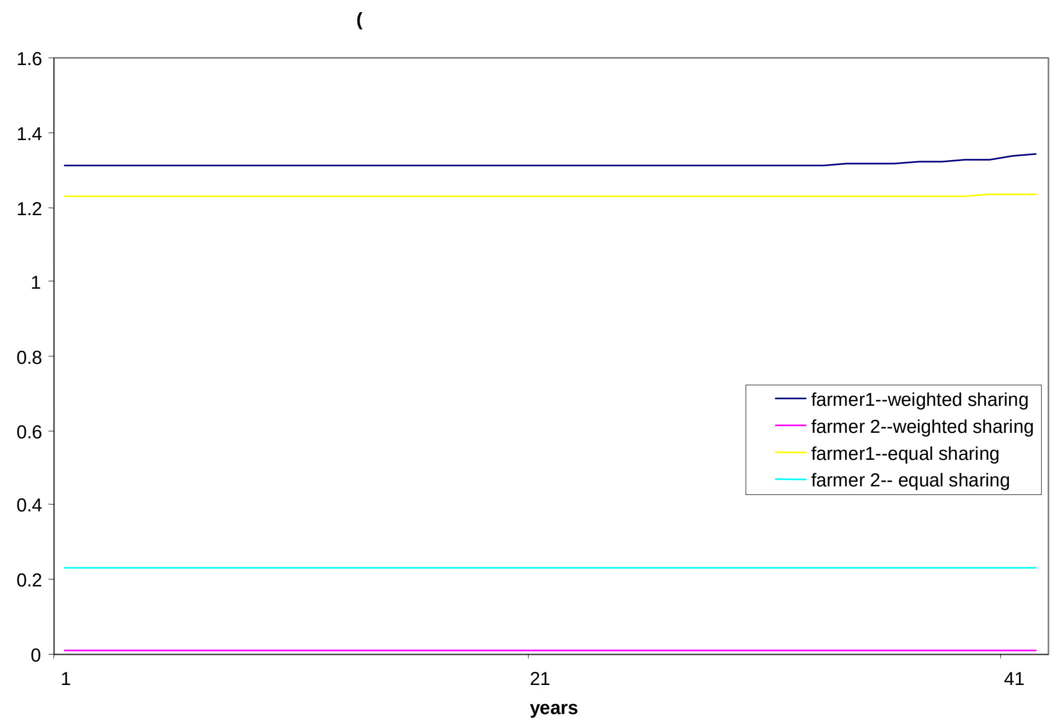
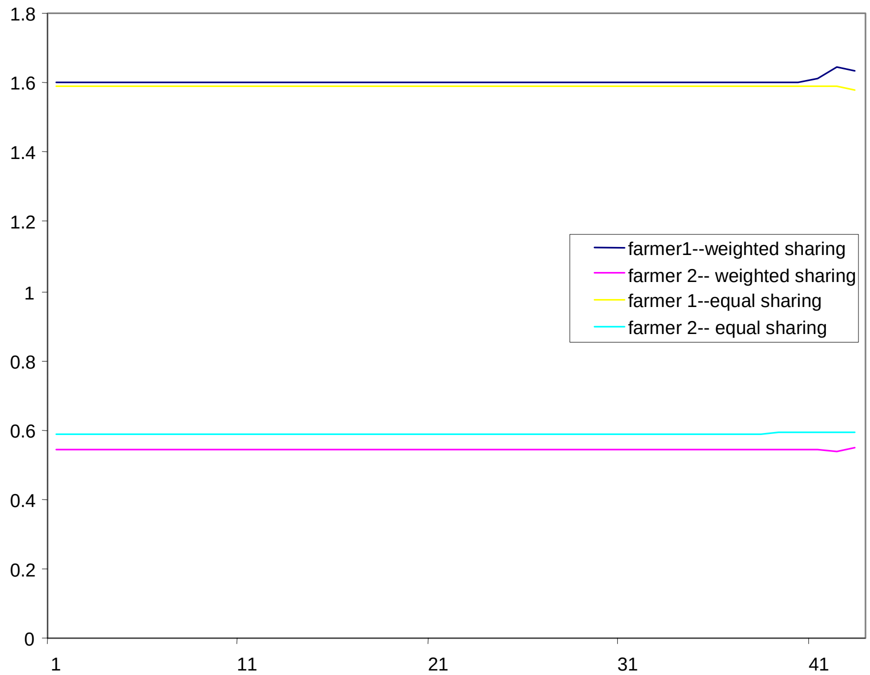


Figure 9: Water Sale-- Two Farmers Case --Low risks



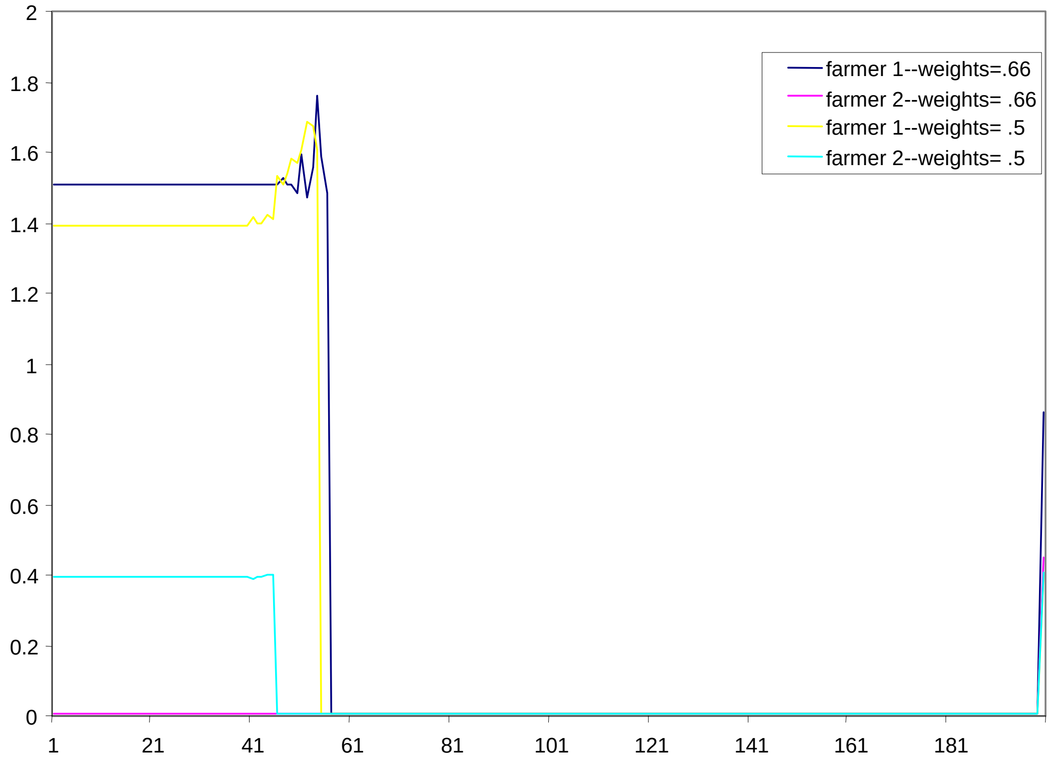
(Gamma1=Gamma2=.25, Theta1=Theta2=.45)

Figure 10: Water Sales--Two Farmers Case--High Risks



(Gamma1=Gamma2=.025, Theta1=Theta2=.45)

Figure 11: Water Sales--Differential Risks



(Gamma1=.025, Gamma2=.25, Theta1=Theta2=.45)