Factors Affecting Participation in Spot and Options Markets for Water

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Abstract

In this paper, using a stylized mathematical simulation model, the participation of farmers in spot and options markets is analyzed in a two-period setting. Farmers assess the benefits from entering one of the two markets based upon anticipated water supplies in a subsequent period and relative expected profits in water and agricultural markets. Supply of water for urban use is a function of uncertain weather conditions and water demands for agricultural uses. The analysis offers insight on water market participation by deriving conditions that favor spot or options market participation. Findings highlight the importance of market size, agricultural profitability and other parameters in predicting the potential success of spot and options market formation.

Keywords: water scarcity, spot and options, water markets, water trading
1. Introduction

Agriculture accounts for nearly eighty percent of total consumptive water use in the U.S and about sixty five percent in Australia. Agricultural water supplies support a highly productive irrigated sector, accounting for nearly half of total crop revenues on just 16 percent of the United State’s cropland. However, increasing water demands for non-agricultural purposes—including municipal, industrial, and environmental uses—are competing increasingly for available water supplies. As opportunities for large-scale surface-water developments are limited, emerging water demands must be met largely through reallocation of existing agricultural supplies. Water markets have been offered as a means of facilitating the transfer of water from agriculture to higher-valued non-agricultural uses. But operational markets for water have been slow to develop, and limited transfer of agricultural water has contributed to water-supply shortages in the broader economy (Gaffney 1997, Michelsen 2000, and Howitt and Hansen 2005).

This paper explores the role of water markets in facilitating water transfer between agricultural and non-agricultural uses. The analysis compares the potential of two relatively new markets, namely spot and options markets, in mitigating water shortages to non-agricultural users. The spot market, as the name suggests, comes into play without prior agreements and allows for mitigating water shortages through on-the-spot trading between parties needing water and those having surplus water. The options market (or ‘contingent’ market) for water allows for an advanced contractual agreement between two parties to buy and sell water at pre-determined options and exercise prices during water-short years. The holder of an option must pay an option price in order to have the option to buy water at some predetermined price, typically in response to a
predetermined drought trigger. The exercise price is an additional amount that must be paid at the time the option to buy or sell water is exercised. Options contracts may be structured based on a single year or longer term period with multiple exercise options.

One of the key decisions facing potential market participants—and a focus of this paper— involves the relative tradeoffs in producer risk and expected returns across spot and options markets. Spot markets offer potentially higher rewards to water sellers, but also carry higher risks of price fluctuations. Options markets help hedge against water-price fluctuations for both buyers and sellers. At the same time, long-term options contracts may introduce additional uncertainty regarding water supplies for future agricultural production. As farmers typically retain water-use rights in average and wet years under an options contract, income and production impacts are generally not as severe as in the case of permanent sales and long-term lease agreements for water.

In order to understand the market participation incentives, we need to account for the various factors that influence decision-making for market participants. The risks facing farmers from the transfer of water-use rights constitute a significant element in the participation decisions. Such risks involve uncertainty in demand- and supply-side conditions as well as future opportunity costs of water. Profits from water transfer may also be affected by the size of the market, as determined by the number of market participants, and elasticities of demand for both agricultural commodities and water. An individual farmer’s choice between the spot and the options market is affected by expected profits in the two markets, compared against expected returns to agricultural production. Market participation in such cases involves incorporation of forward-looking
rational expectations into individual decision-making. Such feedback calculations may help to explain the relative predominance of transactions in one or the other market.

The paper develops a stylized theoretical model to examine farmer decisions to participate in spot or options markets under uncertain price and resource-supply conditions. The model considers N farmers with assumed uniform productivity. Simulations are performed to assess the effect of key variables on market participation, including number of market participants, agricultural water demand and price, land supply and agricultural productivity, price elasticity of demand for agricultural output, and elasticity of urban water demand. Special attention is devoted to forward-looking behavior in determining the potential for market formation. Factors resulting in the lack of sufficient participation in any market, where incentives are insufficient to promote participation, are also evaluated. The paper closes with a discussion of policy implications and conclusions. First, a brief introduction to the water market literature is in order.

2. Water Market Literature

Water transfers through markets have been advocated as a means of mitigating water-supply shortages to non-agricultural users. However, a variety of factors have limited the development of operational markets for water. These include physical, financial and institutional limitations. Young (1986) describes four basic ingredients of an institution that would make water markets viable—security, flexibility, certainty, and consideration of third-party impacts. Third-party impacts, such as water-supply reductions to downstream users due to water trading upstream, can be a significant
bottleneck for market development (National Research Council 1992). Even where the physical conditions have been optimal, institutional hurdles exist in the form of transaction costs and risks. For the sellers of water, the fear of adverse consequences from trade may form the most significant hindrance to market participation. The risk of selling the rights at a lower price could be high. These risks introduce significant transaction costs. Long-term water transfers may also involve losses to the broader sector, including forgone agricultural output and farm returns, reduced agricultural productivity, an increase in maintenance costs on fallowed acreage, farm employment losses, and forward linkage effects that impact the buyers of agricultural outputs (Howe, 1997, and Howe et al. 1990). Besides, there may be externalities and political costs.

There are three main types of water markets—the spot market, the options market and permanent rights market. In the case of permanent rights market, the seller evaluates the value of his rights given current and expected future demands.

Options market allows the buyer the option to exercise his right to buy water during droughts. Spot market refers to leasing of temporary water use rights for a very short period (usually one season) in response to a water-supply shortage from drought. Calatrava-Leyva and Garrido (2005a) compare implications for farmers’ profitability under water uncertainty with and without trading through spot markets for water in Guadalquivir Valley in Southern Spain. They develop a stochastic two stage discrete programming model along with a spatial model to predict irrigator behaviour and market equilibrium. Their findings indicate that when farmers make ex-ante decisions under price uncertainty, losses are partly mitigated when market participation is allowed. Calatrava-Leyva and Garrido (2005b) have explored the influence of water supply
uncertainty and risk aversion of farmers to predict participation in spot markets. They find that spot markets unambiguously reduce risk exposures for both buyers and sellers of water.

Much of the water transfer currently occurs through spot markets, though the merits of the options market in terms of managing uncertainty may far exceed those of the spot markets (Howitt 1998, Michelson and Young 1993, Huffaker et al. 1993). Howitt (1998) makes the case for options markets by arguing that spot markets and the permanent-rights markets constitute two polar cases wherein risk is shifted from one party to the other. In the case of spot markets, most of the risk is borne by the buyer due to the thin market characteristics of such transactions. In the case of a permanent market, the seller of the rights needs to evaluate the value of his rights given current and expected future demands. These risks and uncertainties introduce significant hindrances to water transactions. Options markets can help lower the risks arising from both supply and price uncertainties to both parties. Ramos and Garrido (2004) promote options contract along with a compensating premium as a means to sharing uncertain water supply related risks between the urban city supply and water rights holders in Seville of Spain.

The role of options markets has been evaluated in the literature to some extent. Villinski (2003) designs a methodology for valuing multiple-exercise options contracts for water from a buyer’s perspective. Villinski notes some of the drawbacks of the current options water market approach. One major drawback of adopting the options market approach from finance involves the manner in which evolution of uncertain prices has been handled. The assumption of a Brownian motion implies that prices follow a continuous-time, random walk with mean zero and variance of one that is rising linearly
over time. Villinski points out that water prices might show seasonality, and perhaps a mean-reverting approach would be more fitting. While she follows a similar framework as Howitt (1998), the methodology used is quite different. Drawing on data from Watters (1999) and applying it to the case of California, she solves for the European call option value of water, which could be exercised two times in a three year period. While the calculated option value is quite low, it approximates the real option value that the buyers of water in California were willing to pay in case of an options market in 1994-95.

Michelsen and Young (1993) examine the role of water-supply options contracts in facilitating water markets. The authors identify a number of conditions which must be satisfied in order for the options markets to work. Chief amongst them are reliability of water supplies (to ensure sufficient water during dry years and plenty during normal years), well-defined property rights, ability of the seller of the water rights to temporarily suspend operations, availability and knowledge of risks of drought, and attractiveness of options contract costs as compared to alternative costs of attaining water in dry years. However, their analysis focuses chiefly on reasons that buyers would participate, but not sellers. The authors note features of the options contract that distinguish it from other kinds of water markets, including the temporary nature of contracts (transferring use versus ownership rights), potential exercise of the option multiple times over the contract period, and exercise of option being supply-dependent rather than price dependent. They define the option value of water as the difference in the cost of the options contract and the next best alternative source of water.

In sum, the spot and options markets serve the needs of both the buyers and sellers in terms of risk sharing and smoothing uncertainties in water demand and supply.
Despite such advantages, their development has been slow in the U.S. thus far. In certain cases, the success has been partial with one of the markets failing to materialize, thus posing significant challenges to participants in terms of risk sharing and supply insurance.\(^1\)

While considerable literature has been devoted to the various legal, institutional and administrative barriers to water market formation, relatively little attention has focused on production incentives that drive market participation, and the factors that favor spot and options market formation.

Whereas a few studies such as Calatrava-Leyva and Garrido (2005 a & b) and Ramos and Garrido (2004) have explicitly modeled farmer participation in either spot or options market, none so far have explored the possibility of farmers evaluating participation in both options and spot markets simultaneously. Further, forward looking behaviour, where a farmer anticipates the decisions of other farmers before deciding which market to participate in, has not been modelled. Our analysis is intended to shed some light on the influence of these factors and add this new dimension to the literature on spot and options markets.

### 3. Model

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\(^1\) There exists some commonality between the futures markets in water, agricultural commodities and some natural resources. In agriculture, the main purpose of commodity future options has been to allow the farmer to hedge against the risk of volatile future prices. Brennan and Schwartz (1985) apply the option pricing theory to study investment in copper mines. The option to invest is related to the value of mines, which is related to the price of copper in spot markets. Watters (1995) points out the supply-side similarities between oil and water markets; while oil supply is a function of geological uncertainties, water supply risks are hydrological. However, the futures market in water is slightly different from the oil and agricultural commodity markets in the sense that urban buyers of water are more interested in insuring themselves against supply fluctuations rather than price fluctuations as is the case with oil and agricultural commodity markets.
In this model we explore the interaction between a large urban buyer and a group of farmers assumed homogenous, a situation typical of exchange in water markets, using a simultaneous decisions framework. Two time periods are defined to reflect the two phases in water markets, one before water availability in a season is known and the other after it. The availability of water in a given season is a function of uncertain seasonal weather conditions which cannot be predicted in advance. In the first period, the urban buyer offers an option and exercise price for water purchase in the options market. Farmers potentially interested in transferring water must decide between entering the option market and waiting for prices in the spot market. In the second period, water supply becomes known and the spot market evolves to meet the urban buyer’s residual demand. However, the decision to enter either of the markets needs to be made at the beginning of period one, based upon the expectations over relative profits in the two markets. The same pieces of information influence expected profit in the spot versus option market (e.g. probability of alternative states of nature, expected profit in agriculture under alternative states of nature, expected urban demand). The only difference between the two markets (from the producer's perspective) is that the options market provides an opportunity to eliminate price uncertainty.

Benefits from sale of water in either the spot or options market are affected by the collective choice of the farming community. That is, individual farmers are making their own water-sale decision, but the number of farmers participating in the spot versus options markets affects the price individual farmers receive for their water. For instance, if farmers expect the future spot prices to be high, they would hold back their water from
the options market. This in turn would lead to a glut of water supply in the spot market, thus potentially lowering its price.

Similarly, the composition of farmers between the spot market and the options market would determine the total supply of the agricultural output. If the demand for agricultural output is price elastic, profitability in the agricultural market would also depend upon the distribution of farmers between the spot and options market by affecting the total agricultural output produced. Farmers who sell their water in the options market would have limited or no flexibility to use it for agricultural purposes in a dry year, while farmers in the spot market could decide the optimal allocation between the spot market sales and agricultural use based upon the profit differential between the two markets.

The expectation of future water supply determines the availability of water to the spot and options markets, and hence profitability of participating in those markets. A dry year would raise the spot market benefits whereas a wet year would raise the options market profitability relative to the spot market. Therefore, in equilibrium the expected benefits to the last farmer choosing to participate would be equalized across the two markets. If expected benefit of participating in the spot market were greater than for the options market, farmers would switch from the options market to the spot market (switching implies the system is in disequilibrium). As more farmers enter the spot market, the expected price for water in the spot market would decrease, until so many additional farmers have entered that the spot market profitability has been driven down to the same as that in the options market. At this point farmers would have no incentive to switch markets, and the system would be in equilibrium. This is the decision-making framework adopted for the model below.
Let there be \( N \) farmers, each farmer with one unit of surface water right \((W)\), and access to a maximum \( G \) units of reservoir water through a shared reservoir capacity. In addition each farmer gets \( L \) units of land. Note that, reservoir water is not the source of surface water (which it is in many on-river reservoir systems) and reservoir water cannot be sold in the spot or options market. Farmers also have to pay to get surface and reservoir water\(^2\)

Farmers have a choice between entering the spot market and the options market. If they decide to enter the options market they must sell the water to the urban buyer at the pre-determined options and exercise prices. There is, however, some uncertainty over the supply of surface water. This uncertainty is denoted by a probability density function \( f(s) \), with \( 1 > s > 0 \), where \( s \) is the ‘realized’ sale of water to the urban buyer. The idea is that, although a farmer receives an option price for the sale of his entire one unit of water, the amount of water that is actually sold is determined by availability of water in a dry year. For instance, if a farmer receives only half of his annual supply of water, he can deliver only that much to the buyer.

Also, the farmer has access to \( G \) units of reservoir water in a wet year. Thus, if in a dry year the surface water supply to the farmer is \( s \), then his reservoir water supply would be \( Gs \). This assumption is based upon the fact that a reduced rainfall would lead to a reduced availability of recycled water for injection into the aquifer. Reservoir water, in

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\(^2\)Reservoir capacity could be generated through water banking, a practice adopted in several European countries and Australia. The process involves injecting recycled water into aquifers and withdrawing it for irrigation when needed. This helps reduce water losses through evapotranspiration, which is a problem with surface reservoirs.
fact, could be affected differently than the surface from a reduced rainfall or in a lagged time period; however, simplification of this assumption does not lead to any loss of generality. Some farmers may have higher access to reservoir water than the others, but as long as trading is costless (which is an assumption in this model), same outcomes would materialize.

3.1. Variables and Parameter Definition

\( N \) = total number of farmers participating in surface water market (scalar)

\( n \) = number of farmers in the options market (scalar)

\( w \) = demand for surface water in agriculture (Litres/year)

\( W \) = maximum quantity of surface water available to each farmer; \( W=1 \) by assumption.

\( G \) = maximum quantity of reservoir water available to each farmer.

\( Q \) = urban demand for surface water (Litres/year)

\( E^{Supply\ (Spot)} \) = expected supply of surface water in the spot market (Litres/year) from farmers.

\( E^{Demand\ (Spot)} \) = expected demand for surface water in the spot market by farmers and the urban buyer (Litres/year)

\( E^{Supply\ (Options)} \) = expected supply of surface water in the options market (Litres/year)

\( f(s) \) = probability density function over proportion of maximum surface and reservoir water supply actually available, where \( 0 < s < 1 \) (scalar)

\( x \) = agricultural output (tonnes)
\( E^s(\text{spot}) \) = expected agricultural output in the spot market (tonnes), i.e. agricultural output produced by farmers who participated in the spot market.

\( E^s(\text{options}) \) = expected output in the options market (tonnes) i.e. agricultural output produced by farmers who participated in the options market

\( E(\pi(\text{spot})) \) = farmers’ expected profits from spot market participation ($), including profit from agricultural output and water sales.

\( E(\pi(\text{options})) \) = expected profits from options market participation ($), including profit from agricultural output and water sales.

\( A \) = technology parameter of the production function (scalar)

\( L \) = land used for agricultural production per farmer (hectares)

\( \gamma \) = revenue share of surface and reservoir water combined in the total agricultural output

\( h \) = option price offered by the urban buyer ($ per litre), which is assumed fixed in this model.

\( k \) = exercise price offered by the urban buyer ($ per litre), which is assumed fixed in this model.

\( p \) = price of surface water in the spot market ($ per litre)

\( \alpha \) = elasticity of urban demand for surface water (scalar)

\( u \) = price paid by farmers for surface surface water ($ per litre)

\( d \) = price paid by farmers for reservoir water ($ per litre)

\( z \) = price of agricultural output ($ per tonne)

\( \beta \) = price elasticity of demand for agricultural output (scalar)

\( r \) = rent paid on agricultural land ($ per hectare)
$MVP_w =$ marginal value product of water in agriculture ($)

3.2. Derivation of Equilibrium Conditions

Let the production function for the agricultural commodity $x$ be denoted by a Cobb-Douglas functional form:\(^3\):

(1) \[ x = A \cdot (w + G)^\gamma \cdot L^{1-\gamma} \]

In addition, let the urban demand for surface water ($Q$) be specified as:

(2) \[ Q = p^{-\alpha} \text{ or, } p = Q^{-1/\alpha} \]

The expected supply of surface water in the options market $E^{Supply\ (Options)}$ would be the sum over the expected realization of surface water for the $n$ farmers who choose to participate in the options market:

(3) \[ E^{Supply\ (Options)} = n \cdot \int_{0}^{1} W \cdot s \cdot f(s) ds \]

Where $n$ is an endogenous variable that captures the influence of agricultural output price, expected profit in the spot versus options market, etc., on the expected supply of water to the options market. Therefore, the expected supply of surface water available to the spot market is derived from the remainder of farmers who have not entered the options market:

(4) \[ E^{Supply\ (Spot)} = (N - n) \cdot \int_{0}^{1} W \cdot s \cdot f(s) ds \]

\(^3\) The production function for the agricultural commodity may be more complex than specified above, but we assume constant returns to scale Cobb-Douglas specification for ease of analysis. An alternative specification, such as the constant elasticity of substitution (CES), would have been appropriate had the analysis focused on the role of additional inputs in determining participation between the two markets. Given the complexity of the current model, we have assumed the simpler specification.
Note that because we have assumed farmer homogeneity, all farmers who enter the spot market will end up selling or buying the same amount of water. Technically, farmers in the spot market can purchase any surplus water from the urban buyer acquired by him through the options market.

The residual expected urban demand for surface water in the spot market would be the difference between the existing demand and the expected realized supply in the options market:

\[ E(Q) = p^{-a} - n \int_{0}^{1} W \cdot s \cdot f(s) ds \]

Note that because we have assumed farmer homogeneity, all farmers who enter the options market will end up selling the same amount of water. Expected demand for surface water for agricultural uses in the spot market would be given by the equality between expected profitability of surface water in agriculture and the price of surface water in the spot market:

\[ E(MVP_w) = A \cdot \gamma \cdot L^{1-\gamma} \cdot (w + \int_{0}^{1} G \cdot s \cdot f(s) ds)^{1-\gamma} \cdot z = p \Rightarrow w = \left( \frac{P}{z \cdot A \cdot \gamma \cdot L^{1-\gamma}} \right)^{1-\gamma} - \int_{0}^{1} G \cdot s \cdot f(s) ds \]

where \( z \) is the price of the agricultural output and \( w \) is the demand for surface water. Note that the expected marginal product includes the expected output from use of reservoir water as well. The total expected demand for surface water in the spot market across agricultural and urban uses is given by the sum of expected demands for agricultural use (as given by equation 6) and residual expected demand of the urban buyer (as given by equation 5):
The spot market for surface water would clear when expected demand equals expected supply. This is achieved by equating equation (4) with equation (7). This results in a solution price for surface water in the spot market, \( P \), in terms of all other variables as:

\[
\text{p} = p(A, N, n, \alpha, z, \gamma, L, f(s), s, G)
\]

Expected agricultural output in the spot market would be given by the combined use of surface and reservoir water in agriculture as:

\[
E^s(\text{spot}) = (N - n) \cdot A \cdot \gamma \cdot L^{1 - \gamma} \cdot \left( \frac{p}{z \cdot A \cdot \gamma \cdot L^{1 - \gamma}} \right)^{\gamma \cdot \gamma} - \int_0^1 G \cdot s \cdot f(s)ds + p^{-\alpha} - n \cdot \int_0^1 W \cdot s \cdot f(s)ds
\]

The agriculture market clears when expected demand equals expected supply. Let the demand for agricultural output be equal to:

\[
z^{-\beta}
\]

If the agricultural output is traded in a small region its supply would have a significant influence over the price. However, cases where the agricultural output is traded in a larger market could easily be accommodated by varying the value of \( \beta \). The expected
price of agricultural produce is solved for by equating its demand to the expected supply as:

\[
z^{-\beta} = (N-n) \cdot A \cdot L^{1-\gamma} \cdot (\frac{P}{z \cdot A \cdot \gamma \cdot L^{1-\gamma}})^{\frac{\gamma}{\gamma-1}} + n \cdot A \cdot L^{1-\gamma} \cdot \int_0^1 (G \cdot s) \cdot f(s) ds
\]

This gives the price of the agricultural commodity as:

\[
z = z(A, L, N, n, \alpha, \beta, \gamma, f(s), G)
\]

Now, let us turn to expected profits in the spot market. Expected profits to a single farmer from spot market participation would be the sum of expected agricultural profits and the expected profits from spot market sale of surface water to the urban buyer:

\[
E(\pi(\text{spot})) = A \cdot L^{1-\gamma} \cdot z \cdot (\frac{P}{z \cdot A \cdot \gamma \cdot L^{1-\gamma}})^{\frac{\gamma}{\gamma-1}} - r \cdot L - \int_0^1 (u \cdot W + d \cdot G) \cdot s \cdot f(s) ds + p \cdot \int_0^1 f(s) ds - ((\frac{P}{z \cdot A \cdot \gamma \cdot L^{1-\gamma}})^{\frac{\gamma}{\gamma-1}} - \int_0^1 G \cdot s \cdot f(s) ds)
\]

The expected profits in the options market is the sum of revenues based on the net benefits from the agricultural output and option and exercise prices for surface water:

\[
E(\pi(\text{options})) =
\]

\[
h + \int_0^1 k \cdot s \cdot f(s) ds + z \cdot L^{1-\gamma} \cdot (\int_0^1 G \cdot s)^{\gamma} \cdot A - r \cdot L - \int_0^1 (u \cdot W + d \cdot G) \cdot s \cdot f(s) ds
\]

Farmers would weigh the expected profits from the options market against the expected profits from the spot market in deciding between the two. Therefore, under equilibrium the two would be equal; otherwise, farmers would switch from one market to the other, driving relative profitability down in one market and up in the other, until they were
equal. Solving this would lead to \( n \), the number of farmers who decide to enter the options market, and \((N-n)\), the number of farmers who decide to enter the spot market.

### 3.3 Further Assumption for Numerical Simulations

The solution to the above equations is analytically intractable due to exponential terms in the equations, so we impose more structure on the model and perform numerical simulations. A listing of the key assumptions is provided below:

1. The production function for the agricultural commodity is Cobb-Douglas.
2. The uncertainty associated with the surface and reservoir water supply has a uniform distribution. i.e. \( f(s) = \begin{cases} \frac{1}{b-a} & \text{for } a \leq s \leq b \\ 0 & \text{for } s > b \end{cases} \), where \( a \) and \( b \) are the upper and lower bounds of available water.
3. Only surface water is traded in the water markets.
4. Farmers exhibit homogeneity in production function and land and reservoir water endowments.
5. Agricultural commodity is traded in a small market so that the price is responsive to supply.
6. A farmer can only participate in either spot or the options market, but not both.
7. Profits are equalized between the two markets in equilibrium; that is, farmers move from one market to another until for the last farmer deciding to switch the profits are same in the two markets.
8. There are no transaction costs for water in the spot and options markets.
9. The options and exercise prices are assumed to be exogenous. In addition, whereas the holder of an option can choose not to buy the good, here it is assumed that the urban buyer would always exercise his option. The spot market clearing water price would be determined by the spot market water supply and the sum of water demanded by the farmers and the residual water demand of the urban buyer (which may be negative).

Derivation of the equilibrium conditions with the above assumptions is provided in the Appendix. Next, results from a numerical example are provided in the following sections to derive insights into the effect of key parameters on farmer participation.

4. Results

TABLE 1

Table 1 presents base case parameters and the results of the numerical simulations. The base case involves a total of 50 farmers who have the option of either entering the spot or the options market. Sixty percent of the participants enter the options market. Market clearing price for surface water in the spot market is $0.068/litre and the price of agricultural commodity is $0.161/tonne. The expected supply of surface water in the spot market is

\[ \frac{N - n}{2} = 9.95 \] litres out of an expected total realization of 25 litres. This follows from equation (4) as we have assumed a uniform distribution for \( s \). Total agricultural output in the combined markets is about 15.5 tonnes which comes mostly from the spot market. The urban buyer ends up selling about 13.1 litres of water in the spot market. This however, does not mean that his net demand for water is negative.
Note that the expected supply of water in the options market from the 30 participants is 15 litres, which implies that the urban buyer would only keep about 2 litres of water at the market clearing spot price of water at $.68/litre. The expected spot price of water is higher than the combined option and exercise price paid by the urban buyer (at $.06/litre). This leads to a feasible equilibrium for the market. There may be cases where an equilibrium outcome is possible only when the urban buyer is forced to sell water in the spot market at a price lower than the combined option and exercise price paid by him in the option market. This would imply that in that case one of the markets would fail to attract any participants.

Cases 1 through 7 examine the sensitivity of the success of surface water market transfers and relative participation rates across spot and options markets to key parameters.

Cases 1 through 4 consider the effect of market size, or potential pool of surface water sellers. Case 1 considers the impact of a smaller number of farmers (45) on the participation rate in the two markets and resulting prices. Note that the options market now accounts for less than 50 percent of market participants, however both the agricultural and surface water prices have increased. This is because of a reduction in the agricultural output which leads to higher commodity prices. Surface water price increases as the marginal value product of surface water in agriculture is relatively higher due to higher agricultural prices. This effect is further magnified when the total number of farmers (as given by case 2) falls to 40. Now, there are more farmers in the spot market as compared to the options market. Agriculture is yielding much higher returns than the options market, thereby increasing participation in the spot market. The primary
reason for increased profitability in agriculture is the reduced output from there being less number of farmers. Therefore, spot market participation is inversely proportional to market size.

Case 3 explores the effect of a larger number of farmers than the base case ($N=80$). Eighty percent of the farmers choose to be in the options market, lowering the price of water. However, notice that the price of water in the spot market falls to $.044/litre (which is much less than the option price paid by the urban buyer). The urban buyer is required to sell 30 units of water at this price for market equilibrium conditions to be satisfied. A high option price attracts too many participants in the options market by making the spot market unattractive. A lowering of the option price may resolve this. This case therefore highlights the possibility that equilibrium may not be attained in absence of a bargaining between the farmers and the urban buyer over option pricing. This is further reinforced by case 4 which has a higher price elasticity of demand for the urban buyer of surface water. Notice that there are still 80 percent of farmers in the options market as previously, yet the spot price of water is higher than the option price. This is made possible by lower water supplied by the urban buyer in the spot market as his demand for water has increased. Therefore, option market participation is increased when price elasticity of demand for urban water is higher. A similar rate of participation can be achieved by increasing the exercise price as shown by case 5.

Case 6 increases agricultural productivity by increasing agricultural technology parameter $A$. This significantly increases agricultural output in the spot market by reducing options market participation by half as compared to the base case. Note that the urban buyer is not able to dispose off large amounts of water in the spot market due to a
lower turnout in the options market. The influence of market size (in terms of total number of participants) becomes readily evident in case 7 where \( N \) is increased to 60 keeping other parameters same as case 6. Now, more than 50 percent farmers participate in the options market (as compared to less than 30 percent in case 6), yet the agricultural output in the spot market is higher than case 6.

5. Policy Implications

Several insights emerge from the above numerical simulations. Specifically, cases 1 to 3 highlight the potential impact of the market pool on participation rates between the two markets. A smaller group of farmers results in lower levels of agricultural output. Where a reduction in output has a significant impact on commodity prices (as perhaps in the case of local fresh produce and hay crops), higher agricultural profits encourage lower participation in the options market. Consequently, government policies aimed at promoting participation in the options market may need to account for market size and agricultural price response.

Case 4 brings to fore the influence of a high price elasticity of urban demand for water in influencing outcomes in large markets with a large number of participants. A large number of participants has the influence of dampening water and agricultural prices. Throughout most of the analysis the options and exercise prices offered by the urban buyer were kept exogenous. When the buyer can anticipate future water scarcity or is risk averse, he may increase his offer to attract more participants. Case 5 highlights this possibility where an increase in the exercise price significantly increases participation in
the options market. In fact, a high enough offer can pre-empt the spot market altogether by attracting all farmers to the options market.

On the other hand, scenario 6 highlights the possibility when the urban buyer may not succeed in getting enough water when agricultural productivity is enhanced through a technological breakthrough. Increased profitability in agriculture would discourage selling of water in the spot market and the urban buyer would need to raise his bid to attract water sellers. The obvious policy implication of this scenario is that spot and options markets would be successful in reallocating water efficiently across sectors, but the urban buyer can be successful in procuring water from agriculture only when he is the higher valued user of water. Finally, case 7 yet again reminds us of the key role market size plays in influencing outcomes.

It was noted in the introduction section that even though the merits of the options markets have been argued to outweigh those of the spot markets, the latter has been found to be more prevalent. This model provides insights into the reasons for the relative success of the spot markets. In general, it is found that the spot market participation is inversely proportional to market size, that participation is increased when price elasticity of demand for urban water is higher, and lower water prices discourages spot market participation.

The findings, that options markets are favored when agricultural demand is low or when the market size is large, are also corroborated by real world examples. The success of options markets have been found to be directly linked to rainfall as was evident from the case of the California water options market in 1995. The projected demand for options was 382 million m$^3$ in December 1994, but only 35 million m$^3$ were sold by
February 1995 (Howitt and Hanka 2005) as the rainfall situation improved. Further, the demand fell to zero by April 2005. However, recently, with a reduction in allocated water supply to Southern California and a reduction in farm commodity prices, close to 206 million $m^3$ of options contracts were signed between the Municipal Water District of Southern California and several districts in the Sacramento valley (Howitt and Hanak 2005).

Spot and options markets cater to two opposite ends of a spectrum of water users. While risk averse buyers and sellers of water would prefer the options market by locking in fixed prices and quantities of water, the spot market is suitable for those who are willing to expose themselves to fluctuations of demand and supply caused by an uncertain water availability in future. Yet, both these types of markets are needed simultaneously if society is to make the most out of a water scarce situation. Consequently, understanding the factors that drive successful market formation has important policy implications. It will help mitigate the obstacles that may arise in a proper functioning of these markets. This fact is increasingly being recognized all over the world. Hadjigeorgalis (2007) conducts a survey of 166 farmers in the Rio Grande basin to conclude that farmers are more likely to participate in short terms markets than permanent transfers that alienate water rights with land. Further, she argues that an *a priori* understanding of factors affecting the success of these markets is crucial for designing a successful market mechanism for the basin.
6. Conclusion

As competition for available water supplies intensifies, the reallocation of water to meet critical water demands becomes increasingly important. Market mechanisms that value water resources and provide compensation through voluntary transfers of water-use rights are an important tool in achieving water policy goals. However, the success of markets will depend on many factors that are region-specific and potentially difficult to discern.

The analysis presented in this paper highlights several conditions that may favor the development of operational spot and options markets for surface water. The prediction of relative participation may help in guiding public policies that are aimed at securing future water supplies for key water users such as urban and environmental.

In general, higher levels of agricultural water productivity favor spot market participation. The same may or may not be true for higher levels of uncertainty related to future water supply and their prices, and agricultural input and output prices. It is pertinent to understand all the parameters that influence market participation for a given region. When such understanding is lacking, government policies may focus on developing State water banks that align spot and options sellers and buyers in water-short years.

The results derived in this paper are based upon several assumptions, some of which may require further refinement to capture the ground realities conditioned by geographic location, market size, informational asymmetry, farmer heterogeneity and collusion and bargaining possibilities between farmers. The impact of heterogeneity
amongst the sellers on their distribution between the spot and the options markets could be significant. This might involve differences in risk perceptions, productivity, crop choices and management practices, land endowments and access to reservoir water across the potential pool of participants. When some farmers may have higher productivity than others, more productive farmers would prefer not to enter the options market. Further, under substantial farmer heterogeneity with varying water endowments, it is possible that a farmer considers participating in both spot and options markets by allocating his water endowments between the two markets. Another possibility is that the equilibrium condition of profits equalizing in the two markets may not hold due to significant transaction costs, a nascent market or a small market size, collusion amongst farmers and lack of sufficient information on the part of the farmers. Further, here it was assumed that the options and exercise prices are fixed. In reality, the prices in the options market may be determined through bargaining, which would make the outcome dependent upon the market size. Finally, when market size is too large, farmers may not be able to correctly predict expected outcomes in the two markets. However, latest research through experimental economics predicts that farmers get better at trading in spot and options market with repeated experience.

Considerably more research is needed to fully understand the role of factors that influence farmer participation in water markets and equilibrium market conditions and market composition. In this paper, the social aspects that might influence farmer participation were not considered. Demographic factors such as a farmer’s age and education might play an important role in determining participation in markets for water. Risk perceptions across various demographic groups and farm categories are also likely
to be a significant factor in market participation. Expectations regarding water availability in the future could be weighted by the risk perceptions of farmers. Producers of high-valued specialty crops and perennial crops may face higher probability of water shortfalls relative to other farmers. Farmers might be skeptical of their ability to draw the stipulated amount of water in the future if government policies are inconsistent or if they fear adverse governmental responses to surface water trading (such as alienation of their water rights), thereby discouraging participation in either of the markets.
References


Appendix: Derivation of Relative Participation using a Cobb-Douglas Production function with Uniform Distribution Function for Water Supply

Expected profits in the options market are given by solving (15):

\[ E(\pi(Options)) = (h + z \cdot A \cdot L^{1-r} \cdot (G/2)^r - r \cdot L - \frac{(u + d \cdot G)}{2} + K/2) \]

Expected supply of water in the options market is given by solving (3):

\[ E(Supply(Options)) = \frac{n}{2} \]

Expected residual demand in the spot market is given by solving (5):

\[ E(Q) = p^{-a} - \frac{n}{2} \]

Expected supply of water in the spot market is given by solving (4):

\[ E(Supply(Spot)) = \frac{N - n}{2} \]

Spot market expected demand for water to be used in the agricultural sector is given by solving (6). Spot market in water clears when expected demand for water equals the expected supply of water:

\[ E(Demand(Spot)) = (N - n) \cdot \left(\frac{p}{z \cdot A \cdot \gamma \cdot L^{1-r}}\right)^{\frac{1}{\gamma - 1}} - G/2 + p^{-a} - \frac{n}{2} \]

Equation (20) would give \( P \) as the market clearing price of water. Solving (13) we get the market clearing condition in the agricultural output sector:
\[(N - n) \cdot A \cdot L^{1-\gamma} \cdot (\frac{p}{z \cdot A \cdot \gamma \cdot L^{1-\gamma}}) \gamma + n \cdot A \cdot L^{1-\gamma} \cdot (G / 2)^\gamma = z^{-\beta}\]

Finally, the market clearing condition between the spot and options market is given by:

\[E(\pi(\text{spot})) = E(\pi(\text{Options})) \Rightarrow\]

\[A \cdot L^{1-\gamma} \cdot z \cdot (\frac{p}{z \cdot A \cdot \gamma \cdot L^{1-\gamma}})^{\gamma - 1} - r \cdot L - \frac{u}{2} - d \cdot G / 2 + p \cdot (\frac{1}{2} - (\frac{p}{z \cdot A \cdot \gamma \cdot L^{1-\gamma}})^{\gamma - 1} + G / 2) =\]

\[= h + z \cdot A \cdot L^{1-\gamma} \cdot (G / 2)^\gamma - r \cdot L - \frac{u}{2} - d \cdot G / 2 + \frac{K}{2}\]

Solution of (20)-(22) simultaneously would yield the prices and the distribution of farmers between the two markets. Model parameters and results are presented in Table 1.
Table 1: Scenario Results

<table>
<thead>
<tr>
<th>Case</th>
<th>Parameter Values Different from the Base Case</th>
<th>Price of Water in the Spot Market ( (p) )</th>
<th>Price of Agricultural Commodity ( (z) )</th>
<th>Number of Farmers in the Options Market ( (n) )</th>
<th>Total Spot Market Supply of Water</th>
<th>Total Spot Market Agricultural Demand of Water</th>
<th>Total Spot Market Urban Demand for Water</th>
<th>Total Output in the Spot Market</th>
<th>Total Output in the Options Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>*</td>
<td>.0684</td>
<td>.161</td>
<td>30.1</td>
<td>9.95</td>
<td>23.04</td>
<td>-13.1</td>
<td>13.64</td>
<td>1.89</td>
</tr>
<tr>
<td>Case 1</td>
<td>( N = 45 )</td>
<td>.076</td>
<td>.168</td>
<td>21.5</td>
<td>11.71</td>
<td>20.6</td>
<td>-8.88</td>
<td>13.18</td>
<td>1.35</td>
</tr>
<tr>
<td>Case 2</td>
<td>( N = 40 )</td>
<td>.088</td>
<td>.173</td>
<td>6.7</td>
<td>16.65</td>
<td>18.16</td>
<td>-1.5</td>
<td>13.42</td>
<td>.42</td>
</tr>
<tr>
<td>Case 3</td>
<td>( N = 80 )</td>
<td>.044</td>
<td>.126</td>
<td>65.11</td>
<td>7.44</td>
<td>37.8</td>
<td>-30.4</td>
<td>18.07</td>
<td>4.07</td>
</tr>
<tr>
<td>Case 4</td>
<td>( N = 80, \alpha = 1 )</td>
<td>.061</td>
<td>.151</td>
<td>64.32</td>
<td>7.84</td>
<td>23.48</td>
<td>-15.64</td>
<td>12.93</td>
<td>4.04</td>
</tr>
<tr>
<td>Case 5</td>
<td>( k = 0.05 )</td>
<td>.062</td>
<td>.175</td>
<td>40.64</td>
<td>4.68</td>
<td>23</td>
<td>-18.32</td>
<td>11.08</td>
<td>2.55</td>
</tr>
<tr>
<td>Case 6</td>
<td>( A = 0.75 )</td>
<td>.084</td>
<td>.115</td>
<td>14.36</td>
<td>17.82</td>
<td>23.14</td>
<td>-5.32</td>
<td>24.31</td>
<td>1.35</td>
</tr>
<tr>
<td>Case 7</td>
<td>( N = 60, A = 0.75 )</td>
<td>.069</td>
<td>.108</td>
<td>35.27</td>
<td>12.36</td>
<td>28.05</td>
<td>-15.68</td>
<td>25.03</td>
<td>3.33</td>
</tr>
</tbody>
</table>

*\( =>, N = 50; \gamma = \gamma; \alpha = 0.25; \beta = 1.5; L = 2; G = 0.1; A = 0.5; u = 0.01; d = 0.01; k = 0.01; \rho = 0.1; h = 0.05*