Implementing Options Markets in California
To Manage Water Supply Uncertainty

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Abstract

In California, the tremendous spatial and temporal variation in precipitation suggests that flexible contractual arrangements, such as option contracts, would increase allocative efficiency of water over time and space. Under such arrangements, a water agency pays an option premium for the right to purchase water at some point in the future, if water conditions turn out to be dry. The premium represents the value of the flexibility gained by the buyer from postponing its decision whether to purchase water. In California, the seller of existing option arrangements is often an agricultural producer who can fallow land, in the event that a water option is exercised.

In this simulation-optimization approach, we seek to determine the value of transferring water uncertainty from one party to another at several locations in California, given current water prices and the spatial and temporal distribution of water year types in the state. (Preliminary analysis covers northern California; future analysis will incorporate southern California.) We analyze within a mathematical programming framework whether increased trading among water agencies across time as well as space would result in significant gains from trade. We use output from CALVIN, an economic-engineering optimization model of the California water system which runs the current configuration of the California water system over historical hydrological conditions, to generate water's imputed price at different locations during different seasons. We also explore reasons why previous theoretical calculations of option value in the western United States have far exceeded option premia on existing bilateral contracts.

Keywords: water markets, state-contingent outcomes, options
JEL: Q25

I. Introduction

As water value increases, institutional mechanisms evolve to reflect increased scarcity of water. One such institutional mechanism is water markets, which have significantly improved the allocation of water. (See, for example, Hearne and Easter (1987) and Howitt (1994), who have calculated gains from trade associated with water market implementation in Chile and California, respectively.) In California, the tremendous spatial and temporal variation in precipitation suggests that flexible arrangements for trading water, such as option contracts, would even further increase allocative efficiency of water over time and space. Under such arrangements, a water agency pays an option premium for the right to purchase water at some point in the future, if water conditions turn out to be dry. The premium represents the value of the flexibility gained by the buyer from postponing its decision whether to purchase water. In California, the seller of existing option arrangements is often an agricultural producer who can fallow land, in the event that the water option is exercised.

Although the variation in precipitation suggests that option agreements would benefit water users, water options trading in California has been limited. A well-functioning options market in California would help make better use of existing storage, provide an alternative to additional storage construction, and reduce the supply-side risks inherent in the California water system. In this analysis we seek to determine the likely value of transferring water uncertainty from one party to another at several locations in California, using current water prices and the spatial and temporal distribution of water year types in the state. We prepare the ground for future research on calculating the potential gains from trade associated with widespread adoption of option agreements, and explore reasons why water options have not been more fully utilized.

This paper lays the groundwork for calculating water option value in California within a simulation-optimization framework. We first describe existing option arrangements. However, we describe a few of them, and offer them as a benchmark for comparing theoretical option value, once we have identified what the theoretical value of a water option is at various locations throughout the state. One key piece of information required to determine option value is a distribution of the price of the underlying water resource. Unfortunately, the history of water transfers in California is relatively short, and the prices we do observe for short-term transfers are often distorted by administratively set prices and long-term, multi-dimensional contractual arrangements.

To circumvent this problem, we employ a simulation-optimization framework to construct a distribution of water prices reflecting the true economic value of water. The model determines water prices by allocating water to agricultural and urban water agencies according to economic demand, across 72 years of historical hydrological flow data. The resulting distribution will be used at a further data to estimate water option value at various locations in California.

Background

In the fall of 1994, the California Department of Water Resources implemented an options bank (Jercich, 1997). Option contracts purchased from willing sellers through the bank allowed wholesale water purchasers to manage their supply risk in the event that 1995 was as dry as the previous year had been. Fourteen water agencies purchased options to buy water, which could be exercised any time before May 1995. The options were purchased for $3.50/acre-foot, with negotiated exercise prices between $36.50 and $41.50/acre-foot. After the option contracts were signed, late season rainfall and snow-pack changed the water year from dry to wet. Consequently, no water agency that had bought an option exercised its purchase rights. However, the willingness of water agencies to purchase options through the bank demonstrated that options can be a cost-effective way for water agencies to prepare for potential drought.[1]

Since the 1994-95 options bank, water agencies in California have implemented several long-term bilateral option agreements. Most notable among recent deals is the 2003 sale of water by the Imperial Irrigation District to the San Diego County Water Authority, a contract which may endure for as long as 75 years. Metropolitan Water District of Southern California and Palo Verde Irrigation District have signed a 35-year, long-term option agreement, whereby Metropolitan may call from 25,000 to 111,000 acre-feet each year. To participate, Palo Verde receives a one-time fee of $3,170 for each acre participating in the program, and $600 for each acre that is fallowed under the program (MWD, 2006). In preparation for this long-term arrangement, Metropolitan and Palo Verde entered into a two-year pilot program in 1992. Under the pilot program, Metropolitan received the right to claim nearly 100,000 acre-feet. Watters (1995) calculated the water price for the short-term pilot program to be approximately $140/acre-foot. Under the terms of the pilot program agreement, Metropolitan could call the water in five or six years. Using the Cox, Ross and Rubinstein method for approximating the Black-Scholes option pricing model, Watters determined the imputed

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[1] Howitt (1998) notes that the DWR options bank had low transaction costs, because any water transferred through the bank would have been based on measurable reductions in use rather than on permanent rights that would have been difficult to adjudicate.

call price of the water to by $15.70 for the six-year option and $9.40 for the 5-year option.

Further, Metropolitan Water District serving Los Angeles has option agreements in place with 11 water districts in the Sacramento Valley, for 167,000 acre-feet. The terms on the MWD option contracts are identical; MWD pays a premium of $10/acre-foot. The exercise price is $115/acre-foot in extremely dry years and $95/acre-foot otherwise. There is also a $5/acre-foot surcharge for resolution of third party impact issues. In 2003, MWD exercised its option to purchase 120,000 acre-feet (Quinn, 2004). In 2006, it did not.

Thus, option agreements provide an additional mechanism for water agencies to manage the risk of water supply uncertainty. They may also act as a substitute to the use of more expensive methods of meeting contractual obligations. For example, the Bureau of Reclamation is exploring the use of forbearance agreements with its water contractors on the Lower Colorado River, as a relatively cost-effective way to meet its treaty obligations with Mexico in dry years (Kleinman, 2006).

The benefits of implementing dry-year contingency markets have been calculated in other parts of the western United States. Hamilton, Whittlesey and Halverson (1989) determined that forming interruptible power markets, so that agricultural users in the Pacific Northwest could leave water in the river for hydroelectric generation during dry years, would increase the value of water nine times over. Clark and Abt (1993) also found through simulation that implementing water options in northern Colorado would be less expensive than water rights purchases and new infrastructure investment. Michelsen and Young (1993) came to the same conclusion, noting that option contracts on irrigation water rights in Colorado are a relatively inexpensive form of drought insurance for urban water agencies. Our model addresses these aspects of option value and whether, given the state's existing water system and hydrology, intra-year or inter-year options would generate greater gains from trade in California.

Watters (1995) calculated the efficient option prices predicted by the binomial and Black-Scholes option pricing models for three bilateral contracts in southern California and determined that the contracts were sensibly priced. Her analysis suggests a role for wider use of options contracts to manage risk among water traders. As Watters only had access to historical prices of water transactions in California, she was unable to use her results to determine whether a much more active options market would benefit California, as we are able to do. More recently, Villinski (2003) used a finite-horizon, discrete-time, stochastic dynamic programming methodology for valuing multiple-exercise option contracts in the Texas Lower Rio Grande. Our analysis will have the benefit of a longer data series (72 years of monthly simulated data rather than 18 months of actual data) and option price predictions across all sectors of the economy (rather than trades solely between irrigators).

Model

Cox, Ross, and Rubinstein (1979) derive a binomial option pricing model which approximates the Black-Scholes option price model in the limit. Watters (1995) follows their approach, using existing bilateral option agreements in California as the input into her model. We also follow Cox, Ross and Rubinstein, though rather than relying on existing agreements, of which there are not many, we use the simulation-optimization model described below to generate a distribution of water prices from which to calculate option prices.

To price a call option for California water, we need the underlying water price, the variance of the rate of return on water, the exercise price of the option, the time to maturity of the option, and the risk-free interest rate. The simulation-optimization model provides a vector of water prices from which to make a theoretical calculation of option value in future analysis.

The generalized network flow optimization framework of CALVIN allocates water to agricultural and urban users so as to minimize economic losses, subject to flow and balance constraints on the network (Draper, et al., 2003). CALVIN runs the current configuration of the California water system and estimation of current economic demand functions through 72 years of historical hydrological conditions. CALVIN is the first engineering model of the California water system to utilize economic demand functions to allocate water among users.

However, CALVIN makes storage, flow and use decisions with perfect foresight of the entire 72-year hydrological cycle. Thus, the resulting storage patterns are only optimal in the presence of full knowledge of future water conditions. Our model addresses this shortcoming by optimizing annual allocations of the current California water system on a monthly time step over historical hydrological conditions. This model maximizes agricultural and urban surplus subject to water transport costs and a constraint on the carryover value of water from one year to the next. The challenge is to infer from observed behavior for known water year conditions how allocation on the network will occur over a variety of water years, when future water supply is uncertain. We use self-calibration. The methodology, as described in Howitt (1998), is as follows.

The model allocates flows over the network, using observed deliveries and inflows, to generate the economic values which underlie the observed decisions. We use several years for this initial calibration stage, in order to capture behavior over a variety of water year types. In this analysis, observed behavior is from a base run of the CALVIN model. These values are used to generate a calibrated cost function, which is unconstrained yet still reflects the values which underlie the observed decisions. This cost function, or forcing function, represents factors that affect behavior but that have not been specifically quantified in the underlying engineering model. Such factors may include risk, cost and benefit function nonlinearities, and operating constraints.

Finally, the model uses this unconstrained, calibrated cost function to run existing demands through a longer series of water years. The resulting limited foresight model generates shadow values on the reservoirs which indicate water's imputed value at different locations during different seasons in California.

Thus far, the model extends from the three northernmost reservoirs in California (Lake Shasta, Whiskeytown Lake, Clair Engle Lake) to the floor of the Sacramento Valley. In addition to the three surface water reservoirs, the model includes a groundwater reservoir, agricultural and urban demand. The model currently uses hydrological conditions from 1922 to 1993.

Results

In this current configuration of the model, there are two network nodes across which the economic value of flows across the node is measured. The first node, called

C3, is directly adjacent to the urban and agricultural demand centers of the region. The second node, called C5, is the southernmost node in the current configuration of the model, connecting the current model with the remainder of the California water system. The marginal values on these flows indicate the economic value associated with one additional unit of water passing across these points. At the first node, C3, there is no economic value associated with moving additional water across this node. Given the functions of agricultural and urban demand currently utilized in the model, the marginal value of water is effectively zero. At the second node, C5, there is considerable economic value associated with additional flows. This result is unsurprising, given the strong demand for water downstream from C5, in the south of California.

Conclusion/Discussion

Simulated flows and deliveries from CALVIN, historical hydrological data, and data on current agricultural and urban demands allow us to indicate the value of water options with some accuracy. While the existing simplified model makes clear the principle of calculating water value using these simulation methods, we are ultimately interested in using these methods to provide policymakers in California with an indication of the locational and seasonal value of water options. Thus, in the future, we will expand our model of northern California to a full model of the California water system. We will also compare these simulated results to theoretical calculations of option value.

Third, in the future, we will also discuss why previous theoretical calculations of option value in the western United States have far exceeded option premia on existing bilateral contracts. Actual option value will be lower than the theoretical calculation in the presence of other mechanisms for allocating water efficiently over time, such as storage, groundwater substitution, and spot and exchange contracts. However, avoidable transaction costs may also explain why past calculations of gains from trade associated with option markets have been significantly higher than option valuations negotiated in existing contracts.

Finally, an interesting extension to the current analysis would be an exploration of the benefits to different water user groups of adopting options. For example, the Environmental Water Account allows state fishery managers to lease water in real-time for the protection of salmon runs and habitat, in response to changes in hydrological and environmental conditions. Water options might potentially provide these fishery managers with even greater flexibility?

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