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Water price dynamics, water derivatives and general equilibrium modelling

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Abstract: The Council of Australian Government's (COAG) water reforms of 1994 opened a new era in the irrigated agriculture market. After the separation of land and water rights, water became a tradable commodity. In the past, the value of water was significantly underestimated, which led to irrational ways of using this valuable natural resource. The water tariffs were not related to the marginal values of crops grown by irrigators, which caused unsustainable consumption of water, especially during the drought years. The major aim of the COAG reforms was to enable a proper market value for water and to re-allocate water consumption to more economically valuable crops.

In 2004-2005, the total water traded in Australia was 1300 GL with 502 GL of Victoria water traded, i.e. about 10% of overall use. Given the severity of drought conditions throughout Australia in recent years, and the uncertainty of whether this is a permanent climate change, water price and supply is a critical issue for farmers. In their present stage of development, markets offer farmers little information about long-term prices and quantities, and limited opportunity for avoiding disastrous water shortfalls or unaffordable water prices beyond the current season. Even for the current season, the present trading system still leaves farmers facing unhedgable uncertainty concerning water prices and quantities. This uncertainty appears to be increasing. For example, in the Goulburn system, managers aim to provide full allocations for 96 years out of 100. Yet three times in the past decade, in 2002-03, 2006-07 and 2007-08, allocations in Goulburn have been below 100%. In response, with growing concerns over changes in rainfall patterns, there may be a growing bias among irrigators against the production of water-dependent perennial commodities which require secure water allocations. Moreover, the annual values for these prices and quantities are not enough for effective risk management and farmers are keen to have this information with more detailed temporal resolution, on a fortnightly or weekly basis. The analysis of historic records of water prices over 5 irrigation seasons in the Goulburn – Murray system, suggests that jumps are a distinctive feature of the water price series, and to account for these jumps, the jump diffusion modelling approach is appropriate. A Brownian motion plus Compound Poisson process is proposed to model the water price dynamics. The simulation result suggests that the stylised water price dynamics can be reproduced by the model. The concept of integration of a modified computable general equilibrium (CGE) model TERM-H2O, with a weekly/fortnightly stochastic model for water prices is introduced.

As the water market is gradually maturing and water continues to be a valuable commodity, some new assets existing on other economic markets can be introduced to the water market. Options are one type of very important assets in the financial market, which allow significant increases in the hedging ability of their users. In addition, options also provide greater price certainty to their users and allow them to manage their financial risks in a more efficient manner. This work discusses and conceptualises the possibility of introducing options into the water market. Some important restrictions for water options are outlined: a) the option trading will be only initiated after a short initial period of water trading has passed; b) options are available only for a specified season; c) weekly pool water prices are not impacted by the actual water allocation, i.e. they are purely stochastic and d) as the water price tends to drop sharply towards the end of a season, the option's maturity date is restricted to much earlier than the seasonal ending date. The model of option pricing for the water market is developed and the potential impacts on the underlying water market and market risks are discussed. Taking into account these restrictions and some classical assumptions from financial mathematics (zero transaction cost, arbitrage opportunities, no storage costs etc.) a model for European options for water was developed. The potential impacts, positive as well as negative, of the introduction of water options to the market are discussed.

Keywords: *Irrigation water, water trading, CGE modeling, water options*

1. INTRODUCTION

Multi-billions of dollars worth of irrigated lands in Victoria and New South Wales have been severely affected by a series of droughts, which were especially serious during the 2006/07 and 2007/8 seasons, and are expected to continue well into the foreseeable future. The agricultural industry in Australia is a very risk-prone business. The major risk factor is associated with the high variation of climatic conditions which leads to water abundant years, often associated with floods, regularly alternating with extreme long-lasting droughts. Climatologists have many reasons to believe that the climate variability will get considerably larger in future. The duration and severity of droughts will also increase driven by the global change of climate. The agriculture industry of Australia will face more risks in future and new measures of risk management and adaptations are very topical at present. The Garnaut Report (2008) indicates that under no mitigation measures it is expected a 92% decline in irrigated agricultural production in the Basin, affecting dairy, fruit, vegetables, and grains.

The problem of risk management is an especially important problem for regions of irrigated agriculture, such as the Goulburn-Murray irrigation district in Northern Victoria or the Murray-Murrumbidgee catchment in New South Wales, where security of water supply depends not only on current climatic conditions but on many additional factors such as the previous years' precipitation level, current water allocation, water price dynamics and the current water price. Farmers in such regions tend to grow crops with high marginal value per unit volume of water, very often perennial crops, whose survival depends very much on the level of water supply security which makes local industry very vulnerable to risks associated with climatic variations. A closely related issue, which also highlights the importance of risk management in the agricultural business, is the maturing of the Australian water markets. The current system of water trading in Victoria works as follows: Each farm in an irrigation region, for example the Goulburn valley, has a historically determined water entitlement. At the beginning of each irrigation season, say September, the water authority announces what fraction of the entitlement they anticipate will be available for the season. The determination of this fraction depends mainly on the level of water reserves. The fraction may be raised during the season if rainfalls are favourable and lowered if they are not. Throughout each season, farmers can sell their water rights to other farmers through a water market which is organised by the local water authorities (The Goulburn-Murray Waters in the Goulburn-Murray irrigation region).

The volume of water traded in Northern Victoria has significantly increased over the last decade. Water trading is now an important managerial problem each irrigator in the region is faced with. What is the better choice: to use allocated water to irrigate crops or to sell water allocations to another market player? If a farmer sells too much water without leaving any reserves for irrigation he faces the risk of loosing his crops, especially perennial ones, if precipitation level remains low. If he stores too much entitlements and rainfall level is high over the season he looses the possible water revenue. Determination of more efficient water trading strategies for farmers is one of the challenging research problems. This objective has been realized through the development and implementation of TERM-H20, a computable general equilibrium (CGE) model (Dixon *et al.*, 2008). The advantage of applying CGE models (Dixon *et al.*, 1992) for water trading prediction has two main aspects. Firstly, all partial equilibrium models are based on a single objective function (OF) optimisation. The typical OFs used are revenue or profit and the assumption of constant prices of agricultural commodities is applied. This assumption is not valid for such large economies as Goulburn-Murray irrigation district, nor on the macroeconomic scale. In CGE models all commodity prices can be treated as endogenous variables. Secondly, CGE models use as a system input the input-output tables provided by the ABS. Similarly, their output can be easily represented in the form of ABS data. This makes CGE models the most convenient tool for keeping account of trading water and water used for irrigation.

To keep irrigated water included in the water account, the CGE model should be combined with a water allocation model; details of this integration process are presented in the accompanying paper (Fernandes and Schreider, 2009). The TERM-H2O model can predict water prices and quantities bought and sold, and access the macroeconomic impacts of water trading. However, this model is implemented with an annual time step and is unable to trace the water price dynamic within the irrigation season. This paper provides a model for predicting a water prices on the weekly basis using the theory of stochastic processes with jumps.

2. WATER PRICES AS A STOCHASTIC PROCESS WITH JUMPS

2.1 Water market in Victoria

Watermove is a water exchange operated by Goulburn-Murray Water and it acts as an intermediate to facilitate water trading by providing market information for people seeking to trade water. It conducts both temporary and permanent trading throughout Victoria and conducts water exchanges for all water trading zones. Trading zones (total of six in the state) defines the physical boundaries to, from or within which water may be traded in Victoria. Thus, Watermove determines a pool price for each trading zone where trade can occur. Successful sellers will receive a price greater than or equal to their offer price and successful buyers will receive a price less than or equal to their offer price. In most locations, water rights and diversion licences can be traded permanently and temporarily. In some locations and with some limitations, sales water can be traded temporarily. Sales water is the volume allocations above water rights and diversion licences. A pool price is calculated by Watermove for all trading zones where trade can occur. All successful sellers and buyers within a trading zone receive the same pool price. Sellers are considered on an ascending price basis. The lowest price seller within a trading zone is the first seller eligible to trade. Buyers are considered on a descending price basis. The highest price buyer within a trading zone is the first buyer eligible to trade. The pool price for a trading zone is greater than or equal to the sell price offered by successful sellers and less than or equal to the buy price offered by successful buyers.

2.2 Why jumps?

In order to set up a conceptual framework for pricing water price based options, it is essential to understand the stylised features embedded in water price series. Thus, before we can make realistic assumptions with regard to the water price dynamics, we need to identify these stylised features and understand the behaviour of the water price dynamics. For the purpose of this study, we limit ourselves to Temporary Water Right/Diversion Licence in 1A Greater Goulburn Victoria, as its pool water price series and their corresponding actual water allocations are readily available. Figures 1 and 2 show the weekly pool water prices and the actual water allocations for the irrigation periods 2005/06 (relatively wet) and 2006/07 (severely dry).

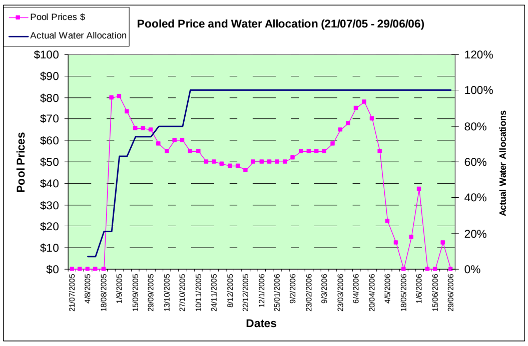

Figure 1: Pool water price and water allocation for the period 21/07/05 – 29/06/06.

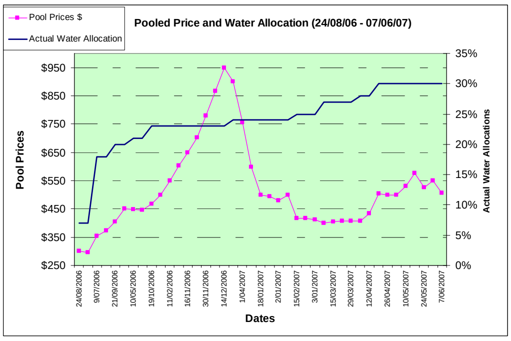

Figure 2: Pool water price and water allocation for the period 24/08/06 – 07/06/07.

Descriptive statistics and histograms were analysed for the price series for all five irrigation seasons starting from 2002/03. In addition, the Kruskal – Wallis ANOVA and Median test was performed to determine whether these five price series are from the same distribution with the same median. The analysis of the water price data identified four stylised features:

1. Weekly pool water prices tend to be at a level specific to a particular season;
2. The level of water allocation has an impact on the weekly pool water price levels, but this impact is not very strong: prices can move up and down when allocation level is constant;
3. The weekly pool water price series show upward and downward jumps;
4. The pool water prices tend to drop towards the end of the season.

To see the first feature, compare the pool water price levels in Figure 1 and Figure 2. The pool water prices for these two consecutive seasons are very different: the average values differ by almost tenfold. This finding is also confirmed by the formal Kruskal – Wallis ANOVA and median test, which suggests that these five pool water price series are from different distributions. To see whether water allocation has any impact on water price levels, we check Figure 1 first: the weekly pool water prices vary from around $80 to $12 when the water allocation is between 21% to 100%, with 100% water allocation counting for most of the season. From Figure 2, it can be seen that the weekly pool water prices vary from around $950 to $300 when the water allocation is between 7% to 27%. Thus, there is a tendency for higher water price levels when the water allocation is low. To confirm that the water price series have upward and downward jumps, we look at the following examples: from Figure 2, it can be seen that the weekly pool water price drops from $900

(21/12/06) to \$755 (04/01/07), a 16% drop in price in one week, and drops further to \$597.50 (11/01/07) the following week (an over 20% drop in price). Thus, our conclusion is that water price series contain jumps.

The fourth feature that the pool price tends to drop towards the end of the season is obvious and can be seen from Figures 1 and 2. This could be due to the ending of an irrigation season in Victoria. The five water price series available for analysis show that the water prices tend to have seasonal differences, are impacted to some degree by actual water allocation (especially when the water allocation reaches 100% there is a tendency for water prices to follow a falling trend, with the exception of the trend shown in Figure 1 for the severe drought of 2006/07) and have upward and downward jumps. In addition, the pool water prices tend to drop sharply towards the end of the season. Among the four stylised features shown in the pool water price series, the most important feature is the price jumps in the water price series. The other three features, namely different price levels, impact of actual water allocation and tendency to drop in price towards the end of the season, can be dealt with separately. However the jump feature is embedded in the pool water prices and can not be assumed away. This feature requires special treatment when we choose a stochastic process to represent the pool water price dynamics. Therefore, the stochastic process, which models water price dynamics, must be able to account for these jumps.

2.3 Model for weekly prices of traded water

Weekly water price series will be modelled as stochastic processes for irrigation seasons. Water prices in the southern Murray-Darling Basin for five irrigation seasons, starting at 2002-03, showed price jumps. Thus, the jump diffusion modelling approach is appropriate. A Brownian motion plus Compound Poisson process with jumps to model the water price dynamics is proposed. This takes the form:

$$\begin{aligned} dS(t) &= \alpha S(t)dt + \sigma S(t)dW(t) + S(t\text{-})d(Q(t) - \beta\lambda t) \\ &= (\alpha - \beta\lambda)S(t)dt + \sigma S(t)dW(t) + S(t\text{-})dQ(t) \end{aligned} \tag{1}$$

Here S(t) is the water price in period t, W(t) is the Brownian motion and Q(t) is the compound Poisson process. The parameter λ is the compound intensity of the M Poisson processes, $\beta = E(Y_i)$ is the average size of jumps Y_i. The mean rate of return on the pool water price is α, and σ is the standard deviation of the Brownian motion process. The solution has been obtained by Cui and Schreider (2009) using methods described in Shreve, (2004).

Under the original probability measure P, the mean rate of return on the pool water price is α. Y_i is the random jump size variable taking values of $-1<y_1< y_2 <\ldots<y_m$, with probabilities $p_1, p_2,\ldots p_m$. This assumption guarantees that although the pool water price can jump down, it can not jump from a positive to a negative value or to zero. This is simply because Y_i+1 is always greater than zero based on the above assumption.

The solution to (1) is

$$S(t) = S(0)\exp\{\sigma W(t) + (\alpha - \beta\lambda - \frac{1}{2}\sigma^2)t\}\prod_{i=1}^{N(t)}(Y_i+1) \tag{2}$$

Similarly, under the risk neutral measure $\tilde{P}$, the water price dynamics can be described as

$$S(t) = S(0)\exp\{\sigma \tilde{W}(t) + (r - \tilde{\beta}\tilde{\lambda} - \frac{1}{2}\sigma^2)t\}\prod_{i=1}^{N(t)}(Y_i+1) \tag{3}$$

Figure 3 shows five simulated forty weekly pool water price series based on the following specifications: S(0) = \$100, $\alpha = 0.05$, $\beta = 0.10$, $\lambda = 0.125$ and $\sigma = 0.20$. The sizes of five jumps Y_i are -0.20, 0.10, 0.15, 0.20 and 0.25, respectively. They are assumed to occur with equal probabilities p_i of 0.20.

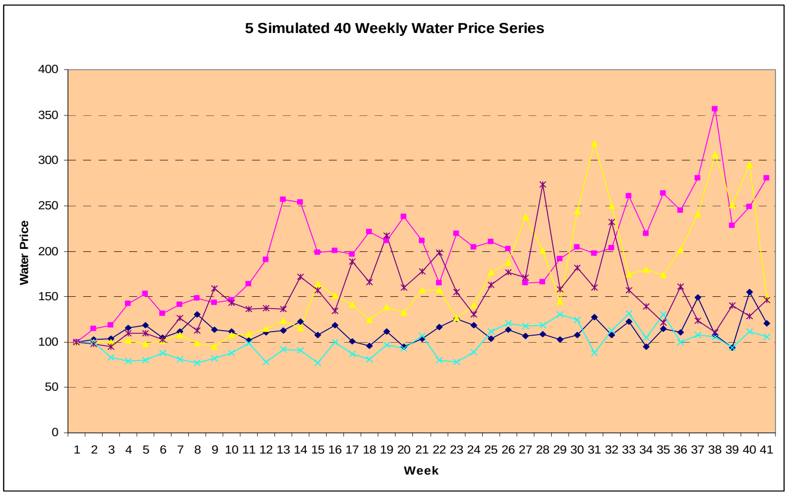

Figure 3: Five simulated pool water price ($/ML) series; the model parameters for them are specified above.

3. WATER DERIVATIVES: MODEL FOR EUROPEAN OPTIONS FOR WATER

The theory of derivatives is concerned with explaining the emergence of derivative markets, the benefits that these markets confer on the economy and the prices at which derivative products are traded. As defined by Hull (2006), a derivative is “a financial instrument whose value depends on (or derives from) the values of other, more basic underlying variables. Very often the variables underlying derivatives are the prices of traded assets”. Typical derivatives include forward contracts, futures and options. Both forward and futures contracts represent agreements to buy/sell some underlying asset in the future for a specified price. Options are a type of derivative that gives the holder the right, but not the obligation, to buy or sell the underlying asset at given date (expiry or exercise date) for given (exercise) price. In this case options are called European; if option holder can exercise it any date before expiry date they are called American.

In order to develop a conceptual framework to price options based on the water prices and account for the observed stylised features, we specify four key restrictions:

1. As weekly water prices tend to be at a level specific to a particular season, we assume that the option trading will be only initiated after a short initial period of water trading has passed. The reason for this restriction is that after a few weeks of water trading, the option maker will have a fairly good idea of what the strike price might be reasonable for the option.
2. Due to the significant water price differences observed between consecutive seasons, we only make options available for a specified season. This implies that we will not price options that have a maturity time that covers two trading seasons.
3. We will assume that the weekly pool water prices are not impacted by the actual water allocation. That is, the stochastic process that the water price follows is independent of the water allocation process.
4. As the water price tends to drop sharply towards the end of a season, we restrict the option’s maturity date to much earlier than the seasonal ending date. By this restriction, we can eliminate the impact of knowing the water price pattern on the option price.

Under these four key restrictions, we can set up our conceptual framework for water price options. Some classical assumptions underlying our option pricing model should be made:

1. There are no transaction costs, taxes and short sale restrictions;
2. There are no arbitrage opportunities;
3. The market is efficient and the water prices reflect all available information on the market;
4. The risk free rate is constant within the life of the option, and
5. There are no storage costs and convenience yield.

The European call price with the pool water price determined by (2) can be shown as follows:

$$c(t, x) = \sum_{j=0}^{\infty} \exp(-\tilde{\lambda}(T - t)) \frac{\tilde{\lambda}^{j}(T-t)^{j}}{j!} \tilde{E}(BSM(T - t, x\exp(-\tilde{\beta}\tilde{\lambda}(T - t))\prod_{i=1}^{j}(Y_i+1))) \quad (4)$$

Here BSM is the Black-Scholes-Merton European call price formula (Sreve, 2004). The expectation operator is there due to the fact that the jump sizes are still random. We omit the proofs of these equations and refer readers to Cui and Schreider (2009).

4. POTENTIAL IMPACTS ON WATER MARKET

The introduction of the options market for the water trades will have some impact on the underlying water market. However, as the actual options market is yet to be established, we can only hypothesise its potential impact on the water market. Introducing water options is likely to provide farmers with additional income, more choices on trading their water allocation and water price certainty. A well known benefit of option trading is the leverage effect: for a fraction of the cost of buying the underlying asset, the option holder can create an exposure similar to that of physical ownership. Thus, farmers can benefit from the leverage effect in the following way: increase their exposure to the water market with limited capital so that they can make additional profit from favourable water price movements while minimising their potential losses. This leverage effect can generate additional income for farmers who do not want to trade in the physical water market due to limited capital resources or other constraints. For instance, a farmer may not be able to buy his water due to limited capital or some other economic reasons, but he can still buy his water allocation in the options market with limited funds to make a profit should water price move in his favour. Thus, the leverage effect is especially useful for annual crop growers who can either buy or sell their water allocation depending on the profitability of their agriculture businesses. In addition, they can defer their buy or sell decision in the physical market by holding only options. In this case, they receive a guaranteed price to sell or buy their water allocation and at the same time have the choice to only trade their options to profit without actually entering into the physical market. Therefore, the leverage effect of options trading is likely to encourage more farmers to participate in both physical and options water markets.

The options market is also beneficial to perennial crops growers such as grape and olive tree farmers. Perennial crop farmers have no choice but buy their water allocation on a yearly basis to sustain their agriculture businesses. The options market gives them the benefit of hedging away any adverse water price movement in advance and at the same time taking advantage of favourable water price movements. This will effectively reduce the cost of their business and make their agriculture business more profitable.

Although the exact impact of the introduction of water options on the water market volatility and water price levels can not be determined at present, farmers are likely to benefit from water options. Farmers can use water options as a tool to manage and secure their water exposure and profit from positive water price movement. The option formula is a very general one and one can calibrate the model to water price data to determine its parameters such as jump size and jump frequency using the maximum likelihood method. Once the model is properly calibrated, it can be used for pricing purposes. In terms of determining a proper strike price for an option, the option designer could choose a strike price that best suits farmers' risk appetite, e.g. making a lower strike price for a call to ensure the option has a higher probability of being in the money.

In our study, we have suggested that the option designer closely examines the water prices for an initial period (a few weeks) of a particular trading season to get a good feel for the possible water price level in order to determine a realistic strike price. In this paper, we have set up a conceptual framework for pricing options for water trades. Although further studies are needed to examine the exact impact of the introduction of water options on the water market, farmers are likely to benefit from water options. Farmers could use water options as a tool to manage and secure their water exposure and profit from positive water price movement. As the demand for water increases, it is expected that the need for the development of an options market for water trades will emerge.

5. DISCUSSION AND CONCLUSIONS

The model of intra-seasonal water prices is based on the formulae (2) and (3). The initial water price for a given irrigation season W(0) and values of jump in prices Y_i will be estimated by modified CGE model TERM-H20. The model in the present development is capable of computing initial water prices whereas calculation of the values of price jumps needs further development, which will allow it to be implemented on sub-annual time steps. Similarly, the number of these jumps depends on the temporal resolution of the model under development. This approach allows one to translate the stochastic series of future rainfall, which is used as an input for the TERM-H20 model, into stochastic series of weekly/fortnightly water prices. This information can be utilized for assessing the impacts of different climatic scenarios to the economy of irrigated regions and to the entire economy of the country.

The paper proposes introduction of water options to the market. This innovation can impact economy in both positive and negative ways. The benefits of the introduction of water options to the market can be summarized as follows:

- *Water price insurance for farmers* By paying a relatively small up-front fee (option price), farmers are protected against adverse water price movements in the future and still allow themselves to benefit from potential favourable water price advances. For water option holders, no matter how adverse the water price movement might be, his loss is limited to the amount he paid for his options.
- *More choices for farmers* Farmers have the choice to participate in either or both of the physical and options markets to achieve their purposes. As options are cheap compared to the price of their underlying assets, it is ideal to hold options rather than the underlying assets. By holding options, farmers could retain future water price certainty without actually trading their water allocation.
- *Advantages for perennial crops growers* The options market gives them the opportunity to hedge from any adverse changes in water prices in advance and at the same time taking advantage of favourable water price movements. This will effectively reduce the cost of their business.

The negative impacts can be outlined as follows:

- *Information gap* As farmers generally do not fully understand the risks involved in trading options, there is an information gap which would need to be filled by the government or financial intermediates.
- *Potential water price distortion* As the water trading market in Australia is not very large, and water price is determined by supply and demand, supply and demand could decrease significantly if a large proportion of farmers use the options market instead of the water trading market.
- *Potentially speculative activities* Although options can be used for hedging purposes, they can also be used for speculation and arbitrage. It is likely that speculative activities will occur given the nature of option trading. Therefore, there is a need for both government and financial institutions to set up controls to ensure that trading activities are closely monitored. This potential problem can also be minimised by restricting the access to the options market.

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