Investment in irrigation technology: an application of real options analysis

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Investment in irrigation infrastructure and technologies, particularly those that reduce on-farm water use have become a major focus of government programs both at a State and Commonwealth level. Particular attention has been given to increasing the uptake of water "saving" technologies among irrigators. The design of programs capable of achieving government objectives at least cost requires an understanding of farm level investment decisions. In this context, the influence of uncertainty on decisions to invest in irrigation technology and infrastructure is examined. The potential for uncertainty to influence investment decisions via strategies to manage risk is demonstrated using the method of real options valuation. The approach is applied to case studies of investment in evaporation mitigation technologies. It is shown that there are circumstances where uncertainty surrounding the value of water savings is significant enough to influence the decision to invest in water saving technologies. The results also demonstrate that where uncertainty exists, rates of subsidy to encourage faster uptake of these technologies need to be higher than those indicated by traditional NPV analysis. This is further exacerbated when irrigators are required to relinquish water entitlements in return for the subsidy.

Key words: investment, irrigation technology, real options, uncertainty, subsidy

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1. Introduction

Irrigators manage a production system in which the supply of water and crop water demands change within and between seasons. Over the past two decades, their concerns about water availability and security have increased in line with community interest in the environmental impacts of extractive water use. Both these points have led to increased attention and research on irrigation scheduling and a broad range of other irrigation technologies aimed at conserving water and improving productivity from agricultural water use. While the generation of new technology is part of the process of technological change, adoption is the step that allows benefits to be realised that contribute to both economic growth (Lindner 1986) and ideally improved environmental outcomes. This has culminated in a range of government programs directed towards investing in modernising irrigation technologies on-farm (eg Commonwealth Government's Water for the Future 'Sustainable Rural Water Use and Infrastructure Program; Murray Darling Basin Commission program 'The Living Murray'; Incentive Funding programs administered by Catchment Management Authorities).

The choice of investment and its timing play key parts in enabling irrigation businesses to improve their on-farm water use and maintain or improve their viability over the longer term. At the farm level, while tactical decisions drive short term profitability, it is the larger strategic investments have the greatest potential to affect long term business viability, in either a negative or positive way. As such, for those with an interest in technology adoption, understanding the way irrigators approach these decisions is important. Studies of investment behaviour have demonstrated it is common for businesses to delay their investment beyond the point at which traditional investment analysis using discounted cashflow methods, would advise (see McDonald 1998; Pike 1996 and Dixit 1992). In agriculture such observed delays in investment have lead to questions about perceived "slow" rates of adoption and likely impediments in terms of the characteristics of farmers and of technologies, to explain this (e.g. Pannell, Marshall, Barr, Curtis, Vanclay and Wilkinson 2006; Lindner 1986; Cary, Barr and Web 2002; Stirzaker 2006). Uncertainty about future returns and high upfront costs are commonly listed impediments to adoption in agriculture because of the potential losses if future returns turn out to be lower than expected. Despite this there has been limited investigation on how to incorporate these findings into relevant decision techniques that producers can use to manage risk (Copeland and Antikarov 2003).

Against this background of private investment decisions, government policy has recently made available funds for on-farm modernisation of irrigation infrastructure, to hasten the uptake of water efficient irrigation technologies. The existence of such programs implies an impatience with the rate of investment currently taking place in the irrigation industry, and also that there are net social benefits for the broader community from governments making investments to achieve higher levels of adoption. To reconcile the pace and rate of adoption in the irrigation industry with community expectations of the level of investment "desirable", there is a need to understand irrigators adoption decisions, particularly with respect to how they approach their investment decisions to manage risk. Strategies to delay investment until a hurdle or trigger point is reached can be a legitimate risk management strategy

that may even be associated with positive social outcomes (e.g. Copeland and Antikarov 2003; McDonald 1998; Dixit 1992; Rosenburg 1976).

In this paper, a framework is developed to examine technology investments where a reduction in water loss is the primary benefit. Two evaporation mitigation technologies are used as case studies: chemical monolayers and impermeable covers for on-farm storages. The extent to which uncertainty in water prices affects the timing of these investments and the rate of subsidy required to increase uptake is examined. Real options valuation was selected as the capital budgeting technique because it extends the traditional NPV approach specifically to account for uncertainty, flexibility and irreversibility in investment decision making (Dixit and Pindyck 1994). The framework addresses these aspects of an investment decision by valuing the option to invest now compared with investing at a later stage (McDonald and Siegel 1986).

This study examines the proposition that an irrigator's investment behaviour reflects the uncertainty of net returns from an investment, particularly where that investment is completely or partially irreversible. The results are relevant for informing irrigators about ways to manage risk. The analysis also helps inform policy makers of why farmers may find it optimal to delay investment, especially where government programs are designed to encourage adoption of key technologies associated with net social benefits. It is recognised that there are a range of economic and sociological factors that explain decisions to defer investment. The existence of option values is simply one explanatory factor of adoption decisions that is examined in this paper.

2. Decision problem

Much irrigation research focuses on improving within season decisions of agricultural water use. However, decisions about when to invest in a new technology also have an important bearing on improvements in water use efficiency and farm viability over the long term. Investments in irrigation technology are strategic decisions an irrigator makes to change or modify their production system. They are usually larger and longer term decisions as opposed to tactical decisions undertaken within a growing season in relation to the use of production inputs and crop marketing. This distinction is of interest because it is the larger investments that irrigators make that will have the most significant impact on farm viability. As observed by Pannell, Malcom and Kingwell (2000, p.76):

> "The farmers most likely to be under acute financial strain at any time are those who bought land or machinery at the wrong time or at the wrong price or who made significant and incorrect major adjustments in their farm operations. Hence, it is not the everyday or even annual risk management decisions that are likely to crucially affect farm viability. Surprisingly, the important long run, major decisions are largely ignored in the risk literature, which focuses mainly on decisions about input levels and output portfolios."

In agriculture, major long run decisions are constantly made in an environment which is almost completely dynamic. Uncertainty arises from weather and climatic conditions, commodity and input prices, policy reform and the complex biology underpinning production relationships. This situation raises questions of how a farmers' decision to invest is influenced by uncertain elements of their operating

3

environment, and the extent to which their decisions reflect strategies to manage risk. Some of these risks or uncertainties can be minimised but others are beyond an individual's control. In both cases there is value from understanding the risk or uncertainty in order to best manage the production system over time.

Traditional investment theory evaluates the present value of revenue against the present value of expenses associated with the investment. It states that if the net present value (NPV) of the project is zero or higher, the investment is viable and should go ahead. Conversely, projects with an NPV below zero should be rejected. This rule is expressed as the sum of the discounted net future cashflow as follows:

$$\sum_{t=0}^{n} \frac{(R_t - C_t)}{(1+r)^t} \geq 0$$

Where R_t is the revenue flow over time, C_t is the flow of cost over time, r is the discount rate and n is the number of time periods.

Two shortcomings in the assumptions of the discounted cashflow or NPV approach were described by Dixit and Pindyck (1994):

1. the investment is reversible, that is, costs can be completely recovered if the decision turns out to be poor; and

2. the decision to invest must be undertaken now, rather than at any stage in the future.
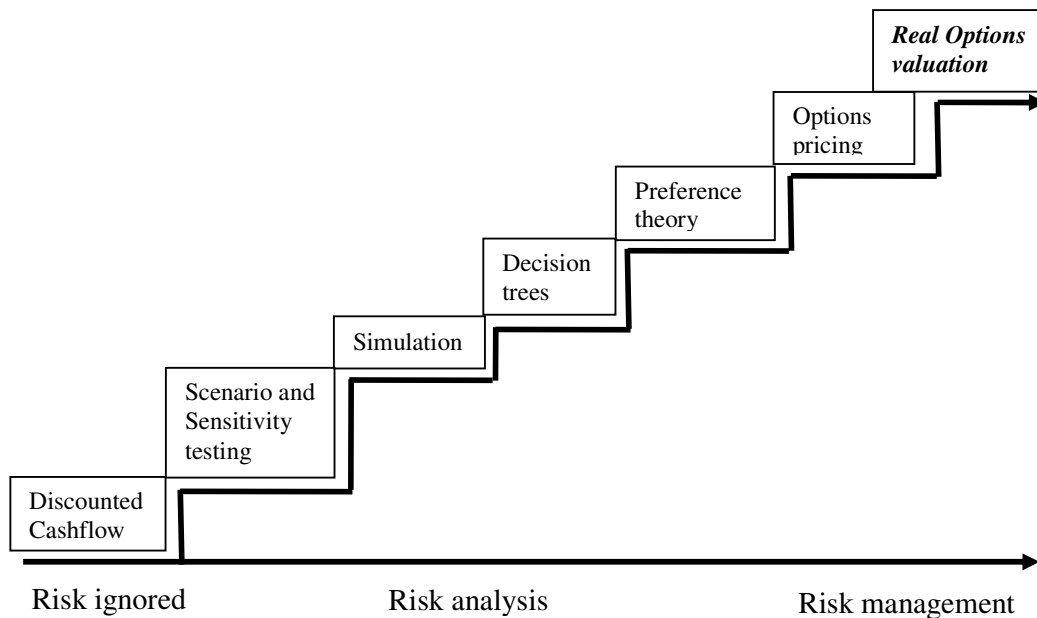
Source: Guj (2005)

Figure 1 Evolution of modelling techniques: from assumed certainty to risk analysis and stochastic models

In practice, the implications of investing over time and with uncertainty have an important influence on the process of making a financially sound investment decision. Consequently, techniques for investment analysis have evolved over time. In Figure 1

4

the progression of methods to incorporate risk into investment decision making is shown. Discounted cashflow analysis, or NPV, started off with the implicit assumption that streams of benefits and costs over time were known. Gradually, theory moved on to doing sensitivity and scenario analysis, to simulation and decision trees in order to reflect the presence of risk. These techniques involved recognising risk by identifying possible ranges of future cashflows, but provided limited insights into how to deal with risk. Revealed preference theory was used to examine utility and to show why some decisions of the same expected value were preferred to others. Then options pricing was developed by Merton, Black and Scholes in 1972 for use in financial markets to approximate the value of financial securities based on the implied volatility of returns. McDonald and Seigel (1986) were among the first to apply options pricing to tangible or real assets, hence the term "real options". This approach began to provide insights into how decision makers could manage risk, particularly downside risk.

2.1 Real options valuation

McDonald and Siegel (1986) described the options value approach to investment decisions as essentially comparing the value of investing now with the present value of investing at all possible times in the future. The difference between these two states represents a cost that is included in the traditional NPV framework. Real options analysis extends the NPV approach to provide an improved basis for making investment decisions where uncertainty, irreversibility and flexibility are present (Dixit and Pindyck 1994). The approach offers the opportunity to manage risk associated with uncertain future payoffs or costs by determining the optimal length of delay given the volatility of an investment's net return. A strategy to delay an investment means that potential profits over the period of waiting are forgone. Real options theory balances this against the value of potential losses to determine how long it is optimal to delay the investment.

A graphical representation of the investment with uncertainty problem is shown in Figure 2. The line V(P) –I shows how the value of a project varies with water price using an NPV framework. The NPV rule would advise to invest when $\tilde{P}$ is reached, the point at which the present value of returns equals (or exceeds) the present value of costs. However, the price of water fluctuates and this price may not be achieved consistently over time. As such the value of project returns will vary with fluctuations in the water price and there may be periods when the water price falls below the NPV trigger price of $\tilde{P}$. To reflect this, the volatility of water prices is used in real options valuation to estimate the curve F(P). This curve shows the value of waiting or the value of being able to avoid downside risk associated with volatility across all future water price paths. The optimal point of investment is when the value from investing now, V(P)=I, equals the value of waiting, F(P). This is shown in Figure 2 at P^* and at any price above this waiting becomes obsolete. The range p=0 to p=P^* is the range over which the benefit of waiting (losses forgone) is greater than the value of investing now (profits achieved). As such the real options investment rule would advise to delay the investment over this range of prices until P^* is reached. Estimating the difference between $\tilde{P}$ and P^* using the volatility of the project determines the hurdle rate or the optimal time to delay. The greater the uncertainty, the greater the difference between $\tilde{P}$ and P^*. It is in this way that real options

valuation can be used to provide insights into how to manage risk by advising on the optimal waiting period, or hurdle rate, before making the investment.
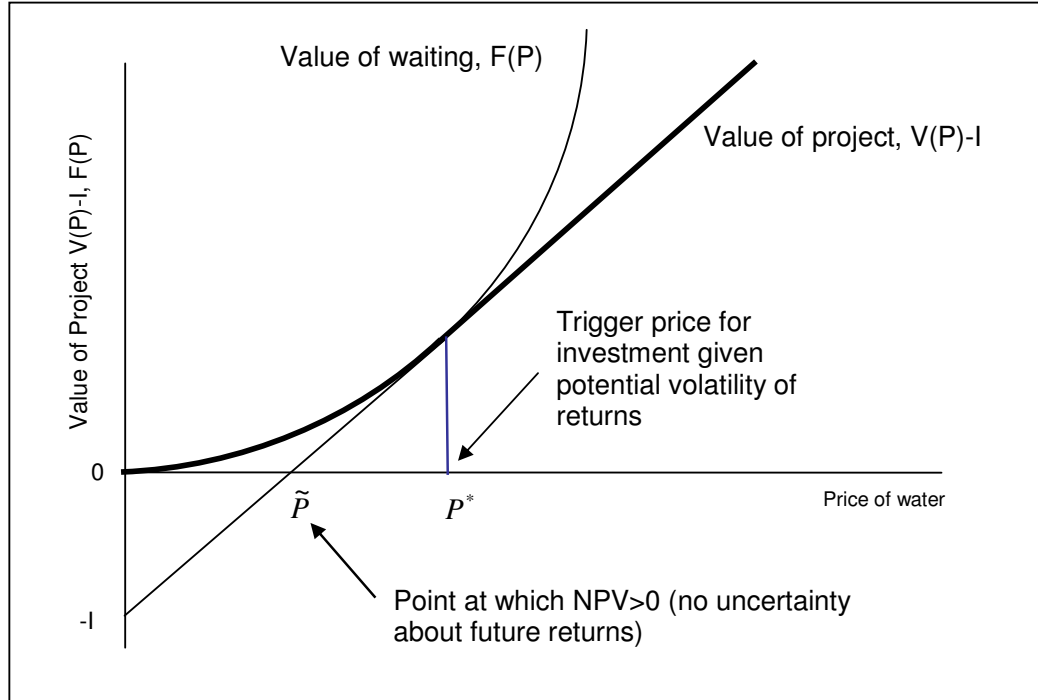
Source: Dixit and Pindyck (1994)

Figure 2 Comparison of NPV and Real Options trigger prices

A real options framework weights up the downside risk avoided by waiting with the value from investing immediately. This approach helps to ensure that the investment will only take place if the value of the project is sufficiently large to offset possible adverse future states. This is shown in Figure 2 as the difference between $\tilde{P}$ and P^*. As Dixit (1992, p.118) described, "The possibility of a downturn, and the ability to avoid an action that could thereby prove to be a mistake, is what makes waiting valuable. That is why the downside risk matters most when deciding whether to wait." In agriculture, this is particularly relevant and is why an application of real options to irrigation investment decisions is being examined within the CRC for Irrigation Futures.

There is an increasing number of agricultural studies applying a real options approach to investment analysis (see Carey and Zilberman, 2002; Odening, MuBhoff and Balmann 2005; Isik 2004; Pervis, Bogges, Moss and Holt 1995; Hafi, Heaney and Beare 2006; Tauer 2006). The approach has been used to help explain a range of observed behaviours, from why farmers may chose to delay adoption of a technology that has a positive NPV (Carey and Zilberman 2002; Hafi et al 2006) and to explanations of farm entry and exit decisions (Tauer 2006 and Seo, Segarra, Mitchell and Leatham 2008).

Applications of option value theory to agricultural investment decisions indicate uncertainty can influence the optimal timing of investments decisions. There are characteristics of irrigation investments that suggest a real options framework warrants consideration. For example, investments tend to be associated with large

6

capital costs that are often unrecoverable; managers have discretion to chose the time at which they commit to the investment; and the price of the asset (in this case water) will vary over time.

3. Real options framework

The mathematical specification of the framework is based on Dixit and Pindyck (Chapter 6, 1994) and Carey and Zilberman (2002). The evaluation framework is defined to determine at what point it is optimal to pay a sunk cost in return for a project. The value of the project changes through time according to price movements that follow a stochastic process specified by a Geometric Brownian Motion. To demonstrate the influence of uncertainty on irrigation infrastructure investment decisions two evaporation mitigation technologies are used as case studies: chemical monolayer and impermeable covers for on farm storages. The chemical monolayer can be temporarily suspended during periods when the cost of operation is higher than the value of water saved. Consequently the value of the option to suspend the technology is also represented in the solution for this technology. The real options valuation has three main elements: the stochastic process used to define future price paths; the value of the investment; and the value of the option to invest. Further detail of the model specification described below is provided in Appendix A.

The geometric Brownian motion equation was used to generate the water price realisations based on the approach used by Winston (2001), Odening et al (2005) and Dixit and Pindyck (1994) for discrete time lognormal random variables,

$$P_{(i+dt)} = P_0 e^{\left[\left(\alpha - 0.5\sigma^2\right)dt + \sigma\varepsilon_t \sqrt{dt}\right]} \tag{1}$$

where P_0 is the initial water price, $P_{(i+1)}$ is the price for water in the following period and ε_t is a standard normal random variable with mean of zero and standard deviation of 1. The remaining parameters are specified as follows: α is the expected price appreciation or drift rate; σ is the standard deviation of the water price (P) per unit of time; and dt is the change in time. The equation was tested using $\alpha = 0$ to ensure the mean price was maintained over time in the absence of appreciation.

Impermeable covers are an example of a technology for which there is no option to suspend operation or use once the investment has been made. For technologies such as these, the real options threshold price is determined by a hurdle rate, referred to by Dixit and Pindyck (1994) as the "option value multiple". The threshold price of the investment is expressed as:

$$P^* = \left(\frac{\beta_1}{\beta_1 - 1}\right)\frac{\delta}{a}\left(I + \frac{C}{r}\right) \tag{2}$$

The component, $\beta_1 / (\beta_1 - 1)$ is the option value multiple (see Appendix A), where β_1 is a constant defined as

$$\beta_1 = \frac{1}{2} - \frac{(\rho - \delta)}{\sigma^2} + \sqrt{\left[(\rho - \delta)/\sigma^2 - \frac{1}{2}\right]^2 + 2\rho/\sigma^2} > 1 \tag{3}$$

The value of β_1 is determined by the following parameters:

        σ = the standard deviation of the asset's value over time

ρ = the risk adjusted discount rate

δ = difference between the discount rate and the rate of growth in the asset value expected over time, that is, $\delta = \rho - \alpha$.

As discussed above, real options adjust the NPV rule to reflect the ability of a manager to defer an investment decision. As such, a real options approach simply modifies the conventional NPV rule to include the value of the option to invest as an opportunity cost, shown as $\beta_1 / (\beta_1 - 1)$. This is demonstrated by comparison of the NPV threshold price shown below in equation (4) with equation (2):

$$\tilde{P} = \frac{\delta}{a^*}\left(\frac{c}{r} + I\right)$$

(4)

Alternatively, as shown in Appendix A the threshold can be defined in terms of the value of the project by:

$$\hat{V}(P) = \left(\frac{\beta_1}{\beta_1 - 1}\right)\hat{I}$$

(5)

When dealing with a stochastic input price and when there is an option to suspend production if the price falls below the operating cost of the associated technology, specification of the real options threshold price is more complex. An example of this is the evaluation of the chemical monolayer technology. For example, if the cost of operating a chemical monolayer was higher than the market price for temporary water, you could chose to suspend using the monolayer. In this case the value of the project includes the value of the option to suspend operations, when price falls below the operating cost. V(P) then takes the form:

$$V(P) = B_2(Pa)^{\beta_2} + \frac{Pa}{\delta} - \frac{C}{r} \qquad \text{if } Pa \geq C, \text{ or} \qquad (6a)$$

$$V(P) = K_1(Pa)^{\beta_1} \qquad \text{if } Pa < C \qquad (6b)$$

Where the term $B_2(Pa)^{\beta_2}$ represents the value of the option to cease operating during periods where the price is below the cost (See Appendix A). This term increases as the level of uncertainty σ, increases. Where price is variable and when the operating costs can be avoided by temporarily suspending operation in periods where the price falls below this cost, the equation for the optimal investment threshold for the project is:

$$(\beta_1 - \beta_2)B_2(P^*a)^{\beta^2} + (\beta_1 - 1)\frac{P^*a}{\delta} - \beta_1(C/r + I) = 0 \qquad (7)$$

An iterative process is then used to determine the value of P*.

For technologies that save water through application efficiencies, such as switching from furrow to drip irrigation, the value of the option to suspend operations becomes irrelevant. This is because the manager would not cease to use the technology if the price of water fell below the operating cost. As such, the simpler approach using the option value multiplier can be used as per equation (2). Where water saving technologies have the option to be temporarily suspended if the price falls below the

operating costs, equation (7) should be used to determine the optimal investment threshold price for water. Both applications of real options evaluation are represented and used where appropriate in the technologies examined below.

3.1 Estimating volatility

Volatility measures the range of values an asset price may take over time compared to its mean level. For investment decisions, knowledge of volatility helps to provide an indication of the possible range of outcomes that could arise from investment in a project. This range offers an insight into risk and is one element into the process of making informed investment decisions. However, the future volatility of prices cannot be observed directly but may be estimated using average historical volatility.

In real options analysis, the volatility of the underlying asset will influence the value of the option to invest. The greater the volatility the larger the value of the option to invest. Although the price of water at any future time period will not ever be known with certainty, an assumed distribution of future prices can be estimated from historical data and current market conditions to indicate the likely range of possible prices. This information is useful for assessing and managing risk associated with an investment.

In financial literature, there are two main methods used to estimate the volatility, or standard deviation, for a set of price data: continuous and discrete. Continuous calculates the continuously compounded rate of return using the equation:

$$R_t = \ln\left(\frac{P_t}{P_{t-1}}\right) \tag{8}$$

Where P_t is today's water trade price and P_{t-1} is the trade price from the previous day's trade.

In the discrete method the return value of water prices, R_t, is calculated over discrete time periods using the equation:

$$R_t = \frac{(P_t - P_{t-1})}{P_{t-1}} \tag{9}$$

The trading of water prices is not continuous as there are times in a year where no trades occur, such as the close of the irrigation season or for short periods within the season. However, water prices can be measured at discrete points in time. To derive estimates of water price volatility, both the continuous and discrete methods were used and compared. Table 1 shows the standard deviation estimates for temporary trade prices in the MIA over the period 2005 to 2008 using both methods of calculating water price return values. Equation (10) was used to estimate the standard deviation based on historical trade price observations:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{t=1}^{n} R_t^2 - \frac{1}{n(n-1)}\left(\sum_{t=1}^{n} R_t\right)^2} \tag{10}$$

The water price data for both regions are presented graphically in appendix 1.

Table 1 Estimated standard deviations (as per cent of means) of MIA Temporary water prices: Continuous and discrete methods

	Continuous	Discrete
2005/06	12%	11%
2006/07	21%	22%
2007/08	10%	9%
All years	15%	17%

For the purposes of this study, volatility was approximately taken as the standard deviation. Temporary water prices were used rather than permanent water trade prices, because temporarily buying water is a short term substitute to invest in water saving technology (Cary and Zilberman 2006) and permanent purchases of water entitlement. Temporary water prices are more frequent and this a better measure of volatility. Due to the availability of data, temporary water trade prices were examined for the MIA and Goulburn Murray regions to provide an indication of annual standard deviation for water prices. In both regions temporary water prices varied significantly from year to year. Between 2005 and 2008, the price ranged from a peak of $1150 per ML during October of 2007, a year of extreme drought, to a low of $25 per ML in February 2006 in the MIA. Similarly, for the Goulburn Murray water prices peaked at $1054 per ML during October 2007 and a minimum pool price recorded of $12 per ML in May 2006. For the purposes of this study, MIA price volatility estimates were used as a proxy for water price variability in the case studies examined.

As shown in table 1, the standard deviation was estimated for each trade year and for the whole period 2005 to 2008 for the MIA. Estimates calculated using the continuous and discrete methods were not discernibly different. In the analysis, 20 per cent is used as the base case for water price volatility, with sensitivity testing undertaken at 10 per cent and 30 per cent.

In this study a discount rate of 7 per cent is used for the base case, with 5 and 9 per cent used for sensitivity testing. For the purposes of the case studies examined, project prices and costs are discounted at the same rate over time. As a result it is assumed that $r = \rho$. A drift term (α) of 2 per cent is applied to reflect the likelihood of an increasing capital value for water supplies over time. An increase in the capital value for water would arise from any increase in demand for available water supplies or any decline in water availability arising from climate change or changes in policy affecting water sharing arrangements with other users. Baseline parameters for the real options valuation are provided in table 2.

Table 2 Baseline parameters

$\sigma_p = 0.20$	$P_0 = \$400$ per ML
$r = 0.07$	$\rho = 0.07$
$\alpha_p = 0.02$	$\delta = \rho - \alpha_p = 0.05$

4. Results - Evaporation Mitigation Case Studies

The case studies used to examine evaporation mitigation systems were sourced from Heinrich and Schmidt (2006) in their review of Evaporation Mitigation Systems prepared for the National Program for Sustainable Irrigation.

4.1 Chemical monolayer evaporation mitigation

Heinrich and Schmidt (2006) developed a case study for the application of a chemical monolayer to storages in the Emerald district of Central Queensland, as a measure to reduce evaporative losses. The chemical monolayer technology is based on the application of a chemical substance to the surface of the water. The chemical forms a microscopic layer on the surface that acts as a barrier to reduce the rate of evaporation (Heinrich and Schmidt, 2006).

In the case study, storage size was 66.8 hectares with an estimated capacity of 2545 megalitres. The contribution of the monolayer to reducing evaporative losses is expressed in terms of an efficiency percentage that indicates the expected reduction in total evaporative losses. The efficiency of the chemical monolayer was set at 15 per cent, with sensitivity done at 10 per cent and 20 per cent levels in line with the recommended range of efficiency values for chemical monlayers (see Heinrich and Schmidt, 2006, p.26). Water savings of 86 ML per year were estimated based on the climatic conditions of the Emerald district (see http://www.readyreckoner.ncea.biz/). Estimates of the capital and operating costs of the chemical monolayer technology from Heinrich and Schmidt (2006) are shown in table 3.

Table 3 Baseline – chemical monolayer For 66.8ha storage, Emerald Qld

I = \$50 121	a* = 86 ML per year
C = \$48 091	$\widehat{I} = I + \dfrac{C}{r} = \$789\ 983$

* Estimated water savings per ha of storage surface area per year.

Based on a traditional NPV approach, the value of water per megalitre when net project returns breakeven is \$429 per ML per year (see table 4). This is the threshold price, or the point at which the project would go ahead if the water price remained constant throughout time. However, as the water price is variable there may be periods in which water price falls below the NPV critical point of \$429 per ML and at that time losses will be incurred. For investments with large capital costs, such losses could affect the longer term viability of a business.

When the uncertainty of water prices is incorporated into the decision rule, the trigger price for investment is higher than the price indicated by NPV analysis. The threshold price using real options valuation increases to \$747 per ML in the base case scenario. In this case there is a 43 per cent difference between the trigger price for investment estimated using the NPV rule compared with real options valuation. Changes in the discount rate tested between 5 and 9 per cent had a relatively small affect on the real options trigger price relative to other variables tested (see table 4).

Interestingly, in the case of chemical monolayers for evaporation mitigation, the user has the option to suspend application of the chemical monolayer in a particular season if the value of water falls below the annual maintenance and operating costs. In this case, there are lower cost sources of water available through the temporary market than by saving water using the monolayer technology. The flexibility to suspend

application of the chemical monolayer will affect on the trigger price for investment. Under the scenario examined, the losses incurred by continued use of the monolayer technology during periods of low water price, would force a higher trigger price of $920 per ML. Through the capacity to suspend operating costs, losses associated with downward movements in the water price are reduced and the trigger price of the investment declines to $747 per ML, a 23 per cent reduction in the trigger price. The potential to suspend application of the monolayer helps to offset some of the risk associated with the technology, because the user is not locked in to incurring the high operating costs each year. Consequently, the results are less sensitive to assumptions about water price volatility compared to the following case study examining impermeable covers.

Table 4 Results, Chemical Monolayer, Central Queensland (r = 0.07 as base)

Parameter	Value	Real options critical price	V(P)-I	% change from based case
σ	10 per cent (-)	$672/ML	$430 380	-10
σ	10 per cent (+)	$817/ML	$811 925	9
ρ	0.09 (+)	$764/ML	$398 331	2
ρ	0.05 (-)	$727/ML	$1 194 519	-3
I	$45 109 (-10%)	$735/ML	$604 416	-2
I	$43 000 (-30%)	$731/ML	$599 035	-2
c	$43 282 (- 10%)	$683/ML	$567 023	-9
a	57 ML (-) (Efficiency 10%)	$1 127/ML	$616 814	51
a	114 ML (+) (Efficiency 20%)	$563/ML	$616 815	-25
Baseline Values		**$747/ML**	$616 814	
NPV Threshold V(P)-I =0		$429/ML		-43
Baseline with no option to suspend operation when cost exceeds price		$920/ML	$846 476	23

In the real options analysis, an increase in the volatility of water price (represented by sigma) has the effect of increasing the value of the project. However, the trigger price critical for investment also increases. In this case study, the trigger price for the baseline case was $747 per megalitre at σ = 0.20. This compares to $817 per megalitre at σ = 0.30 and $672 per megalitre for lower price volatility of σ = 0.10. Even at the lower level of water price volatility of 10 per cent, the real options trigger price is still much higher than the NPV trigger price of $429 per ML.

While some of the volatility in water prices is due to climatic and weather conditions that cannot be controlled, there may be some adjustments to institutional arrangements that could contribute to a reduction in water price volatility. As observed by Carey and Zilberman (2006), policies that contribute to reducing the volatility of water prices will make the adoption of water saving technologies more likely, even though the overall value of the project declines. Such policies may

include changes to dam management strategies, water trading arrangements and improvements in the efficiency of conveyance systems. At the same time, any reduction in the reliability of annual allocations is likely to increase the volatility of water prices. In this way lower reliability may act as a deterrent for the adoption of water saving technologies by increasing the critical price at which investment would take place.

Reductions in the capital cost of 10 and 30 per cent had only a negligible affect on the trigger price (see table 4). The 30 per cent reduction shown in this case, only resulted in a 2 per cent fall in the real options trigger price, compared to the base case. The limited impact of a reduction in the capital cost on lowering the trigger price for investment, indicates cost-sharing arrangements or interest rate subsidies as strategies to increase the uptake of chemical monolayer technology would be of marginal value.

Due to the nature of the chemical monolayer technology, a 10 per cent reduction in operating costs would have a more significant effect on lowering the trigger price for investment. The high costs of applying the chemical monolayer each year, mean that ongoing costs are a significant issue. A 10 per cent reduction in the annual operating and maintenance costs in this case, reduced the real options trigger price by 9 per cent to $683 per ML per year. This is similar to the effect of a 10 per cent reduction in water price volatility. There appears to be greater potential for reducing the trigger price for investment where improvements in management practices and technology can be made that reduce ongoing operating costs for this technology.

By far the largest impact on the trigger price was from the estimated water savings, determined by the efficiency of the chemical monolayer in reducing total evaporative losses. A 10 per cent increase in efficiency dropped the trigger price to $563 per megalitre, while a 10 per cent decrease raised the price to $1127 per megalitre. The high sensitivity of the results to changes in water savings highlights the importance of accurate estimates of the efficiency of the chemical monolayer technology for adoption. It also demonstrates the potentially large benefits from improvements in the effectiveness of the chemical treatments and the increased likelihood of adoption in regions characterised by high rates of evaporative loss.

Carey and Zilberman (2002) and Hafi et al (2006) applied the real options investment rule to examine likely rates of technology uptake over time. Using a geometric Brownian motion (GBM) model for water price movements over 25 years, 5000 realisations of the water price path were generated using the same drift rate, variance and initial water price. The drift rate was 2 per cent and variance was 20 per cent as per the baseline parameters set out in table 2. The initial water price was set at $400 per megalitre, which is equivalent to the median price paid for temporary water in the MIA for 2007/08. The GBM generates a set of paths that the water price may follow over time. However, because the price of water is stochastic the exact path it may take is unknown. Information from the price realisations can be used to generate probabilities of reaching the investment trigger price within a certain time frame (see table 5).

Using the NPV rule, after 5 years the trigger price for investment would have been reached 66 per cent of the time (table 5). In comparison the real options approach suggests the trigger price for investment will only be reached 11 per cent of the time within the first five years. To the extent that irrigators' investment decisions are influenced by uncertainty and their ability to choose the timing of investment, the pace of adoption is likely to be much lower than that implied by NPV analysis.

Table 5 Probability of achieving trigger price within timeframe

	Mean Price (per ML)	Real Options	NPV
Percentage of times price exceeds real options and NPV price within:			
5 years	$446	11	66
10 Years	$497	25	76
15 years	$548	35	80
20 years	$601	41	83
25 Years	$666	46	84

The mean price over the 5000 price realisations is shown in Figure 3 along with three price realisations and the trend or mean water price over all realisations. The mean price falls below the trigger price after 25 years. As a result the probability of adoption within 25 years is about 46 per cent given the current costs and effectiveness of the technology. The earliest time to adoption for the irrigator in this case study was after 2 years.
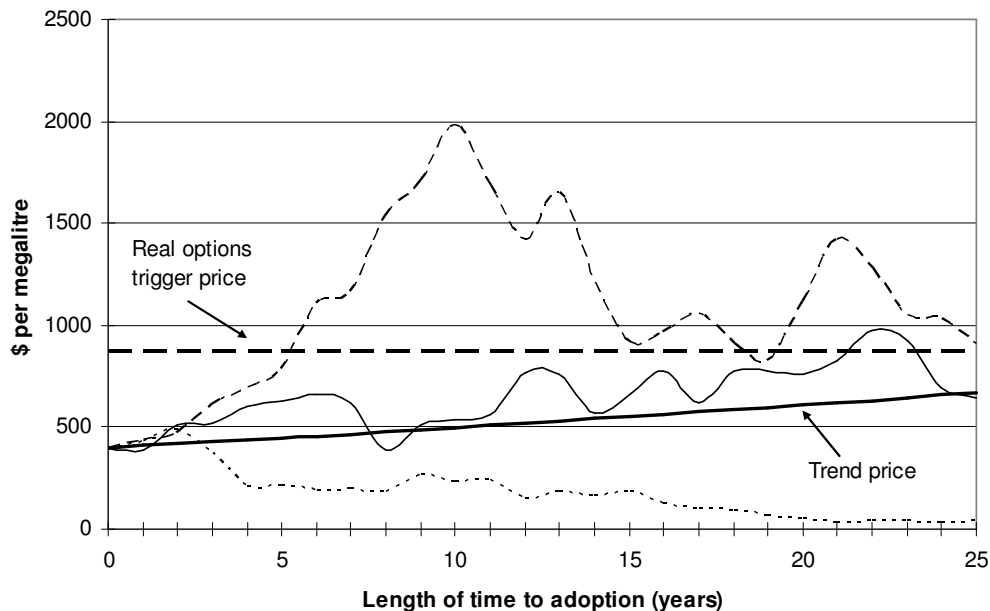

Figure 3 Price Realisations and time to trigger price

4.2 Impermeable Cover

Impermeable covers are an alternative measure to reduce evaporation from storages. The case study prepared for the National Program for Sustainable Irrigation by Heinrich and Schmidt (2006) is extended here to include a real options valuation. The study was based on a small storage with a capacity of 9.4 ML and a surface area of 0.53 ha. Water savings of 6.1 ML per year could be achieved in the region of Birdwood, SA (see

Table 6 Baseline – Impermeable Cover
For 0.53 ha storage, Birdwood SA

I = $36 750	a* = 6.1 ML per year
C = $315	$\hat{I} = I + \dfrac{C}{r} = \$41\ 596$

* Estimated water savings per ha of storage surface area per year.

Heinrich and Schmidt 2006 and http://www.readyreckoner.ncea.biz/). Baseline
parameters are shown in table 6. Because there is no option to suspend operating
costs, the real options price can be simply calculated using the option multiple, or
hurdle rate, $\beta_1 /(\beta_1 - 1)$ (Dixit and Pindyck, 1994 and Carey and Zilberman, 2006).

At a 20 per cent level of water price volatility, the trigger price for investment
increases from \$338 per ML using a standard NPV approach, to \$726 per ML using
real options valuation (see table 7). In this case, the irrigator would wait until the
value of the project, V(P), was 2.15 times the cost of the investment, $\hat{I}$. The results
were most sensitive to assumptions of water price volatility, a finding common with
other applications of real options valuation. A reduction in the volatility of water
prices to 10 per cent would see the critical price for investment fall from \$726 per ML
to \$559 per ML. At a level of 30 per cent volatility in water prices the real options or
trigger price would increase to \$943 per ML, representing a price 2.80 times above
the trigger price indicated by standard NPV analysis. Thus any policy measures that
can contribute to reducing the volatility of water prices will have a positive effect on
adoption.

As with the chemical monolayer, the reliability of estimates for water savings through
an impermeable cover are important. Small changes in the technology's effectiveness
will have a reasonable impact on the trigger price. In this case a 10 per cent reduction
in water savings from 6.1 ML per ha to 5.5 ML per ha of storage surface area per
year, increased the trigger price by 11 per cent. A 10 per cent increase in the
technology's effectiveness of saving water reduced the trigger price by 9 per cent.
This result helps to illustrate that the potential for such a technology will be greatest in
regions with high annual evaporative losses.

Table 7 Impermeable cover, Birdwood -SA

Parameter	Value	Real options critical price	V(P)-I	Hurdle rate $\beta_1 /(\beta_1 - 1)$	% change from base case
σ	10 per cent (-)	\$559/ML	\$26 941	1.65	-23
σ	10 per cent (+)	\$943/ML	\$74 250	2.80	30
ρ	0.09 (+)	\$874/ML	\$35 895	1.89	20
ρ	0.05 (-)	\$576/ML	\$74 079	1.72	-21
I	\$33 075 (-10%)	\$662/ML	\$43 149	2.15	-9
I	\$25 725 (-30%)	\$532/ML	\$34 708	2.15	-27
c	\$220 (- 30%)	\$702/ML	\$45 810	2.15	-3
a	5.5 ML (-)	\$806/ML	\$47 369	2.15	11
a	6.7 ML (+)	\$661/ML	\$47 369	2.15	-9
Baseline Values		**\$726/ML**	**\$47 369**	**2.15**	
NPV Threshold V(P)-I =0		\$338/ML			

A reduction in the capital cost of the technology of 10 per cent has a similar result to
an improvement in water savings of the same magnitude. For example, a 10 per cent

reduction in capital costs reduces the trigger price to about $662 per ML. Reduction in the order of 30 per cent of the capital cost of this technology, reduce the trigger price to about $532 per ML. In comparison, due to the relatively low operating and maintenance costs for the impermeable cover, a 30 per cent reduction in ongoing annual costs only reduces the real options trigger price by only 3 per cent, to $702 per ML per year (see table 7).

4.3 Government investment in on-farm technology

Where the expected net social benefits are sufficient and there is inadequate private incentive, there may be potential to hasten uptake of the technology through the use of cost sharing arrangements or other strategies such as publicly funded research and development to reduce the upfront cost or improve effectiveness of the technology. To examine the impact of a cost sharing arrangement on private investment decisions real options valuation was used to demonstrate the influence of uncertainty in water prices on the take up of a government subsidy for a private investment project. The fact that the water price fluctuates over time indicates there is uncertainty about the value of the water savings. Consequently, the return achieved from investment in a technology for which the main benefit is water savings, will also be uncertain.

Changes to private investment decision

An irrigator has the choice to secure additional water permanently either through buying permanent entitlement or investing in a technology that saves water on-farm. However, given water can be purchased temporarily on the open market, it is the price of the temporary water that is relevant, relative to the cost of making an investment to achieve permanent water savings. While ever the temporary water price is less than the trigger price for the investment it would be better to buy temporary water and defer a decision to invest in the water saving technology or the permanent entitlement. The decision to invest in permanent water entitlement rather than a water saving technology is an alternative investment decision.

The real options valuation was run using the impermeable cover case study to examine a range of scenarios for government cost sharing of capital costs: a 5 per cent subsidy through to a 95 per cent subsidy to the capital cost of the technology. The subsidy is expressed as a percentage of the technology's capital cost. In return for the subsidy it was assumed that irrigators would be obligated to return 50 per cent of the water saved in the form of permanent entitlement to the government. This assumption is in line with the Commonwealth-State Water Management Partnership agreement for Commonwealth funding of Basin State Priority Projects as per the COAG Intergovernmental Agreement on Murray Darling Basin Reform (July 2008).

In the previous section, the price at which the irrigator would invest in the impermeable cover given volatility and appreciation in water prices was estimated. It was shown that in the absence of subsidy where the irrigator keeps the full water saving of 6.1ML per year, the real options trigger price was estimated at $726 per ML for a 0.53 ha storage in the Birdwood region of South Australia. To accept the subsidy under a program of the design examined, irrigators would have to relinquish 3.05ML of their water entitlement, or 50 per cent of the estimated annual water savings from the impermeable cover. The remaining 3.05ML would remain with the irrigator complementing water available through their annual allocation. This assumes the 3.05ML water saving is consistently achieved on farm each year. While the subsidy

reduces the upfront capital cost of the technology, the irrigator must weigh this against the value of the water savings returned to the government. As such the irrigator's investment decision changes compared to the base case discussed in the previous sections – a lower capital cost but also a lower level of water savings retained by accepting the subsidy.

Analysing the farm investment problem using real options valuation suggests that where uncertainty does exist, higher rates of subsidy may be required to induce adoption compared with rates of subsidy indicated by NPV analysis. Figure 4 is used to demonstrate the difference between the NPV trigger price for investment and that calculated using real options valuation, where 50 per cent of water savings are relinquished in return for the subsidy to the capital cost of the impermeable cover. Assuming a temporary water price of about $400 per ML, NPV analysis would imply a 45 per cent subsidy to the capital cost in order to encourage immediate uptake. With real options, the subsidy to achieve immediate uptake of the technology for this storage size is estimated at about 80 per cent (see Figure 4). This result offers a possible explanation as to why adoption rates sometimes remain lower than expected even when a subsidy to the capital cost of the investment is offered through incentive programs. The results of the real options valuation indicate a subsidy of 45 per cent would only induce immediate uptake of impermeable cover technology for this size storage, with water prices in the order of $900 per ML
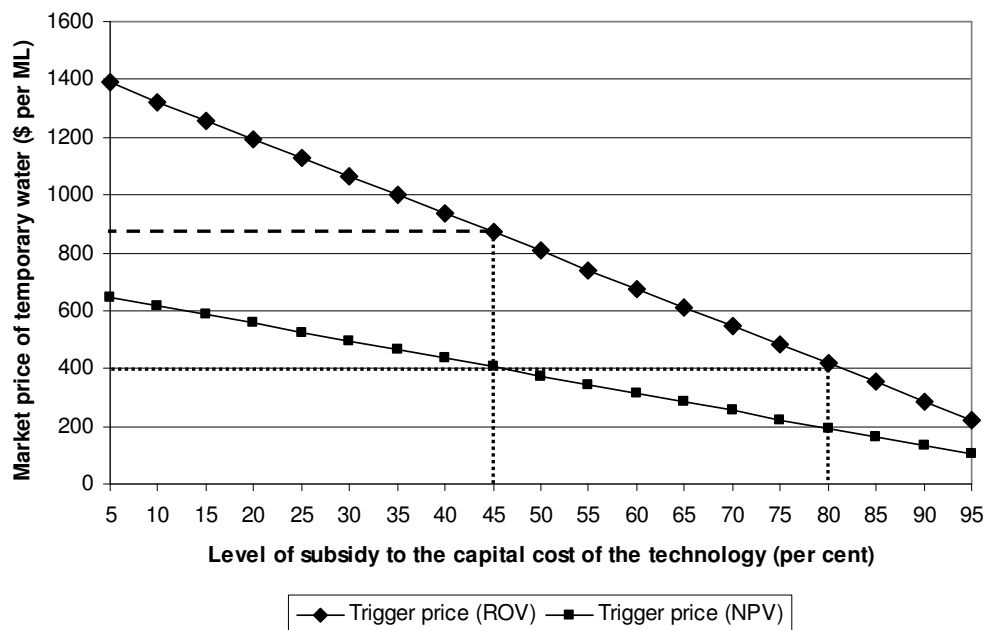

Figure 4 Comparison of NPV and Real Option implied rates of subsidy to capital cost in return for 50 per cent of water savings

To maintain the irrigator's trigger price at the same level as it would be in the absence of the program, about $726 per ML, a subsidy of almost 55 per cent would need to be offered. For this case study, to increase uptake of the technology above the current rate in the absence of the program, an incentive greater than 55 per cent of the capital cost would need to be offered. An indication of how changes in the price for temporary water can affect the uptake of a subsidy program is also derived from figure 4. Further work on the distributional effects of this technology among

irrigators would need to be done before regional levels of program uptake could be commented on.

The fact that the program increases the trigger price for private investment decisions implies that either there may not be a strong uptake of a subsidy program that requires a return of permanent entitlement, or that irrigator interest in the program will occur over a much longer timeframe. For example, while ever the water price is below $900 per ML and above $726 per ML, the incentive for an irrigator to invest in the impermeable cover technology and to retain all the water savings on-farm would be greater than participating in a program that offered a 45 per cent subsidy to capital costs in return for 50 per cent of the water savings.

Threshold values for social benefits

At each level of market price and subsidy rate there is a corresponding cost to securing water for the environment through the program. This cost represents a threshold for the value of water for the environment. It reflects what the environmental value of water would need to exceed before it would be worthwhile offering a subsidy of a certain value to secure water savings through an on-farm investment program. As such the government faces a similar investment decision to the private irrigator, in terms of what amount of subsidy should be offered to irrigators in return for water savings, given expected net social benefits.

In the government's investment decision, there are no ongoing annual costs, just the cost of the subsidy (including program administration costs) for the upfront capital cost of the technology. For example in this case study, a 30 per cent subsidy to the impermeable cover capital cost would cost the taxpayer $11 025. To acquire 50 per cent of the water savings in perpetuity, or 3.05 ML per year in this case study, the subsidy to the capital cost of the impermeable cover is equivalent to paying $3 615 per ML. Two criteria would have to be satisfied for this program to be worthwhile from a community perspective. First, the value of water for the environment would have to exceed a value of $3 615 per ML. Second, it must be lower cost to acquire water through the subsidy program than direct purchase on the market for permanent water entitlement. That is, the permanent market price for water would have to be higher than $3 615 per ML.

As the value of the subsidy increases, the per megalitre cost of acquiring environmental water through a farm modernisation program also increases. This is shown in Figure 5. To maintain a trigger price equivalent to the base case of $726 per ML (that is no subsidy and all savings retained by the irrigator), a 55 per cent subsidy in return for 3.05 ML or 50 per cent of the water savings would be required (shown in Figure 5 by the dotted line). A 55 per cent subsidy to the impermeable cover demonstrated this case study, would cost the taxpayer $20 213, or $6 630 per ML given the water savings acquired of 3.05ML. This is shown in Figure 5 by the dashed line.

The alternative to securing water entitlement through on-farm investment is to purchase water entitlement on the permanent water market. Given this, the difference between the market price for permanent water and the subsidy equivalent price paid under a farm modernisation scheme for permanent entitlement also indicates a threshold value. The premium paid above market value for permanent entitlement is the threshold level that any secondary benefits would need to exceed before it could be justified to pay above market price for water by investing in on-farm infrastructure.

Building community resilience is one of the secondary benefits presented as an argument for investing in on-farm irrigation infrastructure to acquire water, as opposed to a market buy back scheme. The net value of any such community benefits would need to exceed the premium paid above the market price for water. Furthermore, it must be demonstrated that investment in on-farm irrigation infrastructure is the least cost way of achieving these goals or the secondary benefits. Davidson (1969) provides a relevant discussion on secondary benefits that emphasises such benefits are also associated with government investment in other areas of agriculture and the economy more broader, and that this tradeoff must also be taken into consideration: "If capital and labour are limited, as they are in Australia, secondary benefits can only be created in one part of the country at the expense of another" (Davidson, 1969, p. 47).
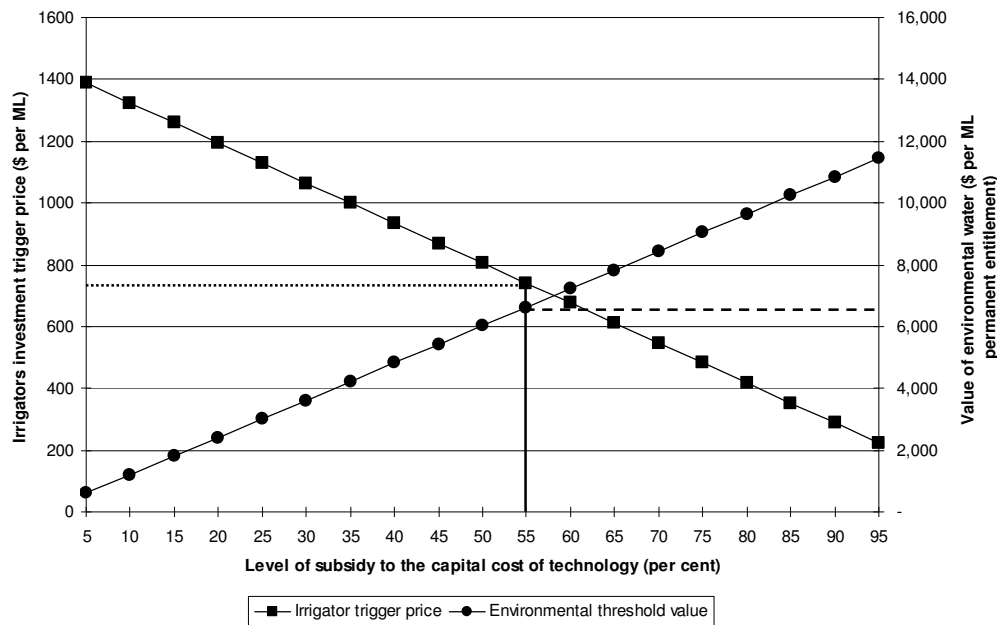

Figure 5 Trigger price for private and government investment, by subsidy percentage

Over the 2007-08 Murrumbidgee water trade season, the permanent price for water varied from $2100 per ML to $3400 per ML (L. Golden, Murrumbidgee Horticulture Council, personal communication, November 2008). Market prices for permanent water trades can be compared to the range of subsidy equivalent prices for permanent water entitlement shown in Figure 5 over a range of subsidy levels. For example, a trade price of about $3400 is about on par with a 30 per cent subsidy based on 50 per cent recovery of water savings in return for the subsidy. The amount paid by an on-farm investment program above this level would need to be justified in terms of secondary and any intangible benefits from securing water through on-farm investment that could not be achieved through direct market purchase or at a lower cost through alternative programs.

In table 8 the probability of program uptake is shown comparing real options with the NPV rule under the scenarios of no subsidy and a subsidy in return for water savings. Assuming a 30 per cent subsidy to the capital cost of the impermeable cover for this storage size in return for half the estimated water savings, the probability of achieving the real options trigger price within 10 years declines from 26 per cent in the absence

of the subsidy program to 9 per cent with the program. Given participation in the program is voluntary it can be suggested from this result that for some technologies there may be limited interest in a subsidy program that requires irrigators to relinquish water entitlement in return. Even under an NPV approach, the program is associated with a considerably slower pace of uptake, again implying low program participation or the need for much higher rates of subsidy if uptake is to be increased above the base case no subsidy scenario.

Table 8 Probability of achieving trigger price within timeframe, per cent

	NPV rule		Real Options	
	No Subsidy[+]	Subsidy*	No Subsidy[+]	Subsidy*
5 years	92	47	11	2
10 Years	94	61	26	9
15 years	95	67	36	16
20 years	96	72	42	23
25 Years	96	74	46	27

[+] Assuming no subsidy to capital cost and irrigator retains all water savings.
* Assuming a 30 per cent subsidy to the capital cost in return for 50 per cent of the water savings.

The use of government incentives to offset capital costs as a means of encouraging a more rapid uptake of technology must be carefully considered. In its review of rural water use, the Productivity Commission (2006, p.129) stated:

> "Providing subsidies for 'technically efficient' irrigation technologies, or for industries to increase productivity without targeting market failures or inadequate government policies, will reduce economic efficiency and involve wealth transfers from the public to benefiting irrigators. In particular, it is likely to reduce community welfare as resources are artificially diverted from other productive uses into the subsidised irrigation activity."

Justification for using government funds to hasten the uptake of technology through on-farm investment may need to be rethought where it can be demonstrated that delayed adoption is being used as a legitimate risk management strategy. Where there are public benefits from technology uptake, any potential opportunities to reduce the uncertainty of water prices through policy reform should be considered as an approach to hastening adoption. Carey and Zilberman (2002) and Hafi et at (2006) provide discussion on the potential for a range of water policy reforms to minimise water price volatility helping to ensure public costs and risk from irrigation technology uptake are minimised.

The expectation of government subsidy for investment in water saving technologies can also be a powerful force in delaying irrigator's investment decisions. As a result the use of subsidies (including grants and cost-sharing) should only be considered when there are large net public benefits and private net benefits are small (Pannell, 2008). Pannell (2008) advocates that positive incentives to encourage change, such as financial instruments like subsidies, should only be used:

1. when the public net benefits are high;

2. where landholders would not adopt the changes without incentives; or

3. where public net benefits outweigh private net costs.

These are valuable points to consider where subsidies to the cost of technologies are being considered as a means to hasten adoption to improve on-farm water use and management.

There is a tendency for some irrigators to hold water entitlement in excess of their requirements as insurance against declining reliability of water supplies and changes in policy affecting the security of water entitlements. To this extent, incentives to participate in programs that relinquish water entitlement in return for a subsidy will be tempered by uncertainties in the supply of water resources. For some irrigators this may influence their decision to relinquish permanent water entitlement, either through the permanent water market or an on-farm investment program. It also implies that a higher rate of subsidy than implied by NPV analysis would be required to encourage program participation and hastened technology uptake.

5. Conclusions

A real options approach has been used to examine the influence of uncertain water prices on the adoption of two water saving technologies. Through the case studies examined it is shown that uncertainty about water prices can play a part in irrigators' decisions regarding the timing of investment in water saving technologies. It was also demonstrated that the ability to temporarily suspend the operation of a technology will partially offset the effect of volatility in water prices. Recognising this flexibility when evaluating projects will lower the trigger price for the investment.

To the extent that uncertainty is reflected in irrigator's investment decisions, the water price at which adoption takes place will be higher than that suggested by NPV analysis. Where uncertainty is shown to be significant enough to effect a decision to wait or defer investment, slower than expected rates of adoption may be the result of irrigators managing risk and uncertainty. In these circumstances decisions to delay investment can be optimal from the perspective of a private investor.

Along side private investment, there has also been an increasing trend for governments to subsidise on-farm irrigation infrastructure and technology, under notions that adoption is too "slow" and that faster uptake will help irrigators adjust to changing conditions of water availability. That delays to adoption may be due to an irrigator's risk management strategy is important to consider when public funds are being directed into private irrigation infrastructure investments. If investment by government in on-farm infrastructure is used to simply transfer the cost of downside risk onto taxpayers through direct subsidies to capital costs, there is potential for investment to occur in areas unlikely to generate reasonable social returns or public benefits.

Real options valuation was also used to demonstrate the impact of government programs on private investment decisions. To the extent that uncertainty effects investment decisions and irrigators have the discretion to choose the timing of investment, the rates of subsidy required to increase levels of investment in water saving technologies are likely to be higher than those implied by NPV analysis. A government subsidy to reduce the upfront cost of technology will increase the uptake of the technology where the irrigator retains all of the water savings from the new technology. In contrast, a subsidy program with 50 per cent of water savings permanently relinquished to the government will increase the trigger price above the water price at which investment would occur in the absence of the program. This implies that there may be limited incentive for irrigators to take up a program of this

design unless considerably higher rates of subsidy are offered. The subsidy would only be justified where the public benefits from on-farm investment exceeds the cost of subsidy and administration and where the same results could not be achieved at a lower cost though alternative instruments to increase technology adoption and acquire water for other uses.

Acknowledgements

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A.1 Stochastic process

A number of stochastic methods can be used to simulate price uncertainty. The Geometric Brownian Motion (GBM) and Mean Reversion Models are used to represent a continuous time stochastic processes for random variation in financial markets, such as stock prices. They are likely to have relevance in applications to modelling water and agricultural commodity prices.

Using a GBM, the stochastic process for water prices is characterised by a drift and a volatility percentage to estimate the transition of a price at one time period to the next time period. The GBM equation below was used to generate the water price timeseries based on the approach used by Winston (2001), Odening et al (2005) and Dixit and Pindyck (1994) for discrete time lognormal random variables,

$$P_{(i+dt)} = P_0 e^{\left[\left(\alpha - 0.5\sigma^2\right)dt + \sigma\varepsilon_t \sqrt{dt}\right]}$$

where P_0 is the initial water price; $P_{(i+1)}$ is the price for water in the following period; α is the expected price appreciation or drift rate; σ is the standard deviation of the water price (P) per unit of time; dt is the change in time and ε_t is a standard normal random variable with mean of zero and standard deviation of 1.

There are four assumptions underlying the Geometric Brownian Motion used to simulate the stochastic price variable, in this case water price (see Sengupta, 2004):

1. Volatility of water prices is constant over time;
2. Water prices cannot be negative;
3. Fluctuations in the price of water are log normally distributed; and
4. The current price is random or independent of historical prices. This referred to as a Markov property.

The issue of whether or not water prices follow a random walk, or that they are log normally distributed is open to debate. In a study of milk prices by Tauer (2006), statistical analysis implied that there was drift in the monthly New York milk price but no trend and that milk prices did not follow a random walk. However Tauer (2006, p. 344) made the following comment with respect to assumptions made about future prices:

> "Tomek (2000) concludes that since the data-generating processes for commodity prices are complex and difficult to forecast, and given the costs of arbitrage, no systematic behaviour of prices can be used to make profitable forecasts. It is thus reasonable to assume that farmers act as if prices do follow a random walk."

In this analysis, the assumption is made that water prices are log normally distributed and follow a random walk. It is further assumed that the volatility of water prices is constant over time, although historical data examined indicates variation does exist.

The trend rate or drift term of the Geometric Brownian Motion represents the appreciation in the capital value of an asset. For water, this would arise from any factors that reduce the supply of water available for irrigation. Increases in competing demands for water such as environment, urban and industrial uses are possible reasons

for an appreciation in the value of water over time. Reductions in supply due to catchment level land management practices that affect runoff and any increase the severity and period of drought will have a similar effect on water prices over time. While there has definitely been an increase in the capital value of water over time evidenced by the progression of permanent water prices, it is difficult to determine the extent to which such appreciation affects the temporary water price. The model can be adjusted to examine randomness with or without a drift or trend term. In the model, a drift term of 2 per cent is applied, to reflect the likelihood of an increasing capital value for water supplies over time.

A.2 Value of the investment

The expected present value of a project to invest in a water saving technology is expressed as V(P) where:

$$V(P) = \frac{Pa^*}{\delta} - \frac{C}{r} \qquad (1)$$

In equation (1), P is the price of the water, a* is the amount of water saved by switching to the new technology and C is the operating cost increase incurred to achieve the water saving with the new technology. Following Carey and Zilberman (2002), because P a stochastic variable, it is discounted by δ, the risk adjusted discount rate. For the parameter C, which is deterministic, the risk-free discount rate r, is used. Over all future time periods, *V(P)* is the expected present value of the increase in profit associated with the technology. The decision is made to invest permanently in the technology and as such the threshold price is calculated as a perpetuity (see Cary and Zilberman 2006).

The NPV rule would advise to invest if V(P) is greater than or equal to the initial cost of the investment, I. As such the threshold price for water using net present value analysis is where:

$$\tilde{P} = \frac{\delta}{a^*}\left(\frac{c}{r} + I\right) \qquad (2)$$

For most investments there will be an uncertain component either in the costs or returns or both, which means the value of a project will vary from one time period to the next. For an investment that saves water or reduces the amount of water used, the changing value of water over time will mean that in some periods the saving in water may be worth more than the increase in operating costs associated with the new technology. In other periods though, it may be worth less.

In traditional benefit cost analysis this uncertainty can be taken into account by using simulation to draw a range of possible values from a probability distribution representing the likelihood of future price events. While a simulation approach does help to reflect uncertainty in decision making, it does not reflect the flexibility or contingency planning available to managers through the option to defer an investment until more is known about future prices. Because an investment is at least partly irreversible and the price of water is uncertain, the option to wait before making an investment has a value. This value of having the option to invest is added to NPV as an opportunity cost.

A.3 Value of the option to invest

At each point in time, the investor can decide between investing now or waiting until the next time period to invest. The value of the investment opportunity, or the option to invest is represented by *F(P)*.

Using the assumption that prices follow a Geometric Brownian Motion[1], the value of the option to invest takes the form

$$F(P) = A_1 P^{\beta_1} \qquad (3)$$

This is derived from the Bellman equation, $\rho F(p)dt = E[dF(p)]$. As define in Carey and Zilberman (2002, p. 175), the LHS of the Bellman equation represents the return on the opportunity to invest over the time interval *dt*. The equation states that this return must equal the expected rate of capital appreciation, shown here by the RHS of the equation.

Using Ito's Lemma, the differential equation for the value of the option to invest *F(P)*, is

$$\frac{1}{2}\sigma^2 p^2 F''(p) + \alpha_p p F'(p) - \rho F(p) = 0 \qquad (4)$$

To reduce the form of equation (4), the set of boundary conditions below are applied:

$$F(0) = 0 \qquad (5)$$
$$F(P^*) = V(P^*) - I \qquad (6)$$
$$F'(P^*) = V'(P^*) \qquad (7)$$

The condition expressed in (5) states that the option to invest will have no value if the value of the project, V, has a value of zero.

The condition expressed in (6) is referred to as a value matching condition and it links the estimate of V(P) found in the previous section to the estimation of F(P) in equation (3). The value matching condition states that, the investment will take place when the value of the project is equal to the direct investment cost plus the opportunity cost of making the investment, that is, $V(P^*) = I + F(P^*)$.

Equation (7) is the smooth-pasting condition. As described in Dixit and Pindyck (1994), this condition ensures that the two curves V(P) and F(P) make contact at a common point, or "point of tangency", P* (see figure 1). The smooth-pasting condition equates the slope of the value of investing with the slope of the value of waiting. This occurs at the optimal trigger price of P*. Dixit (1992) describes this as the point at which the value of waiting falls to zero.

The value of the option to invest takes the reduced form shown in equation (3) when the differential equation (4), is solved subject to equations (5) to (7)

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[1] If mean reversion was chosen as the stochastic process to model water prices, the equations in this section would be respecified. Following Dixit and Pindyck (1994), equation (3) would be specified as:

$$F(V) = A V^\theta H\left(\frac{2\eta}{\sigma^2}V; \theta, b\right)$$ following changes to the differential equation shown in (4) to

reflect the mean reversion process. The same boundary conditions exist as described in this section and A and θ are constants to be determined.

In equation (3), A_1 is a constant yet to be determined, and β_1 is a constant whose value is determined by the parameters below and is defined in equation (8):

σ = the standard deviation of the asset's value over time

ρ = the risk adjusted discount rate

δ = difference between the discount rate and the rate of growth in the asset expected over time, that is, $\delta = \rho - \alpha$. It represents the dividend or yield on the asset.

$$\beta_1 = \frac{1}{2} - \frac{(\rho - \delta)}{\sigma^2} + \sqrt{\left[(\rho - \delta)/\sigma^2 - \frac{1}{2}\right]^2 + 2\rho/\sigma^2} > 1 \qquad (8)$$

The matching condition and the smooth-pasting condition can be rearranged into the following forms given equation (1) for the value of V(P) and equation (3) for the value of F(P).

$$A_1\left(P^* a\right)^{\beta_1} = \frac{P^* a}{\delta} - \frac{C}{r} - I \qquad (9)$$

$$\beta_1 A_1\left(P^* a\right)^{\beta_1 - 1} = \left(\frac{1}{\delta}\right) \qquad (10)$$

Using the above rearranged equations for the value matching and smooth pasting conditions, parameters A_1 and P* can now be solved. The solution for A_1 is

$$A_1 = \frac{\left(\left(P^* a\right)/\delta - C/r - I\right)}{\left(P^* a\right)^{\beta_1}} \qquad (11)$$

Defining the value of the project as $\widehat{V}(P) = Pa^* / \delta$, and $\widehat{I} = I + C/r$, the threshold value of the project for investment is then given as:

$$\widehat{V}(P) = \left(\frac{\beta_1}{\beta_1 - 1}\right)\widehat{I}$$

Alternatively, this can be expressed in terms of a threshold price or the investment:

$$P^* = \left(\frac{\beta_1}{\beta_1 - 1}\right)\frac{\delta}{a}\left(I + \frac{C}{r}\right) \qquad (12)$$

A discussed earlier, real options adjusts the NPV rule to reflect the ability of a manager to defer an investment decision. As such, a real options approach simply modifies the conventional NPV rule to include the value of the option to invest as an opportunity cost. This is shown by a comparison of the NPV threshold price shown in equation (2) with equation (12) above. The expected value from making the investment must exceed the project costs by a factor or hurdle rate. This hurdle rate is refered to by Dixit and Pindyck (1994) as the "option value multiple" and it is shown in equation (12) as the component, $\beta_1/(\beta_1 - 1)$. The option value multiple is used to derive the real options trigger price of an investment cannot temporarily suspended operating costs when the water price falls below the cost of operation. Examples of this include irrigation application technologies such as centre pivots and drip

irrigation and investments in impermeable cover and shadecloth evaporation mitigation.

When dealing with a stochastic input price and there is an option to suspend production if the price falls below the operating cost of the associated technology, specification of the real options threshold price is more complex. An example, of this is the evaluation of evaporation mitigation technologies. For example, if the cost of operating a chemical monolayer was higher than the market price for temporary water, you could chose to suspend using the monolayer and purchase any additional supplies in the market at a lower price. In this case the value of the project includes the value of the option to suspend operations, when price falls below the operating cost. V(P) then takes the form:

$$V(P) = B_2 (Pa)^{\beta_2} + \frac{Pa}{\delta} - \frac{C}{r} \qquad\qquad \text{if } Pa>C, \text{ or} \qquad (13a)$$

$$V(P) = K_1 (Pa)^{\beta_1} \qquad\qquad\qquad \text{if } Pa<C \qquad (13b)$$

Where the term $B_2 (Pa)^{\beta_2}$ represents the value of the option to cease operating during periods where the price is below the cost. This term increases as the level of uncertainty σ, increases. The remaining part of Equation (13a) simply represents the present value of net revenue.

Following Dixit and Pindyck (1994), values for B_2 and K_1 are given by:

$$K_1 = \frac{C^{1-\beta_1}}{\beta_1 - \beta_2} \left(\frac{\beta_2}{r} - \frac{(\beta_2 - 1)a}{\delta} \right) \qquad (14)$$

$$B_2 = \frac{(C/a)^{1-\beta_2}}{\beta_1 - \beta_2} \left(\frac{\beta_1}{r} - \frac{(\beta_1 - 1)a}{\delta} \right) \qquad (15)$$

Following through similar to the above example, the value matching and the smooth pasting conditions shown in equations (5) to (7) are revised to incorporate the value of the option to suspend operation:

$$A_1 (Pa)^{\beta_1} = B_2 (Pa)^{\beta_2} + \frac{Pa}{\delta} - \frac{C}{r} - I \qquad (16)$$

$$\beta_1 A_1 (Pa)^{\beta_1 - 1} = \beta_2 B_2 \left(P^* a \right)^{\beta_2 - 1} + \left(\frac{1}{\delta} \right) \qquad (17)$$

As B_2 is calculated in equation (15), the equations (16) and (17) can be solved for A_1 and P*. The solution for A_1 is

$$A_1 = \frac{\left(B_2 \left(P^* a \right)^{\beta_2} + \left(P^* a \right) / \delta - C / r - I \right)}{\left(P^* a \right)^{\beta_1}} \qquad (18)$$

As described by Dixit and Pindyck (1994), eliminating A_1, provides the following equation for the optimal investment threshold for a project where price is variable and when the flow or operating cost can be avoided by temporarily suspending operation in periods where the price falls below this cost:

$$(\beta_1 - \beta_2)B_2(P^*a)^{\beta^2} + (\beta_1 - 1)\frac{P^*a}{\delta} - \beta_1(C/r + I) = 0 \qquad (19)$$

An iterative process is then required to determine the value of P*.