Optimum Use of Subsidies for Reducing Domestic Water Consumption

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ABSTRACT

Rebate programs have been widely used as a demand-side management tool to encourage the installation and retrofit of water efficient appliances, collection and reuse systems. A review of Australian rebate program effectiveness between 2003 and 2011 was conducted, spanning over one million rebate applications from three states and one territory. The evaluation identified that efficient policy formulation is hindered by limited understanding of consumer uptake, varied estimates of water savings and unclear relationships between combinatorial rebate scenarios and program yield.

This paper develops a framework to identify Pareto efficient rebate policy that maximises program yield whilst minimising cost. A genetic algorithm is applied to a simulation model of uptake, water savings and cost to identify optimal combinations of rebate levels. Domestic water use is simulated at the household scale using behavioural stochastic end-use simulation. The application of this framework to a South Australian case study identifies a Pareto efficient policy mix that could have achieved the same water saving outcomes by reducing the rebate incentive for dual-flush toilets and rainwater tanks and increasing the incentive for low-flow showerheads. Compared to SA's H_2OME program, this optimal policy combination could have achieved the same projected water savings yield at a 44% (~$21.2m) lower cost to the government. This framework is robust to allow for optimal policy combinations to be identified for cost or water saving yield targets or at levelised unit cost targets comparable to supply augmentation. Sensitivity analysis demonstrates that optimal policy combinations are extremely sensitive to the inclusion of washing machine and low-flow showerheads rebates in a rebate program. By considering consumer uptake, this framework extends beyond traditional least cost planning methods to allow for ex-ante estimation of yield.

INTRODUCTION

In water-scarce countries like Australia there are economic incentives to reduce domestic water consumption. One demand-side management tool is the use of financial incentives to encourage the adoption of water efficient equipment (Olmstead and Stavins, 2008). Rebate programs induce the uptake of water efficient measures, bring forward the replacement of less efficient equipment, increase consumer awareness of water scarcity and support the manufacture of more water efficient equipment (Gillingham, 2009).

When faced with the difficult question of "Which measures should be subsidised and at what level?" policymakers are hindered by limited insight into consumer uptake, varied estimates of water savings and unclear relationships between combinatorial rebate scenarios and program yield.

Least cost planning methods of demand management are effective at estimating the levelised unit cost of rebating various measures in isolation (White & Fane 2007) but are limited in being able to estimate yield and cost from a combination of rebates. The problem is more complex than a classical capital budgeting decision – policymakers do not 'assign' the distribution of various retrofit measures to achieve a target yield. Rather, the market makes decisions about which rebates to uptake, and thus the water saving yield based on the suite of rebates which policymakers offer.

Building on insights from a review of past Australian rebate programs, this paper develops a framework that seeks to support robust decision making and efficient policy formulation. This approach extends beyond existing research in three key areas. Firstly, by reviewing an eight year dataset of uptake from four Australian states and territories of over 1 million rebate applications, new understanding of consumer response toward rebate incentives for water saving measures is presented. Secondly, improved estimates of water savings are developed through the application of a behavioural end-use stochastic simulation model which incorporates end-use behaviour, occupancy and climate variability. Finally, a genetic algorithm applied to a simulation model of uptake, water savings and cost allows a Pareto efficient frontier of rebate price combinations to be produced for objectives of yield and cost. This method allows for posterior articulation of preferences from decision-makers and ex-ante estimation of yield. That is, a trade-off curve allows optimal policy combinations that achieve a target yield or operate within a limited budget to be identified. Our framework also allows economically efficient rebate policy combinations which deliver programs at, or below, the long run marginal cost of supply to be identified.

BACKGROUND: AUSTRALIAN REBATE PROGRAMS 2003 to 2011

Between 2003 and 2011, water authorities in all Australian mainland states and territories implemented programs that provided rebates to households that installed or retrofitted a number of water saving measures. The most commonly subsidised measures included dual-flush toilets, low-flow showerheads and the installation of rainwater collection and reuse systems.

Identifying the water savings achieved from each installation or retrofit is inadequate when estimating the effectiveness of demand side management policy at a regional or state-wide scale. Yield from a water resources management perspective is achieved when water savings from individual measures are multiplied by uptake. To gain a better understanding of how consumers respond to rebate incentives, water authorities in five Australian states and two territories were contacted between April and June 2011 to obtain historical rebate uptake data. Data was obtained from programs in South Australia, Victoria, Western Australia and the Australian Capital Territory.

Rebate programs in these states have had success in inducing households to install or retrofit water saving measures. Over 1 million successful rebate applications were paid representing at least $115 million of government spending. By June 2011, programs in South Australia, Western Australia, Victoria and the Australian Capital Territory had encouraged 46 357 households to replace their showerheads, 40 755 dwellings to install a dual flush toilet, 86 068 residences to install a rainwater tank and 344 200 households to purchase a water efficient washing machine.

For finer scale analysis, rebate applications were disaggregated by product type and program then expressed as cumulative uptake normalised by the number of residential water connections in the state. Analysis reveals that the most popular form of rebate claimed by consumers was for new WELS 4-star or higher rated washing machines. Over a five and seven year program, rebates for washing machines achieved uptake of 25.5% and 30.4% in SA and WA respectively. This compares to rainwater tanks – 2.35% and 5.86%; low-flow showerheads – 3.44% and 2.66% and swimming pool covers – 0.52% and 4.50%, all for SA and WA respectively.

Interstate comparisons reveal variation in uptake rates for the same product are largely independent of rebate level. For instance, a $30 rebate for low-flow showerheads was offered in SA whilst a $10 rebate was paid in WA. Despite this, monthly rates of uptake, normalised for the difference in residential households in each state, were largely similar (0.59 v 0.54%/mth). Analysis of the timing and intensity of advertising of rebate initiatives revealed strong correlation between uptake rates and marketing effort. Rebate programs may affect the adoption of water saving measures by simply increasing awareness of water efficiency rather than through explicit financial means.

Rebate incentives aimed to induce the installation of rainwater tanks achieved greater relative success in South Australia compared to other states. Monthly rates of uptake for standalone rainwater tanks (1.84%/mth) and indoor reuse connected tanks (0.73%/mth) exceeded programs in Victoria (0.02% and 0.01%, per month) and Western Australia (0.29% per month). Apart from the influence of rebate level - the SA rebate for standalone tanks was $150 greater than that offered in WA and $50 greater than that offered in Victoria – the pre-rebate penetration rate of rainwater tanks in South Australian homes compared to the national average (45.4% v 19.3%) potentially explains this difference. Greater acceptability of rainwater harvesting and reuse may be inherent amongst South Australians. Climatic factors may also explain the increased uptake in South Australia relative to Victoria over the rebate period. Adelaide's Mediterranean rainfall pattern – long, dry summers and wet winters – provides incentive for households to 'store' rainwater in the winter for use in the summer. We later demonstrate through end use modelling that this perceived benefit of rainwater tanks is flawed – more effective rainwater tank utilisation is achieved when larger volumes of water are continually used throughout the year. This leads to potential implications for program formulation. Policymakers in areas with consistent rainfall where the public may perceive little benefit in capturing rainwater may need to do more to encourage uptake.

Statistical analysis of rebate applications paired with information about the household revealed some socio-economic insights into the adoption of water efficient equipment. Mirroring the findings of Millock & Nauges (2010) who were limited by their use of a stated preference survey dataset; chi square tests performed on South Australian rebate applications show that home owners are more likely to adopt water saving measures than tenants. Normalised for the proportions of home owners and tenants in South Australia, 30 times as many rebates were paid to home owners compared to renters for dual-flush toilets and rainwater tanks. Even for low-flow showerheads, which have minimal installation difficulty and low capital costs, uptake was 16 times higher (3.93% v 0.24%) in the home owner group compared to the tenant group. Washing machines were the only measure with higher uptake in the tenant group compared to the home owner group. Over the five year H_2OME program, approximately 1 in 3 tenants claimed a rebate for the purchase of a new washing machine compared to only 1 in 5 home owners in South Australia. Regression analyses of postcode median aggregate income against the postcodes of rebate applicants accept, at the 5% level, a null hypothesis that income is not an influence on rebate program participation. Together, these results have implication for efficient policy formulation.

We infer that the adoption of water saving measures which do not add to consumer utility beyond a water saving benefit – low-flow showerheads and dual-flush toilets – are limited amongst groups with minimal financial incentive[1] to save water. On the other hand, rebate uptake for measures that add a utility externality beyond water efficiency – washing machines – is relatively independent of the financial motivation for reducing domestic water consumption. It may be that subsidies for washing machines are being paid to consumers who have already made a purchasing decision independent of rebate incentive. This leads to Pareto inefficiency caused by the free rider problem. Subsidy levels for measures like washing machines need to be set at the typical price differential between WELS 4-star appliances and more inefficient models.

By June 2011, many programs had ended or been scaled back. Results of our cost efficiency analysis identified that in the South Australian scheme low-flow showerheads, pool covers and front-loader washing machines rebates were able to achieve levelised unit costs to the Policymaker of \$0.45/kL, \$2.03kL and \$2.38/kL – all less than the \$2.40/kL long run marginal cost of potable water – as shown in Figure 1. Similarly, the role of a rebate reduces the payback period of a 1kL standalone rainwater tank and dual flush toilet by 10 and 8 years respectively. From the perspective of the consumer, only low-flow showerhead rebates allowed water savings to be achieved below the \$2.48/kL tariff block at which most households are charged.

While rebate programs have proved popular, questions can be raised about whether their cost-efficiency could have been improved by altering the combination and rebate level of water saving measures. A \$150 rebate for a single dual flush toilet has the opportunity cost to policymakers of subsidising five low-flow showerheads at \$30 each. Would subsidising only the most cost efficient measures such as low-flow showerheads produce meaningful volumes of yield? What combination of subsidy level would generate sufficient uptake to deliver water savings at or below the long run marginal cost of supply? The first question requires estimates of uptake response whilst the second question represents a decision space of order 10^{11} combinations for 20 common measures and 9 possible prices.

METHOD: A NEW FRAMEWORK FOR PARETO EFFICIENT REBATE POLICY

A review of Australian examples identifies that policymakers exert influence over the response of consumers to a rebate program through a number of policy decisions. These decision variables include the measures which should be included in a rebate program, the level of rebate for these measures, the duration of the program, the intensity and timing of advertising campaigns and the conditions attached to rebate eligibility. Additionally, a number of conditions outside the control of policymakers influence the uptake and subsequently, the water saving and cost response. Based on data constraints, our analysis simplifies the problem and decision space – policymakers are assumed to influence uptake through only two decisions - whether or not to subsidise a measure and the level at which a subsidy should offered for that measure.

Our approach investigates the trade-off that exists between how much a policymaker is willing to spend and the volume of water savings that can be achieved for different rebate policy combinations. Using the understanding gained from the analysis of Australian rebate uptake, paired with original estimates of water savings; three models – uptake, water savings and cost – are proposed to evaluate conflicting objectives seeking to

1) minimise the cost of the rebate program
2) maximise the volume of water savings

A genetic algorithm, NSGA-II (Deb et al., 2002) in a spreadsheet-based implementation (Savic et al., 2011) is applied to develop the Pareto frontier of all non-dominated combinations of rebate policy. The two decision variables – whether or not a rebate should be offered for a given measure; and the level at which a rebate for that measure should be offered – are represented in the chromosome of the genetic algorithm. This chromosome of 20-bit length is formulated using integer coding with each bit representing a different water saving measure. These include four 'non-tank' measures – low-flow showerheads, dual flush toilets, 4-star washing

[1] Landlords, rather than tenants in South Australia, generally pay the water supply and first 136kL of volumetric tariff charge.

machines and pool covers and 16 combinations of rainwater tank measures representing 1, 2, 4,and 9kL tanks with end-use connectivity to either outdoor; outdoor and toilet; outdoor and laundry; or outdoor, toilet and laundry end uses. A bit coding of '1' indicates that a rebate of $0 should apply to the measure – i.e. it should not be subsidised - and a coding of '2' through '9' represent increasing increments of subsidy as a proportion of the typical acquisition and installation cost of the measure.

Forecasting Uptake

To demonstrate the proposed optimization framework, uptake for a given policy combination is forecasted using observed relationships derived from analysis of Australian programs. That is, we model uptake for a low-flow showerhead rebate of $30 in South Australia to occur at the same rate as the observed South Australian data fitted to a linear regression. To forecast consumer response to rebates at other, previously unoffered and unobserved prices, we apply the economic concept of elasticity - the ratio of percentage change of one variable to the percentage change in another variable – as a method to estimate response to a new policy of rebate prices. A price elasticity of rebate uptake, $E_{U_k,P}$, is proposed in Eq 1 to measure the responsiveness of the cumulative uptake rate of rebates to a change in rebate level. A value of 1.658 was derived from Victorian uptake data. The level of uptake at each time step, shown in Eq 2, is a major driving input into the cost and water saving models.

$$E_{U_k,P} = \left| \frac{\frac{U_{k\ ext} - U_{k\ obs}}{U_{k\ obs}}}{\frac{P_{k\ ext} - P_{k\ obs}}{P_{k\ obs}}} \right| \qquad \text{Eq 1}$$

$$U_{t,k} = Hs * \left(\left(U_{k\ obs} * E_{U_k,P} * \frac{P_{k\ ext} - P_{k\ obs}}{P_{k\ obs}} \right) + U_{k\ obs} \right) * t \qquad \text{Eq 2}$$

Where *Hs* represents the number of households within the target area, $E_{U_k,P}$ is the empirically derived price elasticity of rebate uptake, $U_{k\ obs}$ is the observed rate of uptake for a measure k at an observed rebate level of $P_{k\ obs}$, $U_{k\ ext}$ represents the slope coefficient of cumulative normalised uptake for a new rebate level, $P_{k\ ext}$, and t is the number of months from the start of the rebate program.

Evaluating Cost

The objective of cost is evaluated from the perspective of the policymaker. At each monthly time step, the rebate level for a given measure, plus an administrative loading, is multiplied by the number of rebates taken up. These costs are discounted back to a net present value. Cost can also be evaluated from the perspective of program participants, society or a weighted sum of all three. An 8% discount rate is applied in addition to a 12% administrative cost loading based on empirical estimates of Western Australia's *Waterwise* program.

Evaluating Water Savings

The objective of water saving is assessed by evaluating the sum of water savings achieved in the duration of the rebate program (Eq 3) and the annual yield achieved by measures after the conclusion of a rebate program.

$$Water\ Saved = \left(\sum_{t=1}^{PL} \left[\sum_{k=1}^{DSL} \varphi_k \times U_{t,k} \times (1 - NRR) \right] + \left(\left[\sum_{k=1}^{DSL} (U_{PL} \times (\varphi_k \times 12) \times (1 - NRR)) \right] \times (NSL - (PL * 12)) \right) \right) \qquad \text{Eq 3}$$

Where $U_{t,k}$ is the cumulative uptake of a water saving measure *k* in a given time *t*, φ_k is the monthly water saving value for a given measure *k* as predicted using the dataset of water savings, DSL is the length of the decision string, equal to the number of potential rebate options; PL is the length of the rebate program, NSL is the net saving life of the measures and *NRR* is the non-rebate replacement factor, the percent of water savings measures that would have been uptaken without a rebate offered.

Evaluating Water Savings using an Integrated Urban Water Management Model

Highly variable estimates of water savings from largely similar water saving measures exist in literature and between 'online efficiency calculators' published by many Australian water authorities. Our approach demonstrates the application of a behavioural stochastic end-use model to create improved estimates of water savings achievable by the rebate-induced installation of water saving measures.

The Behavioural End-Use Stochastic Simulator ('BESS') (Thyer et al. 2011) in eWater Urban Developer (Breen et al., 2006) is applied to create datasets of water savings achieved when a water saving measure is installed. Urban Developer is a water balance model which simulates discrete end-use events and allows for source substitution from rainwater tanks. Indoor behavioural patterns from a Residential End-Use Study by Roberts (2005) and outdoor end-use data from Barton (2003), Loh and Coghlan (2003) and Coombes and Kuczera (2003) are used for Adelaide, Perth and Melbourne respectively. Temperature, rainfall and evaporation data for January 2001 to December 2010 from Adelaide, Perth and Tullamarine Airports and household occupancy distributions from the 2006 Census are used as model inputs. A simulation of annual water demand for a household of typical size, appliance stock and occupancy is run to create a baseline reference for each of the three case study locations. Appliance efficiencies such as toilet and showerhead standards are then changed and the model resimulated to obtain an annual water demand due to rebate-induced demand management.

Our analysis identified extreme variability in water saving yield for rainwater tanks due to climate differences. For instance, 1kL rainwater tanks used for outdoor irrigation provide 7.67kL/year of avoided mains demand in Adelaide compared to 15.13kL/year of avoided mains demand in Melbourne. Water saving yield from indoor retrofits depend on behaviour and occupancy whilst water saving yield from rainwater tanks depend on rainfall, roof area connectivity ratio, re-use configuration and tank size.

These estimates differ to arbitrary yield models used by many policymakers – Victorian savings estimates are based on an assumption that a rainwater tank of any size will fill and empty 7.5 times a year for outdoor irrigation. A 9kL rainwater tank connected to outdoor end-uses was estimated to yield water savings 7kL/year higher than our predictions. Through the use of an integrated urban water management model, our approach balances both rainwater harvesting potential and end-use demand to accurately model mains reduction achieved by rainwater tanks.

POTENTIAL POLICY & DISCUSSION

This framework is demonstrated to develop a Pareto efficient tradeoff curve for two case study programs – Western Australia and South Australia. This is demonstrated in Figure 2. The x-axis represents the water savings achieved by a rebate program - accounted for during a rebate program of arbitrary five years and then assuming measures have an average ‘net saving life’ of five years after the conclusion of the program. The y-axis represents cost to the policymaker, expressed as a levelised unit cost – the cost of all rebate measures and administrative costs, adjusted for the opportunity cost of capital; divided by the water savings achieved.

The shape of the Pareto curve demonstrates the trade-off which exists in achieving greater volumes of water savings. At lower target water savings, the genetic algorithm identifies low-flow showerheads are the most cost-effective solution leading to improved cost efficiency. To encourage greater uptake and larger water savings, rebate levels increase, leading to reduced cost efficiency. Toward the right of the Pareto curve, the least cost efficient measures – indoor end-use connected rainwater tanks – become part of the Pareto optimal combination of rebates. Subsidising only the most cost efficient of measures – low-flow showerheads – achieves limited volumes of yield

The two curved lines in Figure 2 represent all non-dominated combinations of policy for South Australia (lower) and Western Australia (upper). The Western Australian frontier lies further within the optimal space – more efficient solutions are able to be achieved due to higher observed uptake of measures at lower rebate levels compared to the observed South Australian program.

The two horizontal lines represent estimates of the long-run marginal cost of supply – that is, the levelised cost associated with the next possible expansion in supply - in Western Australia ($1.08/kL) and South Australia ($2.40/kL). Points on the Pareto frontier which lie below these lines represent policy configurations which would induce sufficient uptake in order to deliver water savings lower than the cost of supply expansion. The intersection of the curved Pareto frontier and the horizontal lines of long run marginal cost represent economically efficient *and* Pareto optimal solutions. For South Australia, this corresponds to rebate policy which applies rebates of half of the retail cost to indoor appliances and pool covers, delivering a program cost of $101.3m and an estimated water saving of 42.55GL for a 10-year period.

Applying an optimisation algorithm which evaluates the entire Pareto front in one run facilitates posterior articulation of preferences from policymakers. They are able to identify the various configurations of policy which are able to meet objectives at either constrained budgets or for target water savings.

On this chart we also model reference points of past Western Australian and South Australian programs. These correlate to the water savings and cost which could have occurred given the actual numbers of uptake, evaluated with our water savings dataset and cost model. These reference points exclude the water savings achieved by, and costs incurred from, measures our demonstration did not include due to lack of data but were part of the programs – e.g. garden measures, groundwater bores. This allows for a ‘like for like’ comparison. Immediately evident on this chart is the fact that these two reference points lie within the dominated area of the Pareto curve. The horizontal distance that these points lie above the curve, multiplied by the water savings achieved, represents the potential cost savings which could have been realised if rebate choices and prices were optimally formulated. For South Australia, this represents removing rebates for 1000L tanks, reducing the rebate incentive for washing machines and most tank rebate options and increasing the rebate incentive for showerheads and pool covers to $60 and $300 respectively.

CONCLUSION

This research develops and demonstrates a new framework for Australian and international policymakers to formulate optimal rebate policies for water saving measures to reduce household water consumption. Multi-objective genetic algorithm optimisation techniques were successfully applied for the first time in this context to allow policymakers to develop a Pareto efficient frontier of optimal policy mixes.

A review of historical rebate programs produces new knowledge about the drivers and expected response of Australian consumers to rebate programs. Applying behavioural end-use stochastic simulation, this research demonstrates a new method of estimating water savings from retrofit and rainwater tank installation measures.

Through the application of a formal optimisation framework, our results demonstrate that improved economic and environmental outcomes can be achieved. Current methods of evaluating program success – through ex-post economic analysis – are plagued as they are retrospective and often rely on poor or exaggerated water savings estimates. Least cost planning methods which identify the levelised cost of measures in isolation are useful only to formulate policy when budgets are unconstrained. Our framework improves upon both through ex-ante estimation of yield and cost with an uptake model, improved estimates of water savings and consideration of measures in combination.

Table 1 – Potential improvements from the application of the proposed framework for three case study schemes

		Cost ($m)	*Water Saved (GL)*	*$/kL*
SA	Previous Rebate Scheme	$48.2	19.3	2.50
	Economically Efficient	$101.3	42.6	**2.38**
	At Similar Water Saved	$27 (**-44%**)	19.5	1.39
WA	Previous Rebate Scheme	$22.8	19.2	1.19
	Economically Efficient	$54.5	52.1	**1.05**
	At Similar Water Saved	$9.7 (**-58%**)	19.1	0.51

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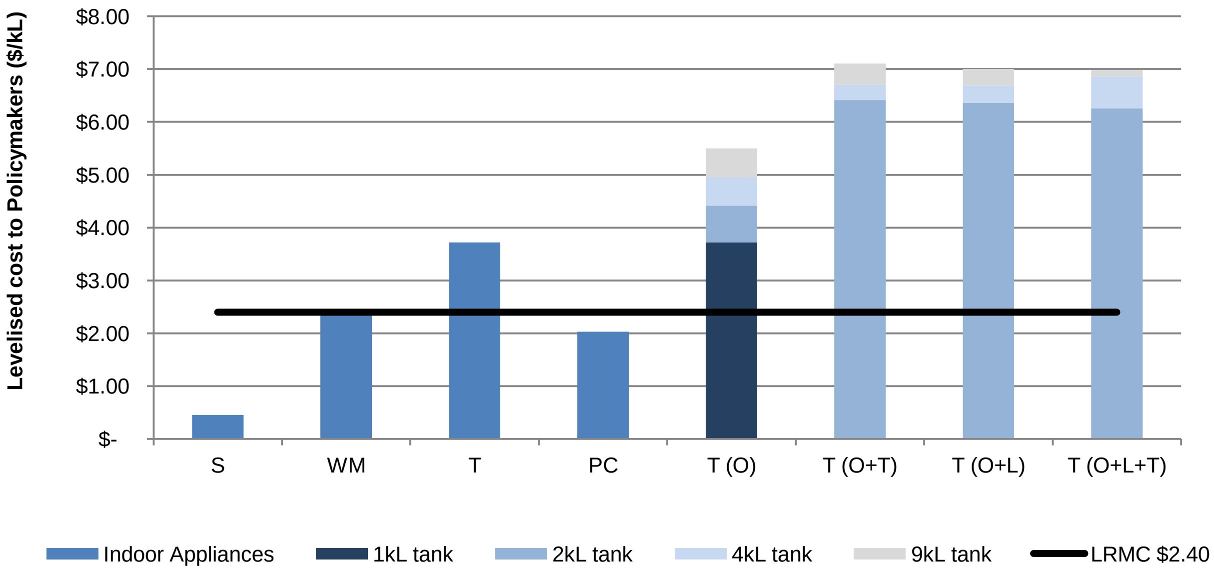

Figure 1: Levelised unit cost of water to the Policymaker for various South Australian rebates.[2]

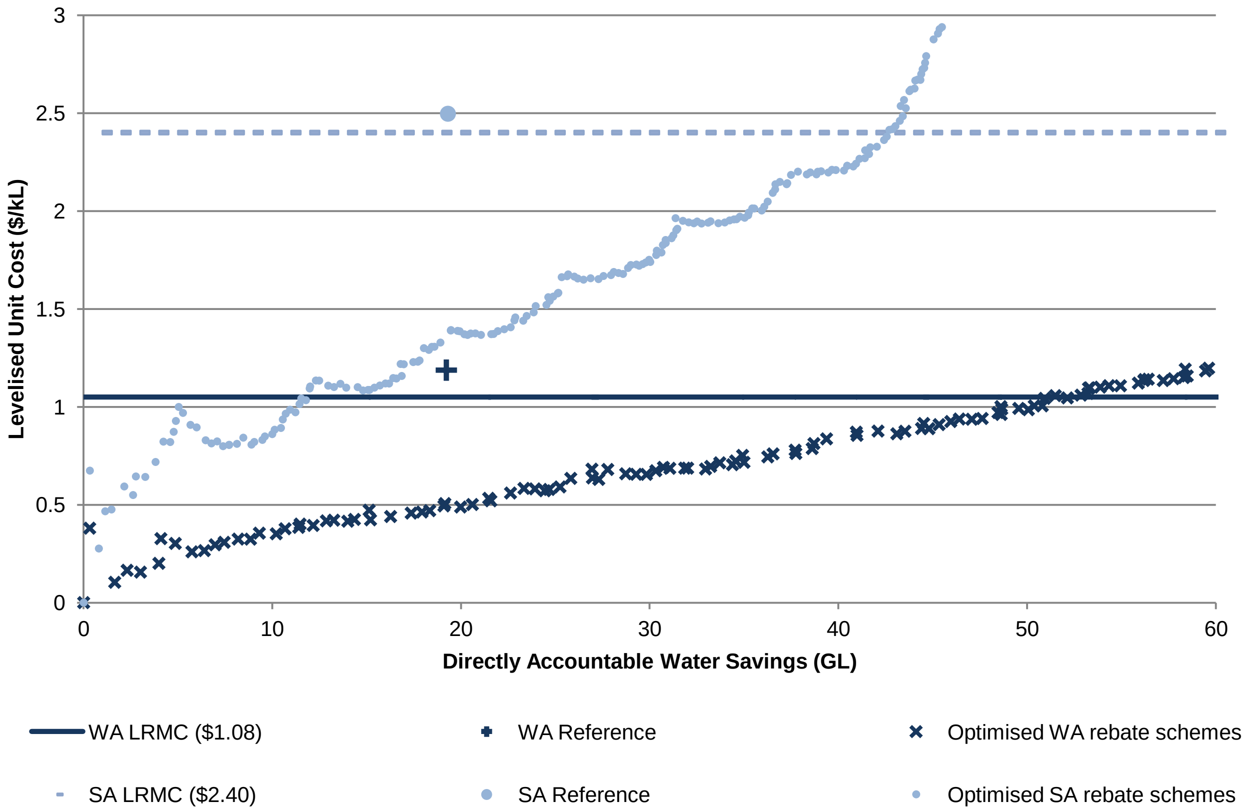

Figure 2: Economical analysis of Pareto efficient solutions showing the economically efficient option for both South Australia and Western Australia

[2] S=low-flow showerhead, WM=Front loader washing machine, T=Dual flush toilet, PC=Pool cover, T(O)=standalone tank, T(O+T)=Tank plumbed into outdoor and toilet, T(O+L)=Tank plumbed into outdoor and laundry, T(O+L+T)=Tank plumbed into outdoor, laundry and toilet.