The Capitalized Value of Rainwater Tanks in the Property Market of Perth, Australia[*]

Fan Zhang*, Maksym Polyakov, James Fogarty, David J. Pannell

Cooperative Research Centre for Water Sensitive Cities and School of Agricultural and Resource Economics, The University of Western Australia, Crawley, WA 6009, Australia

* Corresponding author: E-mail address: fan.zhang@uwa.edu.au

Phone: +61 08 6488 5505

Fax: +61 08 6488 1098

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Abstract

In response to frequent water shortages, governments in Australia have encouraged home owners to install rainwater tanks, often by provision of partial funding for their installation. A simple investment analysis suggests that the net private benefits of rainwater tanks are negative, potentially providing justification for funding support for tank installation if it results in sufficiently large public benefits. However, using a hedonic price analysis we estimate that there is a premium of up to AU$18,000 built into the sale prices of houses with tanks installed. The premium is likely to be greater than the costs of installation, even allowing for the cost of time that home owners must devote to research, purchase and installation. The premium is likely to reflect non-financial as well as financial benefits from installation. The robustness of our estimated premium is investigated using both bounded regression analysis and simulation methods and the result is found to be highly robust. The policy implication is that governments should not rely on payments to encourage installation of rainwater tanks, but instead should use information provision as their main mechanism for promoting uptake. Several explanations for the observation that many home owners are apparently leaving benefits on the table are canvased, but no fully satisfactory explanation is identified.

Keywords: economic valuation; urban rainwater collection; spatial hedonic model; misclassification error

1 Introduction

Globally, there is a growing awareness that rainwater harvesting systems can make a contribution to water supply security and also reduce stormwater run-off. This awareness has resulted in European, North American, and Australian governments promoting rainwater harvesting systems. For example, in Britain, rainwater harvesting has been included as an element in government-supported social-housing projects, and in the U.S., several states, including Ohio, Washington and Texas, are considering or have already developed guidelines or regulations for rainwater harvesting systems (Jones 2010). In Santa Fe County, New Mexico, rainwater harvesting systems are required features on new residential and commercial structures that are larger than 2,500 square feet (Texas Water Development Board 2005). In Australia, governments and water utilities have implemented a variety of financial incentive programs to encourage the installation of rainwater tanks. For example, the National Rainwater and Greywater Initiative -- a nationwide program that ran from March 2009 to May 2011 -- provided up to AU$500 for each household installing a rainwater tank. Sydney Water Corporation offered a rebate of up to AU$1,500 for the installation of a rainwater tank during the period 2002 to June 2011. From July 2007 to June 2009, Water Corporation (Perth, Western Australia) offered a AU$50 rebate for the installation of rainwater tanks of at least 600L; and, at the same time, a rebate to a maximum value of AU$600 for rainwater tanks of at least 2 kL that were plumbed into a toilet and/or washing machine. A review of total installation cost information (e.g. AU$2,109 for a 2 kL tank and AU$2,464 for a 5 kL tank (Tam et al. 2010), discussed in detail below) reveals that in some Australian jurisdictions rebates covered more than half the purchase and installation cost of a rainwater tank.

Subsidies for rainwater tanks continue to be available in a number of Australian jurisdictions, including Western Australia, South Australia, and the Northern Territory, and recent research indicates that subsidies are likely to increase the adoption of decentralised water collection systems such as rainwater tanks (Tapsuwan et al. 2014).[1] However, it is not clear how important installation cost is a consideration for consumers purchasing a rainwater tank. For example, based on information collected as part of the ABS Water Use Conservation Survey (ABS 2013), where respondents were able to select multiple options, only 5% of respondents indicated that rebates were a reason for installing a rainwater tank.

If subsidies to support the adoption of decentralised water collection and supply technologies are to have a positive impact on total social welfare, there must be net public benefits following the adoption of these technologies. The potential public benefits could be in terms of the savings that come from the ability to defer large-scale investments in new water infrastructure projects, such as desalination plants (Tam et al. 2010; Gardner and Vieritz 2010) or, depending on the extent of adoption, potential flood mitigation benefits (Zhang et al. 2010). The public cost is the value of the subsidies provided. The private benefits from the installation of a rainwater tank include lower water-supply charges, and, in locations with water restrictions, access to restriction-free water during periods of water restrictions. Private benefits could, however, be substantially overestimated by residents if they do not have experience with the storage capacity and refilling reliability of rainwater tanks, an issue we explore in later discussion. The private cost is the installation and maintenance cost of the system.

For scenarios where there are both public and private costs, and or public and private benefits, the framework of Pannell (2008) can be used to establish the appropriate public policy response. In the Pannell framework, policy responses are grouped into five broad types: (i) positive incentives to encourage publicly desired changes, including subsidies, the main

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[1] www.savewater.com.au/products/rebates-incentives [accessed 6 June 2013].

mechanism used in Australia to promote rainwater tank adoption; (ii) negative incentives to discourage adverse changes, often including polluter-pays mechanisms such as pollution taxes; (iii) information-provision activities, which includes demonstration projects as well as communication activities; (iv) support for technological development; and (v) informed inaction.

Noting that benefits minus costs can be referred to as net benefits, the relevant policy space under the Pannell framework is shown in Figure 1. In the figure, the upper right quadrant is the space where there are both public and private net benefits, and here the appropriate policy response is to provide information: rational consumers will adopt the technology if they are made aware of the benefits. (In this framework private benefits are measured without any incentive payments or penalties. These may be recommended as an output of the framework.) In the lower right quadrant, if the net private benefits are greater than the public costs, then no action is appropriate. If, however, the public costs are greater than the private benefits, negative incentives are appropriate. In the bottom left quadrant there are both public costs and private costs and no action is required: rational private consumers are unlikely to embrace a technology that lowers their welfare, provided that they have accurate information about it. In the upper left quadrant, if the private costs are greater than the public benefits, investment in technology development to attempt to increase public benefits or reduce private costs may be appropriate if suitable investments are available, otherwise the recommendation is no action; and if the public benefits are greater than the private costs, positive incentive policies are appropriate. Using this framework, for subsidy policies to support the adoption of rainwater tanks to be appropriate there should be net public benefits and net private costs from the installation of rainwater tanks that are less than the net public benefits.[2]

A number of studies find that the average cost of water collected from rainwater tanks is higher than mains water, especially in cities with large seasonal rainfall variations (Tam et al. 2010; Rahman et al. 2012; Coombes et al. 2002; Grafton and Ward 2008). In a new investment analysis for Perth (Appendix A), we too find that there are net private costs from the installation of a rainwater tank. For a 2 kL installation, the benefit: cost ratio under the base-case assumptions was 0.46 (range under sensitivity testing 0.22-0.71); and for a 5 kL installation the benefit: cost ratio for the base case was 0.43 (range under sensitivity testing 0.20-0.65). So, using a traditional approach to project evaluation, installation of a rainwater tank is associated with net private costs. Under the Pannell framework, the appropriate policy response would then be subsidy polices if the public benefits are greater than the private costs; or investment in technology development or no action if public benefits are less than private costs.

However, this investment analysis, in common with those cited above, considers only benefits arising from cost savings through purchasing less mains water. In reality, home owners with rainwater tanks may experience additional benefits beyond these cost savings – benefits from pleasure at perceived environmental benefits, from contributing to broader social goals, or from conforming with the behaviour of an esteemed group within society. If these additional benefits are substantial enough, and sufficiently common, we would expect them to be capitalised into property values. If this occurs, it changes the benefit-cost evaluation and

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[2] Once transaction costs and implementation lag issues are considered the sample space changes slightly relative to that shown in Figure 1. Specifically, in the upper right quadrant, along the vertical, there is some space where positive incentives will be appropriate; and, along the horizontal, there will be some space where no action is appropriate. For a detailed discussion of these issues see Pannell (2008).

this may have consequences for policy. For example, when there are positive net private benefits and positive net public benefits, under the Pannell framework the appropriate policy response is information provision, rather than subsidies.

The specific questions we investigate in this study are: (a) does a house with a rainwater tank sell for a higher price than a house without a rainwater tank? (b) If so, what is the premium? and (c) Is the premium larger than the value of water savings? To answer these questions we use the hedonic price method. The method has been used to study the way house improvements, such as bedroom and kitchen renovations, are capitalised into house prices (Harding et al. 2007; Wilhelmsson 2008), and to estimate the extent to which environmental and recreational assets such as street trees, parks, green space, and air quality are capitalised into house prices (Geoghegan et al. 1997; Irwin 2002; Acharya and Bennett 2001; Polyakov et al. 2013), so it is well suited to these research questions.

2 Methods

2.1 Study area

The case study location is Perth, Western Australia. Perth, with a population of around two million, is the capital city of the state of Western Australia and is Australia’s fourth largest city. Perth has a Mediterranean climate which is generally cool and wet in winter, and hot and dry in summer. Perth residents are subject to both short-term and long-term water restrictions. Short-term restrictions focus on temporary bans on non-essential water usage for things such as garden irrigation. Long-term restrictions, known as permanent water efficiency measures (PWEMs) were introduced in 2007. Current PWEMs include a winter sprinkler ban, which applies to all schemes and bore water users in Perth from 1 June to 31 August each year; and enforcement of a sprinkler roster system, which allows the usage of domestic garden reticulation systems for a maximum of 3 days per week from 1 September to 31 May each year. During this period, a total usage ban applies from 9am to 6pm each day, with fines applying for restriction violations.[3] Installation of a rainwater tank could therefore give residents the flexibility and freedom to water their garden at a time and frequency of their choosing (subject to availability of water in the tank). The current rainwater tank installation rate in Perth is less than ten percent, which is low relative to some other Australian cities (ABS 2013).

2.2 Model specification and data

The hedonic price method expresses total house price as a function of house attributes, plus a random error term. The specific model we use for the analysis includes house-specific attributes; time-specific variables that control for the general rise and fall in house prices; and location-specific variables that control for spatial effects. The house-specific attributes included in the model are: number of bedrooms; number of bathrooms; number of other rooms (including dining rooms and study rooms); brick wall or non-brick wall construction; tile roof or non-tile roof; number of carports; number of garages; presence or absence of a pool; house age; and land area. To control for the effect of time, quarterly dummy variables are used. To control for spatial effects, regional dummy variables are used, where a region is defined as a Level 1 Statistical Area (SA1). The SA1 is designed to be the smallest area of output for the Australian Census of Population and Housing, and is stable between censuses.[4] In the Perth metropolitan area there are 3,367 SA1s. In the hedonic price literature, models that include location dummy variables are referred to as spatial fixed effect models. Although there are other approaches that can incorporate spatial effects into a regression model, such as the spatial error model, due to potential measurement error issues the spatial fixed effect model is thought the most appropriate specification for this study.

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[3] www.water.wa.gov.au/Managing+water/Domestic+garden+bores/default.aspx#1 [accessed 8 October 2014].

[4] www.abs.gov.au [accessed 6 June 2013].

Formally, the hedonic model estimated can be written as:

$$P_{ijt} = \alpha + \boldsymbol{\beta}'\mathbf{x}_{it} + \boldsymbol{\delta}'\mathbf{d}_{it} + \boldsymbol{\gamma}'\mathbf{r}_{ij} + \varepsilon_{ijt}, \qquad (1)$$

where P_{ijt} is the observed sale price of house *i*, in area *j*, at time *t*; $\mathbf{x}_{it}$ is a vector of house-specific attributes; $\mathbf{d}_{it}$ is a dummy variable vector that takes the value one if house *i* sold at time *t*, zero otherwise; $\mathbf{r}_{ij}$ is a dummy variable vector that takes the value one if house *i* sold in location *j*, zero otherwise; and ε_{ijt} is a zero mean random error term. The $\boldsymbol{\beta}'$, $\boldsymbol{\delta}'$, and $\boldsymbol{\gamma}'$ are parameters to be estimated. Specifically, the $\boldsymbol{\beta}'$ provide estimates of the implicit price of different house attributes; the $\boldsymbol{\delta}'$ provide estimates that can be used to create a house price index; and the $\boldsymbol{\gamma}'$ provide estimates of the spatial effects.

House sale price information and primary property characteristics were obtained from Landgate: the government agency responsible for recording land transactions in Western Australia. Information on the presence of a rainwater tank was obtained from a real estate website.[5] Specifically, the presence of a rainwater tank was recorded by real estate agents as an “Eco friendly” feature. The range of eco-friendly features that a real estate agent might identify include whether or not a house has solar panels, whether a house has a rainwater tank and or a grey-water system, and whether the house has a specific energy efficiency rating. Here we focused our attention on houses where the “water tank” feature was recorded as present. The addresses of houses with rainwater tanks were then matched with the Landgate data. The sample includes 77,234 properties sold over the period 2008-2012 in the Perth metropolitan area. To ensure rural properties were excluded from the sample, a search restriction was used to limit the sample to single family homes with land area less than 5,000m^2. Among these

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[5] www.realestate.com.au [accessed 6 June 2013].

properties, a rainwater tank was recorded as present for 155 properties. Summary information on the data set is provided in Table 1.

3 Results

3.1 Baseline results

The specific functional form of a hedonic model is a matter to be determined by the data (Triplett 2006). As such, the Box-Cox method was used to test alternative model specifications and a log-linear model was found to be the most appropriate functional form. Equation 1 was then estimated in SAS 9.3 via least squares, with heteroskedastic robust standard errors used for hypothesis testing.

Summary regression results are shown in Table 2. As the sample is large, implicit attribute values are estimated with precision, and all variables included in the model are statistically significant at conventional levels. Although the standard house attribute variables are not the variables of primary interest for this study, the implicit attribute prices for these variables are largely as expected. For example, more rooms, carports and garage spaces, greater land area, and brick construction all result in higher sales prices. In the model, house age enters as a quadratic, and the estimated coefficients imply house prices fall with each additional year until houses are 55 years old. At this point house prices start to increase again. Around 91 percent of the houses in the sample are less than 55 years old. There are a small number of houses (49) that are older than 111 years; the point at which, other factors constant, the regression coefficients imply that an old house trades for more than a new house. Given these very old houses are likely to have significant heritage value, the implied implicit price effect for house age seems reasonable.

For this study the coefficient of primary interest is the coefficient on the rainwater tank dummy variable, which is 0.0370 as shown in Table 2. Following the Kennedy (1981) approach to the interpretation of dummy variable coefficients, the presence of a rainwater tank appears to add $(\exp(0.037-(0.5\times 0.01))-1)\times 100$ = 3.76% to the value of a house. Evaluated at the sample median (AU$485,000) this implies a rainwater tank adds around AU$18,000 to the value of a typical Perth house. A more conservative approach to assessing the implied value of a rainwater tank might be to evaluate the implicit value using the 95% Confidence Interval lower bound for the rainwater tank coefficient (0.0174), and the lower bound of the interquartile range for house prices (AU$390,000). Using this approach the implied additional capital value added to a house when a rainwater tank is present is around AU$6,700. By comparison, our estimate of the value of water savings from a 2 kL installation collecting water from half the roof (discounted at 5 per cent real over the expected 15 year life of a tank) is AU$665 (Appendix A). Clearly, the majority of the price premium is attributable to factors other than the financial value of water savings.

The cost of installation is a sunk cost and should not influence the house price premium if house purchasers are rational. However, a comparison of the installation cost with the price premium is of interest because it indicates whether home owners have an incentive to install a rainwater tank even if they have no non-financial motivations themselves. We find that our lowest estimate of the price premium is higher than the reported installation cost for adding a rainwater tank, although if we consider the cost of time required to research, purchase and install a rainwater tank, the net benefit of installation may be small, at least for our lower-bound estimate of the premium. On the other hand, our most-likely estimate of an AU$18,000 premium for a median house is much larger than the installation cost, even allowing for additional time costs. This finding has implications for what constitutes the most appropriate public policy response.

3.2 Misclassification – a bounded regression approach

There is no reason to expect that the proportion of houses in the sample that have a rainwater tank installed would match the Perth rainwater tank installation rate. For example, if consumers think of rainwater tanks as an expense item rather than a capital asset, it is reasonable to expect that the proportion of sales observed where a rainwater tank is present would be substantially less than the population installation rate. For the sample period, Australian Bureau of Statistics information suggests that the rainwater tank installation rate in Perth was around 8% (ABS 2010), but fewer than 1% of houses in the sample had a rainwater tank. This suggests the possibility that the presence of a rainwater tanks has been under-reported in the sample data, which is a data misclassification issue. As a general rule, if the R^2 value in a least square regression is high, measurement error issues are unlikely to have a significant effect on the coefficient estimates (Hausman 2001). As the R^2 value for the regression is above 0.90, this general rule of thumb provides some confidence that measurement error issues are unlikely to have had a significant impact on the estimated coefficients; but measurement error is an issue that should be formally investigated.

There is a substantial literature on measurement error in continuous variables, but the literature relating to measurement error in dummy variables is much smaller. A review of the relevant literature does, however, indicate that in general measurement error for a dummy variable results in estimates for the mis-measured variable that are biased downward (Aigner 1973; Klepper 1988; Hausman 2001). This in turn suggests that our estimate of the additional capital value added to a house when a rainwater tank is installed can be interpreted as a conservative estimate.

The most common solution to measurement error in a continuous variable is the instrumental variables approach; but this approach is not well suited to the case of dummy variable misclassification. Further, in this specific case we have no plausible instruments. An alternate approach to dealing with measurement error issues is to estimate upper- and lower-bounds for the mismeasured regressor (Klepper and Leamer 1984; Bollinger 1996; Bollinger 2003; Deng and Hu 2009). Here we base our approach on the framework presented in Bollinger (1996). For our specific case the lower-bound estimate is the estimate from the base regression where we assume there is no measurement error. The formal model used to estimate the upper bound is set out in Appendix B, but the key assumptions relied upon to estimate the upper bound are that: (i) there is no correlation between the misclassification error and the other regressors; (ii) the misclassification rate is less than 100 percent; (iii) the nature of the misclassification problem is that some houses that have a rainwater tank are sold without this feature being identified in the sales data set.

Without non-sample information the estimated upper bound can be large. However, if non-sample information is available, it is possible to shrink the upper bound estimate. Following Bollinger (1996), estimation of the upper bound for the rainwater tank variable with no additional non-sample information implies a value of 227, which is implausibly large. In the current application the relevant non-sample information is the rainwater tank installation rate in Perth. We expect that, in general, people installing rainwater tanks are unlikely to place their house on the market shortly after they install a rainwater tank. We therefore expect the maximum extent of misclassification to be associated with a true installation rate in the sample (much) lower than the reported rate of 8%, but we consider cases up to an installation rate of 8% as the extreme bound for misclassification.

Assuming different values for the true proportion of houses in the sample with a rainwater tank (up to 8%), and using the observed number of sales with a rainwater tank in the sample, it is possible to calculate the implied misclassification rate. Based on the assumed misclassification rate it is then possible to estimate the upper bound for the rainwater tank coefficient, as well all other house attributes. The result of this process is summarised in Table 3. In the table the column headings represent the extent of variable misclassification; so $K=0$ implies no misclassification and corresponds to the base case regression, while $K=0.9514$ corresponds to a misclassification rate of 95.14%, which the point where the bounding regression approach broke down.

If we consider the rainwater tank row of Table 3, it can be seen that for misclassification rates in the sample data of up to 60%, the upper bound estimate is still quite close to the lower bound ($K=0$) estimate. Even with a misclassification rate of 80% the upper bound estimate still implies a range for the true effect that allows meaningful inferences to be made. With misclassification rates above 80% the upper bound estimate for the rainwater tank coefficient starts to rise sharply; and for misclassification rates above 95.14% the bounding regression approach breaks down. The general pattern of results, however, suggests we can be confident in the finding that adding a rainwater tank to a house results in an increase in the capital value of the house. Recall that from a public policy perspective what is relevant is whether or not there are positive net private costs or benefits; we do not need an exact estimate of the net private benefits, we just need to establish whether there are positive net private benefits. For the other house attributes, by reading across each row of the table it can be seen that for misclassification rates of up to 90%, the implicit attribute values are essentially unchanged. At misclassification rates higher than 90% the implicit attribute price estimates start to move around substantially.

3.3 Misclassification – a simulation approach

The implication of misclassification, including extreme misclassification, can also be explored using a simulation approach. For the simulations we consider the case where we set the true population installation rate for rainwater tanks at 2%, 4%, 6%, and 8%. For each scenario we then generate a data set of 60,000 observations, where the independent variables used are a simplified version of the variables in Table 2. Consistent with our actual empirical model we work on a log scale for the simulations. The specific variables and distribution assumptions used for the simulations are: number of bedrooms (1 to 8, uniform distribution); number of bathrooms (1 to 8, uniform distribution); land area (mean 6.499, SD 0.365, normal distribution); rainwater tank (0 or 1, uniform distribution); error term (mean 0, SD 0.12, normal distribution). To investigate the effect of misclassification we systematically work through misclassification rates for the rainwater tank variable of 1% to 99%, in one percentage point increments, where at each step we run 10,000 simulations.

The misclassification simulation results are summarised in Figure 2. In each simulation the true value for the rainwater tank coefficient is 0.037, and in each plot this is indicated by the dashed line. The solid line in each plot indicates the mean estimate for the value of the rainwater coefficient under each level of misclassification. As can be seen from each individual plot, as the extent of misclassification increases, the coefficient estimate on the rainwater tank is increasingly biased downwards, although the extent of the bias is modest. By looking across the plots it can also be seen that for a given misclassification rate the extent of the bias increases with the underlying installation rate. In each plot the grey shading indicates the 95% confidence interval for the distribution, and as can be seen, as the extent of misclassification becomes extreme, the distribution spread increases exponentially.

When we used an approach informed by Bollinger's bounding regression insight, the model broke down once the misclassification rate reached 95.14%. The simulation approach allows us to explore extreme misclassification rates. For example, if the true underlying rainwater tank installation rate in our sample was 8%, then, given the number of observations in the sample with a rainwater tank, the misclassification rate is 97.49%. For this scenario, the simulation mean estimate is 0.0342, with 95% CI 0.0147-0.0538. Again the result provides us with reassurance that our initial finding that rainwater tanks represent an addition to homes that adds capital value is a reliable and robust finding. Even under the most extreme case of variable misclassification the key result holds: the addition of a rainwater tank to a house increases the value of the house.

4 Discussion

4.1 Why is the implicit price for rainwater tanks so high?

The most striking result is that it appears likely the price premium for rainwater tanks is well in excess of the cost of installation, and yet a small minority of home owners have chosen to install a tank. There are a number of plausible explanations for this apparent shortfall in installations. The first possible reason, as outlined earlier, is that the full cost of installation is greater than the financial cost, so that the benefit exceeds the cost for fewer home owners than we might expect. When installing a rainwater tank the actual purchase price is only one element of the total price.

Home owners first need to conduct some research on local planning regulations and engage with the local council to determine where on their property a tank can be located. Next, the home owner has to search across the various products offered by the different manufactures and select the most appropriate tank. This activity is likely to involve a number of visits to different manufacture display show rooms where travel time can be considerable. Furthermore, the installation process will normally require the home owner to be present during normal office hours for at least part of a day. Finally, a rainwater tank occupies space in the yard, which could have been used for other purposes. For example, a standard 5 kL rainwater tank has a diameter of 1.7 metres.[6] Combined, these factors, that do not have an explicit market price but do have a real opportunity cost, representing a substantial cost that is in addition to the tank purchase price. For our lower-bound estimate of the price premium, it appears that these non-financial costs may be sufficient to explain the observed low level of installation. However, for higher estimated premium levels, this is unlikely to be a sufficient explanation.

The second possible explanation for the installation shortfall is information asymmetry. Specifically, unless a prospective home buyer has previous experience with use of a rainwater tank in a Mediterranean climate, it is possible that the prospective home buyer will overestimate the potential water savings from a rainwater tank. For example, when working through the initial investment assessment (Appendix A) it was assumed that demand for outdoor water in the summer months would be 46 kL, but due to the capacity constraint on storage the level of this demand that could be met by a typical urban rainwater tank installation over summer was only 7.6 kL. It is not clear that every potential home purchaser will be aware of the way the storage constraint limits the amount of water that is actually available for use during summer

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[6] www.willoughby.nsw.gov.au/environment---sustainability/water/rainwater-tanks [accessed 26 November 2014].

periods, or the reduction in water supply reliability during drought conditions. Some home buyers may therefore overestimate the value of a rainwater tank. For this to be a full explanation, it would be necessary for this information asymmetry to affect house purchasers, but not existing home owners considering the installation of rainwater tanks. This is, perhaps, questionable, although the latter group may indeed be more likely to become better informed about the benefits of rainwater tanks through conducting research to inform the purchase decision.

A related information asymmetry issue could be that some people are unaware of, or have misperceptions about, the price of water. Rationing access to a good typically implies that the good is in short supply and that the unrationed price would be high. In an environment such as Perth, where permanent water use restrictions are in place, it is possible to imagine that some people may assume that the price of water is greater than it actually is. For example, people may be surprised to learn that the value of 2kL of mains supplied water (enough to fill a typical rainwater tank) is between AU$2.76 and AU$5.22.

Finally, it is worth acknowledging that despite the care taken to estimate an appropriate hedonic model, and the detailed exploration of mismeasurement issues, it is still possible there is some missing attribute from our data set. For example, there could be a missing garden quality variable. Suppose that those home owners who spend an above-average amount of time maintaining their garden are also disproportionally more likely to install a rainwater tank. Given that in Perth it is currently permissible to hand water using mains water all year, there is no reason to think that this correlation actually exists, but let us assume it does. If such a relationship was present, then the average garden quality (something that we do not have information on) would have a positive correlation with the rainwater tank installation variable.

The rainwater tank implicit price would then capture both the pure value of the rainwater tank attribute, and part of the unmeasured garden quality attribute, and hence overstate the value of a rainwater tank. We have no evidence that such a bias exists, but we acknowledge the potential for there to be some factor that has not been accounted for. Nevertheless, given the magnitude of the rainwater tank coefficient, for a missing variable to invalidate the basic findings, the missing variable would have to be both highly correlated with the rainwater tank variable and uncorrelated with all other variables.

Overall, while we are confident that the result reflects real premiums in the housing market, we are not satisfied that we have an adequate explanation for the apparent under-investment in rainwater tanks by existing home owners. We also do not know what would happen to the premium if the proportion of houses with installed tanks was to increase substantially. It is likely that the greater supply of tanks would drive down their implicit price to some extent.

4.2 How broadly relevant are the results?

Although Western Australia is not unusual in having a policy to promote uptake of rainwater tanks, it has characteristics that distinguish it from some other locations. It has a markedly seasonal pattern of rainfall, with less than six days (on average) with at least 1 mm of rainfall between 1 December and 28 February (and 1 mm would not fill a rainwater tank). As a result of public awareness campaigns, its citizens are highly aware of the need to conserve water. They are aware that much of the city's water now comes from two desalination plants, and that the cost of water has risen by a large percentage over the past decade. And they are aware that Perth is one of the cities in the world that appears to have been most affected by climate change, with yearly stream flows having fallen by more than 50 per cent since the mid 1970s, following a 16 per cent fall in rainfall (Silberstein et al. 2012). These characteristics may mean that residents of the city are particularly sensitised to the need for water conservation, resulting in attitudes to rainwater tanks that are not representative of other cities.

Nevertheless, the conclusion that factors other than the dollar value of water savings influence choices about rainwater tanks is likely to be applicable in other cities. The study highlights that conclusions drawn solely from a simple investment analysis can be misleading when it comes to policy formulation.

5 Conclusion

In this study we have used real market data to estimate the implicit price of rainwater tanks once they are installed at homes in the city of Perth, Western Australia. We found that rainwater tanks have an effect similar to that of a home improvement such that once a rainwater tank is installed it results in an increase in the value of the house. This finding has public policy implications. Over the past decade Australian governments and water utilities have provided substantial subsidies to support the installation of rainwater tanks. Such policies are appropriate only if installing a rainwater tank is associated with net public benefits and net private costs. As we find positive private net benefits to rainwater tank installation, subsidy policies are not appropriate. According to Pannell framework, the appropriate policy is, instead, information provision, or perhaps informed inaction, if the public benefits are small.

More generally, the research demonstrates the importance of critically evaluating public policy decisions using a clear evaluation framework. Globally, many jurisdictions face significant challenges in meeting the water supply needs of their citizens. To meet these challenges new ideas and policy approaches for managing water supply security are needed. Governments should be encouraged to trial new approaches, but there should be an objective evaluation process. When a policy is shown to be ineffective or inappropriate the policy should be discontinued or revised.

A specific technical contribution of this paper was the development and presentation of formal expressions that can be used to bind the impact of measurement error in a variable where the measurement error is unidirectional (Appendix B), along with simulation results that illustrate the impact of unidirectional measurement error in a variable.

Appendix A Traditional Benefit-Cost Assessment

Benefit-cost analysis involves comparing the flow of costs and benefits from a project or investment, where the flows are discounted to net present equivalent values. Formally, if we let B_t and, C_t denote benefits and costs incurred at time *t*, and let *r* denote the discount rate, the benefit: cost ratio can be calculated as: $\sum_{t=0}^{T} B_t \big/ (1+r)^t \Big/ \sum_{t=0}^{T} C_t \big/ (1+r)^t$. If the ratio is greater than one the project or investment is worthwhile: the benefits are greater than the costs. Conversely, if the ratio is less than one the costs are greater than the benefits and the investment is not worthwhile.

In the investment analysis the key private costs to consider are the installation cost and the annual maintenance cost. The optimal size of rainwater tanks for domestic water conservation can be determined as a function of annual rainfall, demand for rainwater, house roof area, and the desired reliability of supply (Khastagir and Jayasuriya 2010). However, in practice the average urban residential rainwater tank is thought to be 2 kL; with 5 kL considered to be a large residential tank (Tam et al. 2010). The investment analysis is therefore conducted for tanks of 2 kL and 5 kL, and uses the installation cost values of Tam et al. (2010) of AU$2,109 for a 2 kL tank and AU$2,464 for a 5 kL tank. We further assume an operational life of 15 years and annual maintenance costs of AU$20. For a rainwater tank installation the primary benefit is the water saving, which is a function of rainfall runoff, storage capacity, outdoor water demand, and the price of water. The process of determining the annual benefit is explained below.

The rainwater runoff value for month *t*, denoted R_t, can be calculated as $R_t = m_t \times c \times \alpha \times \sin 65^0$, where m_t is rainfall in month *t*, *c* is the roof collection area in square metres, and α is a coefficient to account for loss due to evaporation and the need to flush the system. Here α is assumed to be 0.9. To obtain calibration values for m_t, average monthly rainfall data from 1972-2013 recorded at the Jandakot Aerodrome station is used.[7] The collection area is defined by home roof size. Marsden Jacob Associates (2009) report the average floor, and hence roof size for new homes in Perth is around 257m^2 for separate dwellings. As such, we assume two values for collection area: 125m^2 (half of the roof area) and 250m^2 (all of the roof area).

Annual outdoor water demand by Perth households is around 116 kL (Marsden Jacob Associates 2009). Information on usage throughout the year, is, however, not reported. Given the monthly rainfall (Table A1) it is clear that the demand for water for outdoor use low in winter and high in summer, and so we use a stylized seasonal water demand pattern. We set the amount of rainwater used in month *t*, denoted U_t as $\min\left(D_t, R_t + S_{t-1}\right)$, where D_t denotes demand for outdoor water; R_t denotes runoff in month *t*, and S_{t-1} denotes the stock of water in the rainwater tank at the start of the month. The resulting values for the amount of rainwater used in each month are shown in the "Used (kL)" rows of Table A1. In practice the decision rule means that in summer months when demand is greatest there is insufficient water available to completely meet the outdoor demand requirement from the rainwater tank.

Perth water charges follow an increasing block price structure. Pricing for the first block is AU$1.381 per kL and pricing in the last block is AU$2.607 per kL.[8] Our preferred

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[7] www.bom.gov.au/climate/averages/tables/cw_009172.shtml [accessed 12 December 2013]

[8] www.watercorporation.com.au/my-account/your-bill-and-charges [accessed 9 July 2014].

approach is to treat the water from the raintank as displacing the marginal unit of water charged at the highest unit rate, but as part of the sensitivity testing we also consider the impact of assuming a value of AU$1.381 per kL.

Table A1 shows the relevant information for the benefit-cost analysis, and by reading down the first column of the table it can be seen that the mean monthly rainfall in December is 11.0 mm, and the assumed outdoor demand for December is 16 kL. For a 2 kL tank with 50 percent of the roof devoted to rainwater collection $R_t = m_t \times c \times \alpha \times \sin 65$ = $11 \times 125 \times 0.9 \times \sin 65 = 1.0kL$, which is the value shown in the Runoff row of Panel A for December. As, in December, $D_t = 16.0$ but $R_t + S$ = $1.0 + 0$ we have the quantity of mains water displaced by raintank supplied water as $U_t = 1.0$. The value of this water is then between AU$1.38 and AU$2.61, with AU$2.61 the preferred value. Similar calculations are then made for the remaining entries in the table, where the table Panel headings describe the specific tanks size × roof collection area combination considered.

Using the information in Table A1 the benefit: cost ratio was then calculated for each tank size × roof allocation to collection × value of water combination using discount rates of 5%, 7%, and 9%. The resulting benefit: cost ratio information is summarised in Figure A1. In the figure the grey bars represent the effect of the assumption regarding the price of water. The figure shows that: (i) the assumed value of water has a significant impact on the benefit: cost ratio; (ii) the benefit: cost ratio increases with a greater allocation of roof area to rainwater collection; (iii) higher discount rates lower the benefit: cost ratio; (iv) the benefit: cost ratio is similar for 2 kL and 5 kL installations; and (v) there is no scenario where the benefit: cost ratio comes close to one.

Appendix B Deriving the upper bounds

To estimate the upper bound in a manner consistent with the insights of Bollinger (1996) the following process was used. First, redefine the model shown at equation (1) to combine all explanatory variables (house specific, time specific and location specific variables) into a general model form, with the variable measured with error -- the rainwater tank dummy variable -- identified separately, and drop the subscript notation to keep the expressions manageable. The model can then be written as:

$$P = \alpha + \beta_1 X_1 + \tilde{\boldsymbol{\beta}}'\mathbf{X}_2 + \varepsilon, \tag{A1}$$

where, P denotes the house sale price; X_1 denotes the rainwater tank dummy variable measured without error; $\mathbf{X}_2$ denotes all other correctly measured variables; and ε is a zero mean error term. In this framework we do not observe X_1, but rather Z_1; which is the rainwater tank variable measured with error. In this application measurement error is in one direction only --we do not think any houses that do not have a rainwater tank are classified as having this attribute -- but more generally, misclassification of a dummy variable can be in either direction. As such, we denote *p* as the probability we observe $Z_1 = 1$ when $X_1 = 0$, and *q* as the probability we observe $Z_1 = 0$ when $X_1 = 1$, and note that we assume $p=0$. Given our assumptions the requirements specified in Bollinger (1996) simplify to:

$$E[\varepsilon \mid X_1, \mathbf{X}_2] = 0$$
$$\Pr[Z_1 = 1 \mid X_1, \mathbf{X}_2, Y] = (1-q)X_1$$
$$\Pr[Z_1 = 0 \mid X_1, \mathbf{X}_2, Y] = (1-X_1) + qX_1$$
$$X_1 \sim Bernoulli(P_{X_1}) \text{ with } 0 < P_{X_1} < 1$$
$$q < 1.$$

These assumptions ensure that mismeasurement does not introduce bias to the other explanatory variables and that the extent of misclassification is not so great that there is no relationship between Z_1 and X_1.

The lower bound in the Bollinger framework is the estimated coefficient of the misclassified variable if misclassification is ignored. So, the lower bound is *b*, the least squares estimate of β_1 in equation A1. Deriving the upper bound involves several steps and some additional notation. Let P^* denote the residual vector from the short regression of P on $\mathbf{X}_2$; and let Z_1^* denote the residual vector from the regression of Z_1 on $\mathbf{X}_2$, with R_{xz}^2 denoting the associated *R*-squared for this regression. Let *d* be the inverse of the slope coefficient for the regression of Z_1^* on P^*.[9] For $\beta_1 \geq 0$ the upper bound is then:

$$\max\left\{d(P_x + (1-P_x)R_{xz}^2) + b(1-P_x)(1-R_{xz}^2),\ d((1-P_x) + P_x R_{xz}^2) + bP_x(1-R_{xz}^2)\right\}.$$

The upper bound, estimated with no additional information, is generally so large as to make inference impractical. However, if additional information is available Bollinger provides an approach that can be applied to tightening the upper bound. Let *K* denote the upper bound to *q* and let *M* denote upper bound to *p*, and as before note we assume *p* = *M* = 0. Bollinger's formulas for deriving the upper bound can then: (i) be expanded to the case of multiple regressors, and (ii) subsequently simplified via the assumption of error in one direction only. Specifically, if:

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[9] Note that *b* can also be derived as the slope from the regression of P^* on Z_1^*.

$d \geq \dfrac{P_x b(1-R_{xz}^2)}{P_x - K\left(\dfrac{P_x}{1-P_x}\right) - R_{xz}^2 P_x}$, the upper bound is: $(1-K)b\left[\dfrac{P_x(1-R_{xz}^2)}{P_x - K\left(\dfrac{P_x}{1-P_x}\right) - R_{xz}^2 P_x}\right]$, otherwise,

$$\max\left\{\begin{matrix} d\left[1-(1-P_x)(1-\left(\left(\dfrac{b}{d}\right)(1-R_{xz}^2)\right)+R_{xz}^2\right] \\ d\left[1-K-P_x+P_x\left(\dfrac{1-P_x}{1-P_x-K}\right)\left(\dfrac{b(1-R_{xz}^2)}{d}+R_{xz}^2\right)\Big]\right] \end{matrix}\right\}.$$

We apply these formulas for different values of K to derive the estimates of the upper bound for the rainwater tank implicit price, and these are the values reported in the body text of the paper. The upper bounds for the other house attribute variables (and the intercept) are obtained via application of Bollinger (1996, p. 394, Theorem 5).

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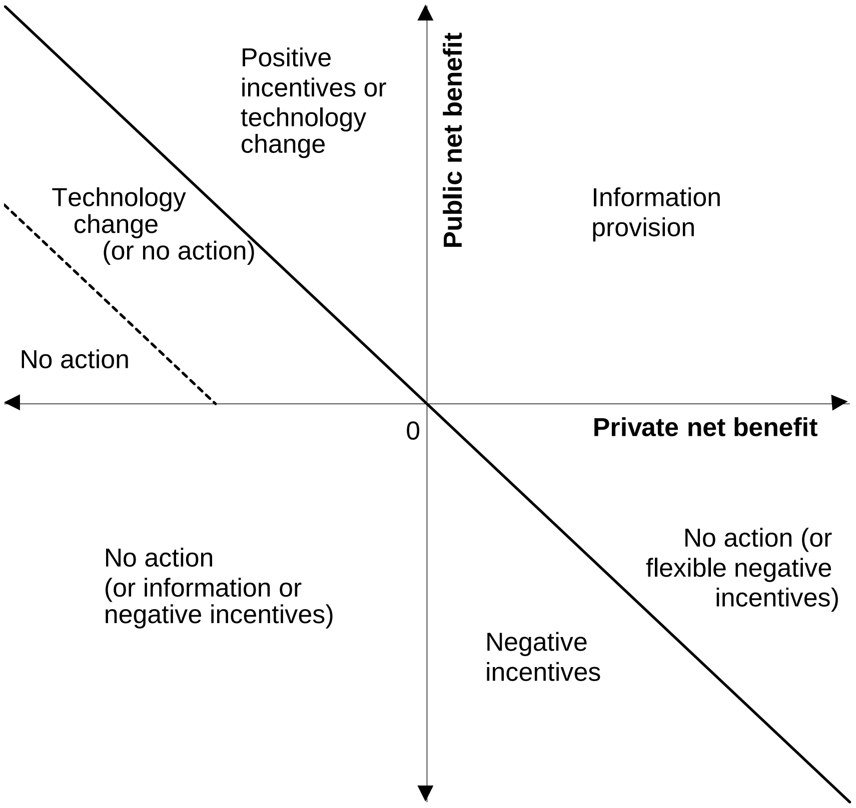
Figure 1 Policy evaluation framework



Source: Adapted from Pannell (2008)

Figure 2 Simulation results for different misclassification rates

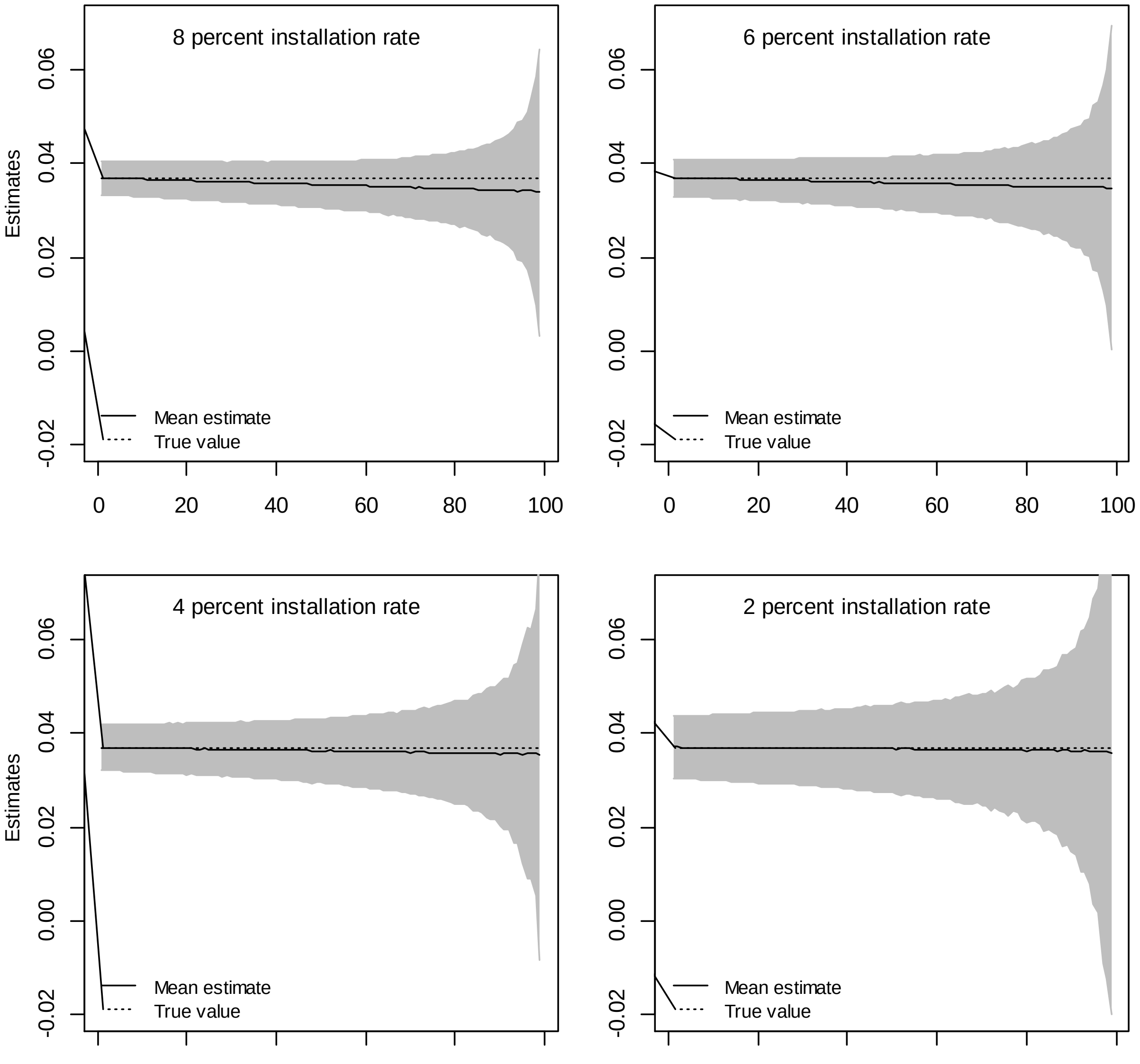


Figure A1 Summary benefit: cost ratio information

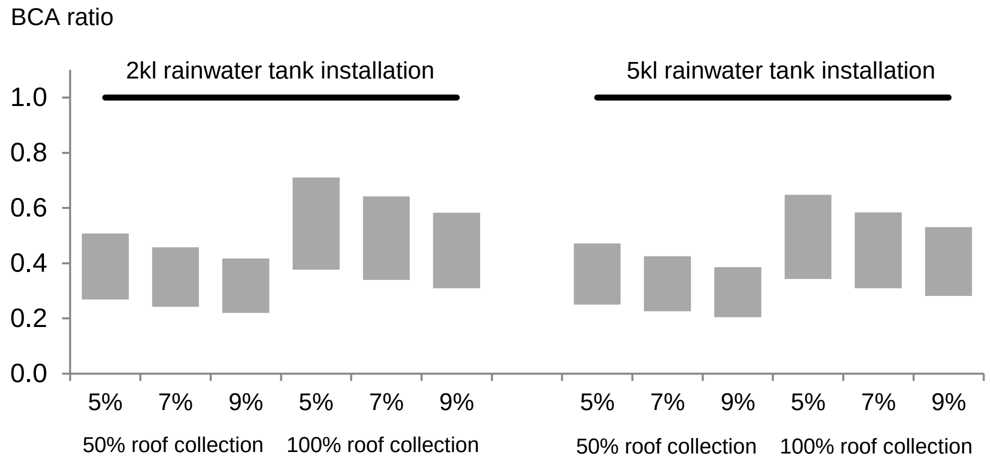


Table 1 Model variables and descriptive statistics

Variable	Mean	SD
Dependent variable		
House sale price (AU$ ‘000)	570	293
Explanatory variables		
Rainwater tank (yes = 1, no = 0)	.002	.045
Number of bedrooms	3.45	0.75
Number of bathrooms	1.62	0.55
Number of other rooms	4.294	1.37
Brick construction (yes = 1, no = 0)	.921	.269
Tile roof (yes = 1, no = 0)	.899	.301
Number of carports	.654	.805
Number of garages	.867	.950
Pool (yes =1, no =0)	.209	.407
House age (years)	25.9	21.0
Land area (m^2)	716	352

Table 2 Baseline regression results

Independent variable	Est.	Robust SE
(Intercept)	5.979^{***}	.0254
Rainwater tank	$.0370^{***}$	.0100
No. bedrooms	$.0243^{***}$	.0011
No. bathrooms	$.0794^{***}$	.0017
No. other rooms	$.0165^{***}$	.0006
Brick construction	$.0095^{**}$	.0031
Tile roof	$-.0186^{***}$	.0023
No. carports	$.0059^{***}$	.0010
No. garage spaces	$.0373^{***}$	.0010
Pool	$.0644^{***}$	.0013
House age (years) × 100	$-.7739^{***}$	.0175
House age $(\text{years})^2$ × 10,000	$.7006^{***}$	.0195
Land area (m^2)	$.3129^{***}$	.0032
Quarters fixed effects	***	
SA1s fixed effects	***	
Observations	77, 234	—
R^2	.9032	—

Note: significance level: *** 1%; ** 5%; * 10%

Table 3 Estimated upper bounds under stronger information

	K=0.0	K=0.10	K=0.20	K=0.40	K=0.60	K=0.80	K=0.90	K=0.951
Rainwater tank	.0370	.0372	.0375	.0383	.0401	.0465	.0683	3.152
No. bedrooms	.0243	.0243	.0243	.0243	.0243	.0243	.0243	.0177
No. bathrooms	.0794	.0794	.0794	.0794	.0794	.0795	.0796	.1468
No. other rooms	.0165	.0165	.0165	.0165	.0165	.0165	.0166	.0633
Brick construction	.0095	.0095	.0095	.0095	.0095	.0095	.0093	-.0630
Tile roof	-.0186	-.0186	-.0186	-.0186	-.0187	-.0188	-.0191	-.1964
No. carports	.0059	.0059	.0059	.0059	.0059	.0059	.0059	.0129
No. garage spaces	.0373	.0373	.0373	.0373	.0373	.0373	.0375	.1163
Pool	.0644	.0644	.0644	.0644	.0644	.0644	.0645	.1019
House age (years) × 100	-.7739	-.7736	-.7738	-.7736	-.7732	-.7717	-.7661	1.830
House age (years)^2 × 10,000	.7006	.7002	.7005	.7003	.6999	.6985	.6932	-1.784
Land area (m^2)	.3129	.3128	.3128	.3128	.3127	.3125	.3116	-.0930
Intercept	5.979	5.979	5.979	5.980	5.980	5.982	5.990	8.655

Table A1 Summary information on water savings

Statistics	Summer			Autumn			Winter			Spring		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Mean monthly rainfall (mm)	11.0	14.4	16.4	16.1	42.9	107.7	159.5	174.3	124.6	86.2	46.5	29.9
Assumed outdoor demand (kL)	16.0	16.0	16.0	13.5	13.5	9.7	1.9	1.9	1.9	7.3	8.7	9.7
A. Benefits with 2kL tank 50% roof (125m^2) allocated to collection												
Runoff (kL)	1.0	1.3	1.5	1.5	4.0	10.0	14.	16.2	11.6	8.0	4.3	2.8
Used (kL)	1.0	1.3	1.5	1.5	4.0	9.7	1.9	1.9	1.9	7.3	6.3	2.8
Min. value ($)	1.41	1.8	2.1	2.07	5.51	13.35	2.6	2.67	2.67	10.0	8.74	3.84
Max. value ($)	2.67	3.4	3.9	3.90	10.4	25.20	5.0	5.04	5.04	18.9	16.4	7.25
B. Benefits with 2kL tank 100% roof allocated to collection												
Runoff (kL)	2.1	2.7	3.1	3.0	8.0	20.0	29.	32.4	23.2	16.0	8.7	5.6
Used (kL)	2.0	2.7	3.0	3.0	8.0	9.7	1.9	1.9	1.9	7.3	8.7	7.5
Min. value ($)	2.83	3.70	4.21	4.14	11.02	13.35	2.67	2.67	2.67	10.01	12.01	10.38
Max. value ($)	5.33	6.98	7.95	7.81	20.81	25.20	5.04	5.04	5.04	18.90	22.68	19.59
C. Benefits with 5kL tank 50% roof allocated to collection												
Runoff (kL)	1.0	1.3	1.5	1.5	4.0	10.0	14.	16.2	11.6	8.0	4.3	2.8
Used (kL)	1.0	1.3	1.5	1.5	4.0	9.7	1.9	1.9	1.9	7.3	8.7	3.4
Min. value ($)	1.41	1.8	2.1	2.07	5.51	13.35	2.6	2.67	2.67	10.0	12.	4.7
Max. value ($)	2.67	3.4	3.9	3.90	10.4	25.2	5.0	5.04	5.04	18.9	22.	8.84
D. Benefits with 5kL tank 100% roof allocated to collection												
Runoff (kL)	2.1	2.7	3.1	3.0	8.0	20.0	29.	32.4	23.2	16.0	8.7	5.6
Used (kL)	2.9	2.7	3.1	3.0	8.0	9.7	1.9	1.9	1.9	7.3	8.7	9.7
Min. value ($)	4.00	3.7	4.2	4.14	11.0	13.35	2.6	2.67	2.67	10.0	12.	13.35
Max. value ($)	7.54	6.9	7.9	7.81	20.8	25.20	5.0	5.04	5.04	18.9	22.	25.20

Note: Rainfall data is for the period 1972 to 2013 and has been taken from the Jandakot Aerodrome; the $ used in this table is Australian dollars.