Effectiveness of incentives to promote adoption of water sensitive urban design: A case study on rain water harvesting tanks

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Effectiveness of incentives to promote adoption of water sensitive urban design: A case study on rain water harvesting tanks

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Abstract: Water sensitive urban design (WSUD) often consists of decentralized multi-functional technologies which are capable of producing both private and public benefits. However, private costs often outweigh private benefits, and therefore agencies must often provide incentives to encourage adoption of such technologies. Scarce resources also require cost-effective schemes. However, there is a lack of comprehensive analysis of the performance of incentive schemes to promote WSUD. In this paper, we develop an agent-based model to study the effectiveness of an incentive scheme to promote adoption of rain water tanks. Using a case-study based on Melbourne, we study how its cost-effectiveness changes with targeting different sizes of rain water tanks (2, 5, 10 kl) and different proportion of districts affected by heat stress. We observe that targeting smaller sized tanks promotes quicker adoption but is less cost-effective in terms of water savings and environmental services per dollar. Public agencies can use such information in developing more targeted approaches to promote WSUD technologies.

Keywords: Water sensitive urban design; DANCE4Water; Incentives

1. INTRODUCTION

Water sensitive urban design (WSUD) is promoted to manage water balance, improve or maintain water quality, encourage water conservation and maintain water-related environmental opportunities. The designs often consist of decentralized, small-scale technologies (such as rain water tanks). Such technologies are expected to provide large public benefits, such as reducing pressure on ground water and reducing pollution runoff. They also provide private benefits, e.g. avoiding water restrictions and watering the gardens. However, private benefits may not be sufficient to cover the private installation and maintenance costs of such technologies by individual households. Therefore, adoption of water sensitive technologies could be quite slow.

There are several ways adoption of water sensitive technologies could be promoted, such as regulations, extension, communication and incentives (Pannell, 2008). Subsidies and financial incentives are major economic tools used by governments to promote technologies which have public benefits, but private benefits from implementing / installing technologies are not sufficient to cover the private cost of installation (Olmstead and Stavins, 2009). They have shown effectiveness in promoting pro-environmental behavior (Hassett and Metcalf, 1995; Jaffe and Stavins, 1995). There are several incentive-based schemes around the world to promote WSUD, such as the rebate or subsidies for installing rain water tanks in major cities in Australia (Zhang et al., 2015).

Some assessments of such incentive schemes exist (Lee et al., 2011). For example, Montalto et al. (2007) estimated the cost-effectiveness of investments in low impact development (LID) for Brooklyn, NY. They observed that a public subsidy mechanism which spreads the costs between private property owners (private cost fraction) and public agency (public cost fraction) to encourage LID installation is a cost-effective alternative for public agencies. However, they considered only the storm water management benefits of the LID system and ignored other environmental benefits. While these studies are informative in telling us about the output of the program, such as the amount of water saved, we are not aware of any study which has looked at the comprehensive bio-physical benefits of an incentive program. (Houssou and Zeller, 2011).
To fill in this knowledge gap we use an integrated agent-based model to study the effect of different incentive structures implemented in DAnCE4Water (Dynamic Adaptation for enabling City Evolution for Water). DAnCE4Water assesses the multiple impacts of an integrated urban water system on water security, pluvial flooding, storm water pollution, urban heat islands and stream health in a dynamic urban environment (Urich and Rauch, 2014a). Agent-based models are suitable to simulate the performance of different incentive programs under different bio-physical, socio-economic and behavioral conditions. Results under different programs are simulated and numerically compared. Results from the simulations could be used as a filtering mechanism for selecting suitable incentive programs (Iftekhar et al., 2014). This allows us to simulate household decisions and link with community-scale bio-physical outcomes (Millock and Nauges, 2010). Using adoption of rain water tanks in Scotchman’s Creek, Melbourne, Australia as an illustrative case, we examine the overall bio-physical benefits of an incentive program to install rain water tanks.

In terms of implementing an incentive program the agency has several choices. For example, it can distribute the incentive uniformly to everyone (i.e., anybody can access the rebate or subsidy if they are willing to install a rain tank). A uniform targeting approach might be administratively simple and easier to manage. However, they might over-spend to achieve a certain level of environmental goals as there is no specific targeting. Alternatively, the agency could employ an eligibility criterion to select suitable households. This approach is likely to be more cost-effective because of its targeted nature. However, it may suffer from ‘moral hazard’ problem as households may hide their ‘true’ condition to be eligible in the rebate program. To avoid this problem the agency would have to employ a costly screening and background checking procedure which would increase the overall cost of an incentive program. There is also the possibility that the truly eligible households could miss out (Houssou and Zeller, 2011).

Given this dilemma between uniform selection and a targeting approach it is interesting to know whether employing a selection criterion improves the performance of an incentive program designed to encourage installation of rain tanks. Based on existing literature, we have selected two selection criteria: based on tank size (or volumetric targeting) and based on heat stress of census districts (or spatial targeting). We ask the following two questions: 1) How does the cost-effectiveness of an incentive program change when incentives target different sizes of rainwater tanks (2, 5, 10 kl) compared to the case when there is no specific targeting (i.e., a uniform incentive for all tank sizes)? 2) How do the incentive schemes perform when heat-stress areas are targeted compared to the uniform (i.e., no-targeting scenario)? With installation of rain tank additional water is available for outdoor gardening which increases evapo-transpiration and results in improving extreme heat condition (Coutts and Harris, 2013) Results from our analysis will be useful for utilities in designing a more cost-effective targeting program. In the following section, we provide a brief description of the DAnCE4Water model and the simulation scenarios. This is followed by a result and a conclusion section.

2. DANCE4Water MODEL

DAnCE4Water is an urban water micro-simulation framework that simulates technical, social and economic dimensions of a city’s integrated urban water system in response to water management strategies and drivers such as climate change, societal shifts and population growth. It builds on an interlinked description of the city’s water consumption units and the urban water supply system, including social, economic and demographic data, data about the urban built and natural environment, and a detailed description of the urban water system (Urich and Rauch, 2014b). To assess the performance of the urban water system in an integrated way, DAnCE4Water first includes an urban water cycle model based on Mitchell and Diaper (2006); it also employs well-known hydraulic and hydrodynamic models, such as SWMM (Rossman, 2010) and Mike Flood (Löwe et al., 2015) for flood risk assessment; CityDrain (Achleitner et al., 2007) for storm water quality; and conceptual models to assess stream health (Coutts and Harris, 2013) and urban heat stress (Coutts and Harris, 2013). The dynamics of the urban water system is driven by an agent-based model which represents the key actors and their decisions, for example household agents installing rainwater harvesting tanks which might be incentivized by the water utility agent.

To assess the multiple benefits of different incentive structures, a DAnCE4Water simulation program has been set up for Scotchman’s Creek catchment in Melbourne. The multiple impacts of rainwater harvesting are assessed in terms of water demand reduction for each household, reduction in number of spills (as a proxy for flood reduction), removal of storm water pollution, and reduction of land surface temperature under extreme heat and improvement of the stream health through the stream erosion index. The model captures decisions at household level. Since rainwater tank
installation is a private household decision, household agents are the main decision makers in the current simulation program. There are four steps in the decision model of individual households:

Step 1: From the bio-physical model feasible rainwater tank options for each household agent were generated. Water savings (non-potable indoor water use and outdoor use) are calculated for each option for each household.

Step 2: To generate total costs for different rainwater tank options we have used data available from Tam et al. (2010) for Melbourne.

Step 3: Generation of total value for different rainwater tank options: There are two components in estimating the total value of water savings. For indoor non-potable use we have assumed that the water available from the rainwater tank is a substitute for pipe water. To calculate the economic value of indoor water savings, we have multiplied the total indoor water savings by the current water price. For outdoor water use, we have assumed that there are some water restrictions in place and installation of a rainwater tank will allow the household to free itself from water restrictions. The willingness-to-pay (WTP) estimates will be applicable only if the option allows the household to free itself from water restriction completely.

Step 4: Agent’s decision model: The agent decides to install a rainwater tank if the net present value of installing it is positive. If government incentive programs are available, the agent will add the rebate to the total benefit of the tank. It is possible that the net present value (including rebate) could be positive for several options. Since a single household is allowed to install only one tank, the agent will implement the option with maximum net benefit. To calculate agents’ willingness to pay to avoid water restriction we have used data obtained from a choice experiment survey conducted in Melbourne (485 respondents) under a separate project of the Cooperative Research Centre for Water Sensitive Cities (Brent et al., 2014). Based on the choice experiment results we have calculated the WTP functions to estimate the relationship between key socio-economic variables (such as level of education, age, income) and WTP as revealed by the survey. From the Australian Bureau of Statistics (ABS) database, households’ profiles based on the key socio-economic variables were obtained for a sample census district level. These distributions were used to generate agent profiles in the simulations, which were then used to calculate the WTP for individual households.

The linkages among the bio-physical and agent-based models are bi-directional. For example, the physical improvement depends on the number and location of rain tanks installed which again depend on the decision made by individual agents. For simplicity, in the current study we have implemented a static scenario (i.e., no dynamic component) with no learning or adaptive capacity of the agents. In each simulation, individual agents decide on whether to install or not adopt rain tank. However, the model has the flexibility to implement a dynamic setting with agents learning from their past actions.

3. SIMULATION SCENARIOS

In order to test the performance of incentive programs comprehensively, a series of simulations were run in the following key dimensions –

- Targeting based on tank size (Volumetric targeting): Three size-specific scenarios where different sizes of rainwater tanks (2, 5, 10 kl) are targeted separately were compared. For example, in one scenario incentives were only paid for installing 2 kl tanks and so on. The size-specific cases were compared with the case where there was no targeting at all.

- Targeting based on heat-stress (Spatial targeting): In order to test spatial targeting, we provide incentives only to the households in 25%, 50% or 75% of the census districts worst affected by heat stress. This was compared with a no-targeting scenario.

In both cases, the level of incentive was gradually increased by $100 steps from $500 to $4,000. To test the robustness of the results, the whole process was repeated for different rainfall patterns, using annual data from the year 2000 to 2010. DANCE4Water model is capable to simulate both physical and economic impacts of policy options. For comparison between different incentive schemes we have used the following performance measures.

Physical benefits: Physical benefits of different incentive schemes have been measured in terms of the following four criteria:

- **Amount of water saved**: It is calculated as the total amount of water saved (in ML) from installation of rain water tanks.

- **Amount of nitrogen reduction**: It is calculated based on the assumption that the nitrogen in the consumed water is not entering urban streams, either because it is infiltrated as part of outdoor use or in case of indoor use transported to the waste water treatment plant. The nitrogen is calculated as the total amount of nitrogen caused by the roof runoff minus nitrogen
removed through consumption of collected rainwater (in kg). The nitrogen load is calculated based on the average concentration for roof runoff for Melbourne (eWater, 2013)

- **Decrease in flooding**: It is the number of spills per tank per year during rain events. It is a proxy for the overflow from rainwater harvesting tanks.

- **Reduction in extreme heat**: The reduction of extreme heat is calculated as the change in land surface temperature under extreme heat conditions (Coutts and Harris, 2013), within a census district, assuming dry soil and water restrictions, and grass watered through the installation of rainwater harvesting tanks for the provision of non-potable water.

To estimate the economic performance of different incentive schemes, a cost-effectiveness measure has been calculated. Cost-effectiveness has been calculated as the ratio between physical benefits and total expenditure. The higher the ratio is the better the performance of a program when it is desirable to achieve an output (such as amount of water saved and total amount of nitrogen removed). On the other hand, when it is desirable to reduce physical outputs (such as number of water spills and average temperature) cost-effectiveness is higher when the ratio is lower. Univariate Analysis was carried out to test the difference in mean estimates under different targeting schemes. If the ANOVA showed significant overall impact of the targeting scheme, post-hoc analysis was carried out using the Least Significant Difference (LSD) test to find out the differences between individual schemes.

4. **RESULTS AND DISCUSSION**

Results are presented sequentially in terms of installation of rain tanks, physical performance and economic performance of different incentive programs.

4.1. **Performance of volumetric targeting**

There is an S-shaped curve where initially, when the level of incentive is low, the proportion of households installing a rainwater tank is low. The rate quickly rises as soon as the incentive rate hits $1000 per tank. With a $3000 incentive, almost all the eligible households (97%) install a tank. Three percent households never install a tank as they do not have a high enough demand to install a tank. The rate of adoption is much quicker with smaller sized tanks (Figure 1) as they have lower construction costs compared to larger sized tanks. Under the uniform subsidy scheme with the maximum incentive rate, 2-kl tanks form around 54% of the installed tanks, 5-kl tanks constitute 37% and 10-kl tanks constitute the rest. The variation in adoption rates for different location targets simply illustrates the fact that with the expansion of district coverage more households can avail incentives.

In terms of cost-effectiveness (i.e., physical outputs per dollar) the 10-kl scheme has performed significantly (P = 0.001) better compared to other schemes with respect to water savings and nitrogen removal per dollar amount. However, in terms of temperature reduction and number of spill events per dollar there is no significant difference (at 5% level of significance) between schemes targeting 5-kl, 10-kl and the uniform (non-targeted) subsidy (Table 1). It should be noted that the standard deviations are very large, which indicates the sensitivity of the results to the rainfall condition. To supplement the mean estimates we also have presented the medians, which show similar ranking among the schemes, except for number of spills per dollar which shows that the 10-kl scheme has performed better.
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**Figure 1** Adoption rate (proportion of households) of different sizes of tanks installed under incentive schemes with volumetric and spatial targeting

**Table 1** Average physical performance per $100,000 total incentive payment, under different targeting schemes

<table>
<thead>
<tr>
<th>Targeting approach</th>
<th>Output / $100K</th>
<th>In proportion to the uniform scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Savings (W) K</td>
<td>Nitrogen (N) kg</td>
</tr>
<tr>
<td><strong>Volume Target</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uniform</td>
<td>Mean</td>
<td>4,503</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>4,503</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>2,552</td>
</tr>
<tr>
<td>2-kl</td>
<td>Mean</td>
<td>3,520</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>3,229</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>2,148</td>
</tr>
<tr>
<td>5-kl</td>
<td>Mean</td>
<td>4,606</td>
</tr>
<tr>
<td></td>
<td>SD</td>
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</tr>
<tr>
<td></td>
<td>Median</td>
<td>2,824</td>
</tr>
<tr>
<td>10-kl</td>
<td>Mean</td>
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<tr>
<td></td>
<td>SD</td>
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</tr>
<tr>
<td></td>
<td>Median</td>
<td>3,207</td>
</tr>
<tr>
<td><strong>Location Target</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All districts</td>
<td>Mean</td>
<td>4,503</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>4,503</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>2,552</td>
</tr>
<tr>
<td>Top 75</td>
<td>Mean</td>
<td>4,661</td>
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<tr>
<td></td>
<td>SD</td>
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</tr>
<tr>
<td></td>
<td>Median</td>
<td>2,663</td>
</tr>
<tr>
<td>Top 50</td>
<td>Mean</td>
<td>4,609</td>
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<tr>
<td></td>
<td>SD</td>
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<tr>
<td></td>
<td>Median</td>
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<tr>
<td>Top 25</td>
<td>Mean</td>
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<td></td>
<td>SD</td>
<td>4,791</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>2,631</td>
</tr>
</tbody>
</table>

Note: The letters after the proportion estimates indicate whether the means are significantly different to each other or not based on the Least Significant Difference test. Numbers with the same letter indicate that there is no significant difference between the two means at 1% level of significance.
4.2. Performance of spatial targeting

In this set of simulations the performance of spatial targeting is measured. It can be observed that with a wider target a greater number of tanks is installed. The proportion of different sizes of tanks installed are almost similar for different location targets. In terms of cost-effectiveness, there is no statistically significant difference between different spatial targeting schemes (Table 1), except for the top 25% target, which performed significantly more poorly in terms of temperature reduction and number of spill events compared to the other schemes. A comparison of the spatial distribution between a uniform incentive-base program and a targeted program is shown in Figure 2.

Optimal level of incentives

It is possible to calculate the optimal level of incentives under different targeting schemes by looking at the net gain reaped by private households who install rain water tanks. Initially when the incentive rate is very low, only a few households who are willing to bear most of the costs of installing a tank would install one. As the incentive rate increases, more and more households would install a tank, which would increase the total cost share by private households relative to the total incentive paid (as a result, the total net gain will be negative). However, there is a tipping point when the incentive rate is high enough to increase the net gain. When the incentive rate is substantially high the total net gain will be positive. Given this trend, the government would be interested to know the tipping point at which the household share of the total installation cost is maximized. From purely cost-sharing perspective the agency should fix their incentive rate at the tipping point.

It can be observed from Figure 3 that the tipping point differs across different targeting scheme. For instance, under the tank size targeting schemes, the tipping point is $1,600 for the uniform and 2-kl schemes; for the 5-kl scheme, it is $1,700; and for the 10-kl it is $2,200. This suggests that targeting larger-sized tanks requires a greater amount of incentives before household agents can reap a net benefit. As for location targets, the tipping point uniformly sits at around $1,600, which is the same amount for the uniform volumetric target.
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Figure 3 Trends in total surplus earned under different incentive schemes (a) with volumetric targeting and (b) spatial targeting. The vertical bars indicate the optimal rate of incentive from cost-sharing perspective

5. CONCLUDING REMARKS

Results from our simulation analysis show the importance of using appropriate criteria to select eligible households or area for incentive programs. Cost-effectiveness differs little between different spatial targeting policies. By contrast, volumetric targeting leads to substantial differences. In terms of number of tanks enrolled and amount of water savings, a scheme targeting 2-kl and 10-kl tanks respectively would be most successful. However, policy makers are often more interested in environmental benefits and cost-effectiveness of targeting policies. In terms of cost-effectiveness, a scheme targeting larger-sized tanks would perform better for water savings and nitrogen removal services whereas a uniform targeting approach would perform better for surface temperature reduction and number of spills. Therefore, which physical indicators are considered for policy evaluation is also a key determinant for assessing (and designing) incentive programs. Results from other similar types of analysis will help in understanding the total impact of government policies and in developing more targeted approaches to promote water sensitive urban designs.

REFERENCES


