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Evaluation of Water Efficiency Programs in Single-Family Households in the UK: A Case Study

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Abstract
Current water supply worldwide is facing growing pressure as a result of climate change and increasing water demand due to growing population and lifestyle changes. The traditional way of fulfilling the growing demand-supply gap by seeking new water supply options such as exploiting new fresh water resources and investing in the expansion of infrastructure is no longer considered environmentally or economically sustainable. A diverse portfolio of water efficiency measures is now a requirement for the majority of water companies in the UK. This paper presents results from a statistical analysis of a unique water efficiency program case study. Specifically, the study evaluates the effectiveness of installing water-saving devices in single-family households in areas where a major UK water supply company operates. Moreover, we examine the factors that influence water consumption of the households in these areas, defining the relationship among daily per capita water consumption (pcc), weather- and household-specific demographic variables. This study can be a valuable asset to water companies as it provides a review of program evaluation procedures and their limitations focusing on a detailed implementation of multilevel modelling, adding to the very limited implementation of the technique in the water efficiency literature. Most importantly, this research attempts to draw attention to common data limitation problems that most companies experience, and suggests possible ways to overcome them.

Keywords
Demand management, water efficiency, water conservation, domestic water demand, multilevel models

INTRODUCTION

The new direction the water industry should follow at a global-scale is the management of water demand through innovative methods, tools and procedures that promote water conservation (Turner et al., 2010). The USA and Australia are leading the way in the implementation of successful water saving initiatives worldwide. A diverse portfolio of water efficiency measures is now an inevitable requirement for the majority of water companies in the UK too. Department for Environment, Food and Rural Affairs (2008) states that as a result of growing population, and changes in the way people use water in the UK, more than half of the public water supply today is for residential use. On the other hand, water use in the industrial and agricultural sectors has been declining. Therefore, controlling domestic water demand is a priority for the UK. In fact, as Defra in their Climate Change Risk Assessment (2012) presents, factors such as population growth and land use change may affect water supply and demand more than climate change. Defra's strategy (2008), aims at reducing residential water consumption from 150 l to 130 l per capita per day until 2030. Since 2010, Ofwat, the water industry economic regulator for England and Wales, has set minimum water efficiency goals for the water industry, equivalent to decreasing water use by 1 l per property daily (Waterwise, 2010).

Several companies in the UK have taken major steps towards residential water efficiency by installing water meters, limiting leakage levels, launching information campaigns and by water-using device and fixture retrofits at their customers' homes. However, little information is publicly available as to the magnitude of water savings that were achieved in the context of each water efficiency initiative. Although important efforts have been made towards decreasing domestic water consumption, the assessment of the effectiveness of such initiatives it still limited, and the need for establishing a robust evaluation framework is imperative (Syme et al., 2000, Turner et al., 2007).

CASE STUDY: RESIDENTIAL EFFICIENCY PROGRAM IN EASTERN ENGLAND

Anglian Water is a company operating in the East of England, providing drinking water to 2.6 million properties. During 2013 and 2014, the company embarked on a water efficiency program that involved a qualified plumber installing water efficiency devices in a sample of metered domestic properties free of charge. Some of the devices that were provided were left to the customers who could fit them later on themselves if they decided to. Each participating household received a number of the following: dual flush toilet converters, garden kits, hosepipe guns, Save-A-Flush devices, shower restrictors, Tap Magic spray inserts and shower timers, among others. A subset of this sample of properties completed a questionnaire, providing household-specific demographic and water use information. Monthly water consumption data over a period of 43 months (2012–2015) comprising a sample of 72 properties across the company's area of operation, were used for the subsequent analysis. In parallel, monthly consumption data from a sample of 92 properties that did not participate in the water efficiency program were obtained for the same months. This sample was drawn from the same neighbourhoods as the participating households. The data used for the analysis are summarised in Table 1.

Figure 1 illustrates consumption patterns of the participants and non-participants groups for 43 months, including the program duration period. While the non-participants' consumption appears to increase constantly during the program period and until the end of the whole study period, it is evident that since the water efficiency program's launch, the participants' consumption decreased. Although this is a sign of the program's effectiveness, further analysis is required to evaluate the water savings achieved.

Table 1. Data used for subsequent analyses

	Participants sample	Non-Participants sample
Monthly Water Consumption (litres/hh/day)	✓	✓
Postcode	✓	✓
Acorn class	✓	✓
Number of Residents	✓	-
Intervention dates	✓	-
Number of water butts	✓	-
Weather data	✓	✓

hh = household, Acorn = geodemographic segmentation of households, developed in the UK based on (among others) social/financial status and property size. Range: Acorn Category 1 (Affluent Achievers) to Category 5 (Urban Adversity) and Category 6 (Not Private hhs)
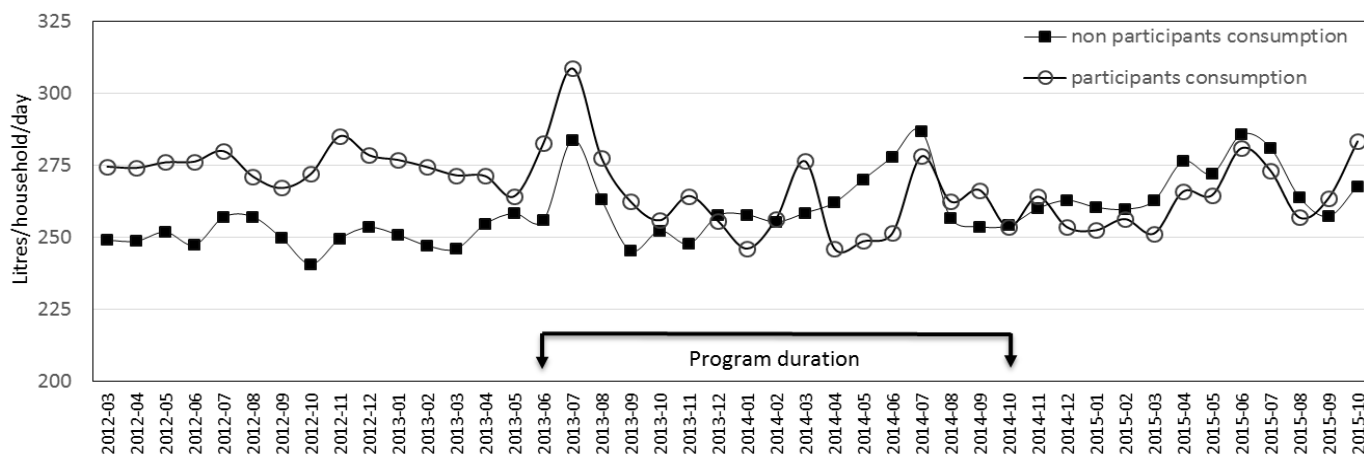
Figure 1. Water consumption of participating and non-participating households

Exploration of factors affecting per capita consumption

Simple multiple regression using participants' consumption data and information derived from their completed questionnaires was employed so that factors that affect water consumption over the sample of single family households could be identified. The outcomes are presented in Table 2.

Table 2. Multiple regression results

	Estimate	Std. Error	Sig.	VIF
Intercept	5.230	0.137	.000	
Number of Residents	-0.093	0.032	.005	1.023
Acorn class	-0.087	0.033	.010	1.045
No. of Waterbutts	-0.065	0.031	.040	1.058

Dependent Variable: log per capita consumption. Explained variance: $R^2 = 0.206$

Per capita consumption (pcc) decreases as the number of residents in a household increases. This finding is well documented in the literature (Grima, 1973; Dziegielewski et al., 1996; Arbues et al., 2003). Interestingly, the number of waterbutts in a home was a significant predictor of pcc. The more waterbutts in a household, the lower the pcc was. This can be explained by the fact that residents use rainwater stored in waterbutts for garden irrigation, car washing etc. instead of consuming potable water for these needs. Acorn class appears to be a powerful predictor of pcc with a negative coefficient estimate. This finding shows that pcc is greater in Acorn class 1 households (usually larger and of higher property value), and it decreases in higher Acorn classes that usually represent smaller and lower property value households. The Acorn classification of households, which is usually known to UK water companies, can be used as a proxy for income and household size when these data are not available.

TECHNIQUES FOR WATER SAVINGS EVALUATION

According to the literature, there are three main methods of residential water efficiency program evaluation: participant before-after parametric or non-parametric tests; participant-control means comparison methods, and regression techniques, including time series, covariate, cross-sectional and panel data regression (Fyfe et al., 2010). Before-after methods are subject to many sources of bias, as they do not account for external factors that may have a considerable effect on consumption. However, there are ways to improve the accuracy of before-after tests. Participant-control comparison methods are designed to limit the bias caused by external factors. However, a control group should possess the same household characteristics and should be drawn from the same geographical area as the participants' sample for the comparison to be accurate. An alternative technique that effectively combines before-after testing with participant-control techniques is Matched Pairs Means Comparison (MPMC), developed by the Institute for Sustainable Futures, University of Technology in Sydney (Fyfe et al., 2010). This method is not discussed here. As far as regression techniques are concerned, panel data regression is regarded as the most robust method of water savings evaluation. However, it is not frequently used in evaluation studies, as it is data-intensive and requires a certain level of statistical analysis skills.

The decision of which method to use depends on the type of available data, their quality and sample sizes; but also on the skills and expertise available for the data analysis and interpretation of results. Most water companies both in the UK and worldwide experience data limitation problems that do not allow them to perform a robust evaluation of water savings. Common limitations include:

- Absence of high-quality, small-interval meter readings (e.g. monthly, 2- or 6-monthly readings without consecutive periods of missing data).
- Unknown program take-up dates for each participating household.
- Small participating households sample sizes.
- No information on participating household demographics (e.g. number of occupants, average household income etc.).
- No information on non-participating household demographics, such as the number of occupants, which leads to the incapability to compare participant and control samples using pcc efficiently, rather than aggregated per household consumption, and to select a control sample that matches the participants' one.
- Major intervention date differences among households and limited period of time that data are available before and after the intervention dates. This common problem makes before-after techniques inapplicable.

Improving the accuracy of before-after and participant-control methods

It is very common that water companies in the UK do not possess household-related information such as the number of people living in each house, property size or average household income when deciding to embark on a water efficiency program. However, these data are essential for a robust water savings estimation using mixed-effects models. If a water company wishes to explore the impact that a water efficiency initiative had on consumers of different social classes/property sizes and thus to draw important information that can be referenced when a similar program evaluation is needed in the future, the Acorn classification can prove to be very useful. Even if no other demographic information is available, neither for the participating household sample nor for a sample of non-participating ones (which could be used as a control group), before-after means comparisons could be undertaken by disaggregating the participants' sample into subsamples of the same Acorn classes and running t-tests. It should be stressed, however, that a sufficiently large sample of households belonging to each Acorn class would be necessary for this technique to be possible.

In a similar manner, if Acorn class and per household consumption are known for a sufficiently large sample of households that did not take part in the program and are located in the same geographical area as the participating homes, the change in consumption for the former group can be used as a representative reference case for comparison to the latter group's consumption change after the efficiency program launch. Unfortunately, in the context of this case study, before-after tests on disaggregated smaller samples were not possible, due to the small available sample of participating households.

Multilevel Modelling (Mixed Effects Models)

It is very common that social data have hierarchical (nested) structures. A well-known form of nested data are panel data (observations over time that are nested in different subjects). In the context of this study, the subjects are the households, and the overtime observations are monthly water consumption readings and monthly weather-related data. Nested data are not statistically independent; thus, linear regression and other techniques such as ANOVA that require statistical independence are not suitable, as they would produce extreme Type I errors if they were to be used. Multilevel regression (i.e. hierarchical linear regression) is designed for application to hierarchical data structures as it accounts for the statistical dependence among sequential observations in the same group. It is an extension of regression; its difference lies in the fact that the parameters can be allowed to vary. Multilevel models also ignore the assumption of homogeneity of regression slopes; they can handle missing data with much greater ease than other statistical procedures; and, most importantly, they make use of data for each and every observation or time point, increasing the power of analysis (Field, 2012).

As far as this study is concerned, multilevel models offer a more appropriate and powerful analysis of the particular dataset than simple Ordinary Least Squares regression, as they allow for the full exploitation of the data, providing the opportunity to make use of both time-varying and time-invariant variables in the same analysis. However, they are much more demanding in terms of software and statistical knowledge. In order to perform the analysis, the *Nlme* package in R software was used.

Model Development

Properties identified as flats were removed from the participants' sample; thus only single-family households were used in the analysis. Pcc was not normally distributed; thus the natural logarithm of pcc was used as the dependent variable. An unconditional means model (empty model) that included only the intercepts and the random effect for the highest level variable of the nested structure – in this case

each household – was run first. The interclass correlation coefficient was 0.656 (p<0.001) for the log of pcc, meaning that 65.6% of the variation in water consumption can be attributed to between-household variations. Therefore, the variation between households should be taken into account in the model by allowing intercepts to vary. The empty model also allowed the assessment of the need for a multilevel model. A baseline model was structured that only includes the intercept. Then, the fit of the unconditional means model (where intercepts are allowed to vary over households) is compared to that of the baseline model. The L ratio was 2603 (p<.001), confirming that the varying intercepts of the empty model improved the model's fit.

The first variables to be entered in the model were the weather-related level-1 variables (Table 3). The natural logarithm of the number of days of more than 1 mm rain per month (Log.raindays) and the hours of sunshine per month (Log.Sunshine) were selected, as they appeared to have a more significant effect on water consumption than the other weather related variables. Also, it was possible for both to be used in the model, as the relationship between them appeared to be weak, with a correlation coefficient of 0.31. At level-2, the dummy variable for the water efficiency program implementation (intervention), Acorn class (Acorn) and the number of residents per household (occupants), were included in the model. The interactions between variables were also explored. The heterogeneity of slopes for Log.raindays was not significant. Thus, Log.raindays was entered in the model only as a fixed effect.

RESULTS

Table 3. Multilevel model results

	Unconditional Means Model	Level-1 fixed	Level-2 fixed	Level-2 fixed (incl. interactions)	Full model (incl. Random Slopes)
Intercept	4.682	4.681	4.91	4.911	4.909
Log.raindays	-	-0.0233*	-0.025**	-0.024*	-0.023*
Log.Sunshine	-	0.0335**	0.041***	0.015	0.013
Intervention	-	-	-0.072***	-0.076***	-0.075***
Acorn class	-	-	-0.074**	-0.074**	-0.073**
occupants	-	-	-0.079**	-0.106**	-0.106**
Interaction: Intervention-occupants	-	-	-	0.052***	0.052***
Interaction: Log.Sunshine-Intervention	-	-	-	0.056**	0.059**
Interaction: Log.Sunshine-occupants	-	-	-	-0.032***	-0.032**

*p<0.1, **p<0.05, ***p<0.001 Notes: water use observations = 2682; households = 66; observations per household = 41 on average. Weather datasets were obtained via the Met Office (www.metoffice.gov.uk/climate/uk/summaries)

Pcc increased with the hours of sunshine and decreased with days of rain of more than 1 mm, as expected. A 10% increase in daily sunshine is associated with a 0.41% increase in consumption, while a 10% increase in days with rain of more than 1 mm can lead to a 0.25% decrease in consumption. At the

household level, water use was negatively correlated with the dummy variable for the water efficiency program, Acorn class and the number of occupants.

We can conclude that after the program launch there was a 6.95% decrease in consumption (*1-exp(-0.072)*), which can be attributed to the water efficiency program. Using the *intervals ( )* function of the *nlme* package, 95% confidence intervals were obtained for the intervention variable: [-0.092,-0.0525]. Taking into account the transformation of pcc to its natural logarithm, we can conclude that the water efficiency program resulted in a consumption decrease of between 5.1–8.8%.

As for the consumption of separate Acorn classes, the full model shows that moving from Acorn class 1 to Acorn class 5, pcc decreases by 7.1%. In other words, an average resident of an Acorn class 1 household consumes 7.1% more water than that of an average Acorn class 5 household. In the case of the number of people in the household, the full model demonstrates that an average occupant of a household of five members consumes 7.6% less water than an average occupant who lives on their own.

The interaction of the intervention with the number of occupants was positive and highly significant. This finding translates into the fact that, as the number of people in the household increased, the effect of device installation became less negative. In simpler words, it shows that in households with more occupants, the water efficiency program was less effective, as the pcc decrease that was caused by the device installation became smaller. The interaction of the intervention with log.Sunshine was positive and significant. This finding shows that in periods of increased sunshine, the effect of the intervention became less negative. This notion translates to the fact that the water efficiency program appeared to be less effective in reducing consumption during periods of sunny weather. Finally, the interaction term of log.Sunshine and occupants was negative and significant, indicating that during periods of sunny weather, a person would consume much more water than usual if he/she lived alone than if he/she lived together with more people. Variance inflation factors (VIFs) of the independent variables were calculated. All VIFs were under 2.4; thus it can be assumed that there is no multicollinearity problem in the dataset.

Results comparison between before-after means comparison and multilevel model
The multilevel model demonstrated that there was a 5.1–8.8% pcc decrease, attributable to the water efficiency program. A simple before-after test for the sample of participating households was also conducted using participants' pcc data only. Six months before the program take-up period and the same six months of the following year were used for the comparison for each household. Bootstrapped 95% confidence intervals were obtained for the consumption change using the *boot.ci()* function from *boot* package in R, showing an average decrease of between 7.98–27.12%. As evident, there is a large difference between the consumption decrease ranges that the two techniques provide, with the multilevel model providing a much more precise estimate and much narrower confidence intervals.

DISCUSSION
In contrast to price-related policies, technological changes such as retrofit programs and other non-price demand management policies have gained less attention, as Millock and Nauges (2010) recognise, mainly because of the lack of adequate data. Even in the cases when researchers have explored the effect of technological changes on water demand, they usually rely on engineering assumptions of the expected demand reductions (Kenney et al., 2008). The accuracy in measuring the effectiveness of water conservation initiatives has been the Achilles' heel of urban water planning (Mayer & DeOreo, 1999). This study further contributes to the existing literature, as disseminating knowledge

obtained through implemented water efficiency programs internationally is crucial for the establishment of a robust evaluation framework that will move existing evaluation practices forward.

CONCLUSIONS
Based on the results of the multilevel model, the water efficiency program was successful in decreasing per capita water consumption of the households that took part by 6.95% on average. Moreover, Acorn class can be used effectively in water efficiency evaluation studies as a proxy for household income and property size when these data are not readily available.

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