Strengthening socio-economic approaches to water demand management through the analysis of tariffs and nudges

Report to the

WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

This report outlines the work to date on the Nudging for Economics of Water Tariffs ('NEWTS') study which aimed to strengthen the socio-economic approaches to water management by integrating economic and social analyses into decision-making processes related to tariffs and nudges. Its analyses a behavioral nudging campaign which was implemented across 400,000 households in Cape Town between November 2015 and May 2016.

The first section provides the introduction and objectives as well as the scope of this study. Following this, the report provides a background of the NEWTS project as a whole as well as the three major work packages associated with this study which were estimating the water demand function, evaluating the interaction between nudges and water tariffs, and a cost-benefit analysis of the nudge program implemented in Cape Town.

The data sources used for this study were the City of Cape Town billing data, water pricing data, Statistics South Africa census community profile 2011, and weather data. Section 3 of this report describes these data sources at length.

The work processes involved in preparing the data for analysis are described in section 4. These include a detailed description of the work involved in preprocessing the municipal billing data provided by the City of Cape Town, the process of merging the census and billing data, as well as the preliminary work that went into assessing the expected correlation between variables along with some descriptive statistics from the data.

The water demand function is estimated in section 5, which provides a description of the methodology for this estimation using the Stone Geary function. The water demand estimates show that once temperature and time trend is controlled for at the household level, the minimum water consumption estimate for households is 5.67 kl per month. The estimate for the price elasticity of water demand was -0.0334 when using household level data. When looking at the SAL level we get an estimate for the price elasticity of demand of -0.2345.

The methodology that would be used to estimate the interaction between tariffs and nudges is outlined in section 6. Descriptive statistics are provided which suggest that the behavioural nudges amplify the effect of increased tariffs in reducing water consumption to the point where households move down a tariff block.

An in-depth cost benefit analysis is presented in section 7, building on the theoretical model developed by Nauges & Whittington (2019) which includes the estimated welfare effects of social norms nudges. Contrary to Nauges & Whittington (2019), this report finds that even if a significant moral tax associated with social norms nudges is assumed, with no moral benefit for informational nudges, the nudge campaign still resulted in a net benefit to society. If the assumed moral costs are valid, the net benefit to society would be overstated if they were not included in the cost benefit analysis; however, the result suggest that even with these moral costs the nudge program is a cost effective and welfare enhancing water demand side management mechanism.

ACKNOWLEDGEMENTS

The authors would like to thank the City of Cape Town for the ongoing collaboration and the access to the municipal billing data. Further, our thanks go to the NEWTS consortium which has been a great support throughout this study.

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1. Introduction and objectives

This study is part of the bigger study, Nudging for Economics of Water Tariffs ('NEWTS'), aimed to strengthen the socio-economic approaches to water management by integrating economic and social analyses into decision making processes related to tariffs and nudges. Through studying the interactions between these two water demand management tools, tariffs and nudges, the study will enable stakeholders to analyse the effects of policy mixes, combining nudges and tariff instruments, on socio-economic performance of demand side management policy.

This report document details all the work that has been completed on this project to date on the NEWTS project. In this study, the household water demand function derived for the City of Cape Town was evaluated, indicating the demand before nudging period. The study also provides some background to the impact of nudges on tariffs, describing the methodology of this estimation and providing some descriptive statistics on the shifts across tariff blocks for the treatment and control groups of our study. This study adds to the previous work package which estimate the water demand function and the interaction between tariffs and nudges by evaluating the cost and benefits of behavioural nudges using the theoretical framework laid out by Nauges & Whittington (2019).

1.1 Scope of report

Chapter 2 provides a short background on the NEWTS project, the water demand function, the impact of nudges on tariff performance and the cost benefit analysis. Chapter 3 describes the data sources used for this project: the City of Cape Town billing data and the South African Census Community profiles from 2011. Chapter 4 describes the steps of data pre-processing and the setup of the analysis in detail. In section 5 we describe the set-up of the water demand function, describe how to address the endogeneity problem using a two-stage least squares approach, and present the water demand function estimation results. Section 6 describes the methodology used to set up the analysis for the tariff nudge interaction, Nordin's difference and Shin's approach and provides some descriptive statistics of the tariff nudge interaction. Chapter 7 presents a cost benefit analysis of the nudges introduced in 2016. Chapter 8 summarises and discuss findings from the work completed

2. Background

2.1 Overview of the NEWTS project

NEWTS is a collaborative project across international research teams and involves four countries: France, South Africa, Spain, and Tunisia. The overall objective of the project is primarily to evaluate the socio-economic performance of water pricing by means of appropriate indicators, using household water demand estimated through econometric methods. Secondly, it will be tested if nudges can improve the socio-economic performance of existing water pricing schemes – through their effects on estimated water demand functions. EPRU is the consortium expert on nudges design, experimental setting and design, randomised control trials and assessment of treatment effects.

Previous field experiments have demonstrated the effectiveness of nudges on reducing water demand showing small to large effects, depending on the behavioural messages sent to households. Nudges impact water consumption and, thus, change households' water demand functions. Essentially, the question is whether a nudge acts through a reduction in captive consumption (top estimated basic needs of the households), and/or an increase in sensitivity of demand, and/or a change in tariff perception. Identifying these transmission channels is crucial for assessing how water pricing is impacted by nudges. We analyse a behavioral nudging campaign which was implemented across 400,000 households in Cape Town between November 2015 and May 2016.

When water demand management instruments, such as nudges and tariff changes, are introduced, consumption patterns as reflected in the water demand function are impacted. This project seeks to use the water demand function as a tool to evaluate the impact of nudges, in order to design tariff structures that are optimised to be complementary. In doing so it is intended that the novel insights gained will enable the impact of nudges and tariffs to both be enhanced and improved upon.

The NEWTS project is made of complementary research work packages. In the first part of the project, EPRU econometrically estimates the water demand function for households in Cape Town. In the second part of this project, EPRU assesses the impact of nudges on tariff performance and socio-economic indicators. EPRU will evaluate the impact of nudges which were rolled out in 2015 / 2016 on the water demand function for Cape Town and explore the influence of them on tariffs. Due to time constraints and delays in output from out project partners due to COVID-19 this evaluation was completed using descriptive statistics only. In the third work package of this project is an in-depth cost-benefit analysis of the nudge program implemented in 2015.

2.2 Household water demand function

The price elasticity of water demand can be derived from the water demand function and shows how responsive water users are to changes in price. In the literature, a Cobb-Douglas function is often used to determine elasticity of demand. Empirical evidence has shown that water is price inelastic with elasticity ranging from -0.1 to -0.3. Water usage is unresponsive to price changes because it is a necessary good, the total cost of water makes up a very small fraction of a household's monthly budget and households are imperfectly informed about water prices (Gaudin, 2006).

Water demand shows different price elasticities at different usage levels: while water use is very price unresponsive at low levels of usage (water used for essential purposes such as drinking, bathing and washing clothes / dishes), it is much more responsive to changes in price at higher usage levels.

A growing literature agrees that there exists a subsistence amount of water which is very inelastic to price changes, and thus modelling a water demand function should attempt to distinguish between consumption at this subsistence level and consumption beyond this level (Al-Qunaibet and Johnston, 1985; Gaudin, Griffin and Sickles, 2001; Martínez-Espineira and Nauges, 2004). The Stone-Geary approach is often used to break down water demand into these two parts.

The Stone-Geary function takes into account that there are non-constant price elasticities, and that water use is made up of two components. The first is a fixed component that is not affected by changes in prices or income. It varies with family size, habitat characteristics and constitutes an upper bound estimate of basic needs. The second is a variable part that depends on income and tariff parameters. Its specification enables to infer perceived prices (through Shin's formulation or a nested model) and sensitivity of demand to changes in tariff parameters (fixed charge, thresholds of consumption blocks, unit prices within each block). Lastly, econometric methods enable us to infer how water demand functions change with observable characteristics, by examining their effects on these three factors.

The Stone-Geary demand function also enables policy makers to assess how price changes will affect water usage and if tariff increases can be used to raise revenues (Dharmaratna and Harris, 2012).

Garcia-Valiñas, Nauges and Reynaud (2010) further note that when there is substantial variation in the ability to pay for water, determining the level of subsistence consumption can help policy makers provide water in a way that is not regressive and harmful to the most vulnerable.

The analysis in this report shows the water demand function derived from the Stone-Geary utility function:

$$\boldsymbol{Q^W = (1 - \beta^W)\gamma^W + \beta^W \left(\frac{I}{P^W}\right) + Z + u} \qquad \textbf{(Equation 1)}$$

Where Q^W is monthly water usage per household; γ_W is the threshold or minimum water usage that is not responsive to price and income changes; I is monthly household income; P^W is the average price of water; Z are housing and socio-demographic characteristics. Z should include variables that affect water use, rather than the price level (Garcia-Valiñas, Nauges and Reynaud, 2010). There should be no excessive collinearity among variables.

The basic variables needed for the Stone Geary function are: water use, price of water in each tariff block (including any fixed charges if applicable), and household income.

Further variables that can be used in the water demand function estimation include socio-demographic variables such as household size, household composition (for example, the number of children and adults in a household or the age structure), and educational level.

Additionally, any kind of housing characteristics are useful to include in the estimation such as the size of the house, garden size (or garden dummy), ownership (owned or rented), pool availability, age of the house, type of housing (free-standing house, apartment). Alternative water supply sources (rainwater harvesting, boreholes) and the number of water efficient appliances could also be included.

2.3 The interaction of tariff and nudges

Municipalities are limited by how much they can use price as a tool for water conservation. Firstly, raising water tariffs is often difficult due to regulatory constraints such as zero profit limitations as well as political opposition. Secondly, a notable feature of the literature on the effect of prices on electricity conservation is that changes in prices are not sufficient to reduce electricity use significantly (Di Cosmo et al., 2014; Wichman, 2014; Jessoe & Rapson, 2013; Allcott, 2011). Olmstead et al. (2007) concludes that consumers do not significantly change consumption as tariffs change because the demand for utilities, such as water, is fairly price inelastic. In a field experiment conducted in Japan, Ito et al. (2018) find that moral suasion and dynamic pricing produce substantially different short-run and long-run impacts on energy conservation. Consequently, policy makers often use a mix of price and non-price demand-management measures, such as behavioural interventions, to encourage energy and water conservation. The behavioural interventions used to encourage voluntary water savings include education campaigns, public information, and social comparisons (Brühl & Visser, 2021; Brent & Wichman, 2020; Binet et al., 2014).

There are several plausible theoretical ways in which prices and nudges may interact. For instance, a number of studies posit that information treatments mitigate the distortion in consumer's perceptions of price and quantity consumed, consequently reducing consumers' optimization errors thus lowering their consumption levels (Allcott & Taubinsky, 2015; Wichman, 2017; Brent & Ward, 2019).

A growing list of research evaluates the implications of behavioural nudges in various domains but only a few examine the interaction of behavioural nudges and prices or other conservation tools. Findings from some studies show that behavioural nudges interact with prevailing conservation policies (Brent et al., 2015; Allcott & Rogers, 2014). Using randomized field experiments to analyse the interaction of social comparisons with existing conservation programs, Brent et al. (2015) finds that social norms do not appear to crowd out existing conservation programs, as treated households are more likely to participate in additional programs. (Brandon et al., 2019) using data from a natural field experiment, find that social nudges reduce peak load electricity consumption by 2 to 4% when implemented in isolation and by nearly 7% when implemented in combination.

Although a few studies have examined the interaction of behavioural nudges for utilities consumption, we are aware of only one study that attempts to investigate the interaction of prices and nudges for water conservation. Using data from a randomized behavioural messaging campaign for households who face differential exogenously assigned marginal prices, Brent & Wichman (2020) explore the interaction of prices and behavioural nudges. The authors find no consistent evidence that social comparisons generate more conservation for households facing an exogenously larger marginal price of water. Additionally, the authors find weak evidence of norm-based conservation campaigns influencing customers' price sensitivity; treatment induces small increases in the magnitude of the price elasticity in some specifications, although these effects disappear in alternative specifications.

In section 6 of this report looks at the methodology behind estimating the interaction between behavioural nudges and tariffs and provides some descriptive statistics to evaluate this relationship.

2.4 Cost-Benefit Analysis of Green Nudges

There is substantial evidence that behavioural nudges are effective in reducing consumption however, there are few studies that evaluate whether nudges are necessarily welfare enhancing. Some studies have gone further than simply estimating the change in water and energy use and assessed the impact of green nudge interventions using simple cost-effectiveness or cost-benefit analysis. Datta et al. (2015) estimate the benefit-cost ratio of their social norm comparison and their informational treatments, which they found to vary between 6% and 13%.

Although it is common for studies to mention the cost effectiveness of nudges, there are few authors that use a theoretical framework to estimate the welfare effects of behavioural interventions. Alcott & Kessler (2015) determine the welfare effects of social comparison reports for energy consumption. They find that social norm interventions are welfare enhancing but that the welfare gains are significantly over estimated when using a standard evaluation approach. Brent et al. (2016) build on the theoretical framework developed by Allcott and Kessler (2015), and designed experiments to explore whether it is the relative moral cost or the information component that drives household's behavioural change. They find that there is significant individual level heterogeneity in willingness to pay for the nudge. They also find the social welfare gains of the nudge in their analysis to be massively overstated by a factor of 3.7. Nauges & Whittington (2019) illustrate a conceptual framework for conducting a cost-benefit analysis of social norms nudges in the municipal water sector. Their framework breaks the cost benefit calculations into four sections. Firstly, they look at the cost of delivery and implementation of the nudge. Secondly, they look at the utility's cost savings due to the reduction in consumption brought about by the nudge. Thirdly, they determine the welfare cost of the nudge to households. Finally, they investigate measuring the value associated with leaving an extra kl of water in the environment.

Section 7 of this report will use the theoretical model developed by Nauges & Whittington (2019) to evaluate the cost and benefits of the nudge program when considering the welfare effects of such nudges.

3. Data Sources Used

The main data used for this analysis was from the City of Cape Town. The City of Cape Town's billing data includes information on water use and tariffs for each residential household in Cape Town.

3.1 City of Cape Town billing data

The billing data included all information that is shown on the monthly invoice that each household in Cape Town receives. This included all account details such as property rates, water consumption, electricity consumption (if the electricity meter is not prepaid), refuse removal charges and sewerage charges. It also gives an account summary of what the previous account balance was, how much was paid and what the current amount due is. This municipal data is collected by the City of Cape Town.

EPRU has an ongoing non-disclosure and confidentiality agreement with the City of Cape Town. This includes permissions to access and analyse the City's monthly municipal billing data. Original approval to analyse the municipal billing data was given when a large-scale behavioural nudging study was rolled out across the city in 2015/2016. Households were provided with differently framed information about their monthly water consumption. In order to assess the longer term impacts of the nudges campaign and other interventions that the City of Cape Town rolled out after the behavioural nudges study, the City of Cape Town gave EPRU permission to continuously access and analyse the municipal billing data.

For the analysis in this study, the crucial variables were monthly household water use and the price of water in each tariff block.

The data used in this analysis was provided by the City of Cape Town under the cooperative agreement mentioned above. Because this billing data contains sensitive private information, the agreement states that researchers may not share the dataset with anyone not party to the agreement. The City of Cape Town, however, has created a formal procedure whereby any researchers wanting to use the data for research purposes can approach them independently.

3.2 Water pricing data (part of the billing data)

Cape Town water users face a non-linear pricing structure. Before October 2018, there was only a volumetric charge. Since October 2018, residential water users have been facing a monthly fixed charge and a volumetric charge. The volumetric charge was based on an increasing block tariff structure of 6 tariff blocks (before October 2018) and has been based on 4 tariff blocks since October 2018. The tariff blocks before and after October 2018 are shown in Table 1.

Table 1: Overview of tariff blocks before / after October 2018

Before October 2018	From October 2018
Step 1 (0 < 6 kl)	Step 1 (0 < 6 kl)
Step 2 (>6 < 10.5 kl)	Step 2 (>6 < 10.5 kl)
Step 3 (>10.5 < 20 kl)	Step 3 (>10.5 < 35 kl)
Step 4 (>20 < 35 kl)	Step 4 (>35 kl)
Step 5 (>35 < 50 kl)	And basic fixed delivery charge
Step 6 (>50 kl)	

Table 2 shows the water price schedule across years. Up until July 2017, water in the first step tariff block was at no charge for all residents. As a result of the drought, Cape Town increased the price of water in the first block to R4 per kilolitre for all non-indigent households in July 2017. Throughout the Cape Town drought, tariffs were increased, often in combination with an increase in restriction levels and other drought measures. The prices shown in Table 2 are the actual prices charged at the time (no adjustment for inflation, excluding VAT).

Table 2: Changes in the water tariffs for residential users from 2015 to 2018

Step	Level 1		Level 2			Level 4B	Level 6B	Level 5 '18	Level 3 '18
	Jan 2015	Jul 2015	Jan 2016	Jul 2016	Dec 2016	Jul 2017	Feb 2018	Oct 2018	Dec 2018
1	0	0	0	0	0	4	26.25	21.19	13.68
2	8.75	9.71	10.22	13.75	14.51	15.57	46	34.43	19.46
3	12.54	13.92	16	17.56	20.65	22.78	100	52.39	27.63
4	18.58	20.62	26.09	28.64	35.93	38.32	300	300	60.66
5	22.94	25.47	39.82	43.71	58.25	99.99	800	NB: change in tariff steps and introduction of fixed charge from October 2018 onwards	
6	30.27	33.59	74.64	81.92	175.58	265.12	800		

3.3 StatsSA South African Census Community Profiles 2011

The SA Census Community Profiles has national coverage and its lowest levels of geographic aggregation is the Small Area Layer (SAL). The census data was obtained through DataFirst at the University of Cape Town. The data is freely available and can be downloaded at DataFirst's website: https://www.datafirst.uct.ac.za/dataportal/index.php/catalog/517/study-description. The census data includes household characteristics (type of dwelling, household assets, energy/water access) and individuals' characteristics (such as age, employment status, health). The variables that were downloaded and used for this project are: household size, annual household income, and total number of rooms. Other variables that could be included for further analysis are: tenure status, level of education, and population group.

3.4 Weather Data

Weather data was obtained from the online website World Weather Online for Cape Town during the period of analysis (June 2014 to October 2015). The weather data can be accessed online using the following link:
https://www.worldweatheronline.com/cape-town-weather-history/western-cape/za.aspx

4. Work process

4.1 Pre-processing of the municipal billing data

The municipal billing data used in this study originally came from the City of Cape Town printing service “Mailtronic”. Each month’s billing data came in separate printing files (a total of 20 csv files per month) which had to be combined into one monthly dataset.

The billing data used for this study only includes households who were part of the Cape Town wide nudging study in 2015/2016. In the data cleaning process, additional variables were added to the data such as property values, and the treatment group that each household was part of during the 2016/2015 behavioural nudging study.

Some observations were dropped from the municipal billing data. Households with period days that were longer than 45 days were dropped from the sample because an extremely long billing period is usually indicative of billing related issues. Likewise, estimated municipal bills were dropped from the sample since they did not reflect actual water usage.

4.2 Merging the census data and the billing data

This study spatially joined municipal billing accounts to the South African Census Community Profiles from 2011. The most detailed geographic level for research purposes is the Small Area Layer (SAL). The City of Cape Town municipality contains 5,339 SALs with a minimum of 300 individuals per layer. Statistics South Africa provides GIS data at SAL level with the Census Community Profiles data. We further had the geographic coordinates of municipal billing accounts and were therefore able to join the two datasets spatially using GIS.

The study assumed that a household in a certain SAL has the household income, number of household members, or number of rooms of the SAL-level average.

The Census 2011 income data was adjusted for inflation in the analysis using general inflation rates from Statista shown in Table 3 (Statista, 2020).

Table 3: Inflation rates 2011 to 2015

Year	Inflation rate
2011	4.99%
2012	5.62%
2013	5.76%
2014	6.09%
2015	4.58%

4.3 Assessing Expected Correlations

Household size: Household size is generally positively related to household water use (Arbués, Barberán and Villanúa, 2004; Arbués and Villanúa, 2006; Hoffmann, Worthington and Higgs, 2006; Schleich and Hillenbrand, 2009). However, there is a diminishing effect – household size and water use do not increase proportionally. We expect to see a positive relationship between household size and monthly water use.

Annual Household Income: Income and water use is commonly found to be positively related (Dandy, Nguyen and Davies, 1997; Arbués, Barberán and Villanúa, 2004; Arbués and Villanúa, 2006; Gaudin, 2006; Hoffmann, Worthington and Higgs, 2006). However, water bills usually only form a small part of a household's monthly budget. Income therefore usually only has a moderate effect on water usage.

Previous studies in the context of South Africa, and Cape Town in particular, have revealed that water use is extremely dependent on income levels (Cook, Brühl and Visser, 2020). The strong income inequality that prevails South Africa is reflected in monthly water usage levels of households that are connected to the piped network. Before the drought in Cape Town, the highest water users were high income earners. The drought of 2015-2018 shifted these patterns and the highest income group drastically reduced their municipal water use (Visser and Brühl, 2018; Cook, Brühl and Visser, 2020). At the height of the drought, in the summer of 2018, the highest income quintile used less municipal water than the lowest income group.

This study expected to see a positive relationship between water use and income before the drought and the nudging study which was conducted in 2015/2016. As income increases, water use increases as well.

Total number of rooms: Information about the average number of rooms on a SAL level are used to account for property size. Besides socio-economic factors, such as household income, housing characteristics affect water use. Commonly, pool ownership, garden size, number of bathrooms, alternative water supply infrastructure or water-efficient appliances are controlled for in the water demand estimation. In this study, we use information on the average number of rooms on a SAL level from the Census 2011 dataset. We expect water use to increase with the number of rooms in a property. Large properties usually have more bathrooms and a larger outside area, potentially including a swimming pool or large gardening / grass area which needs to be watered during the dry summer months.

4.4 Descriptive statistics of control variables

Table 4 shows the descriptive statistics for the control variables used in the Stone Geary demand function estimation. The average monthly water usage over the study period was around 20 kl with an average price of 7.4 South African Rand per kilolitre of water. The average household size in in this sample was 3.48 persons and average household income was 20,608 South African Rand (adjusted for inflation). The average rainfall between June 2014 and October 2015 was 35.78 mm. The average temperature was 16.5 degrees with a minimum average temperature of 11 degrees Celsius in July 2015 and a maximum average temperature of 21 degrees Celsius in January 2015.

Table 4: Descriptive statistics of variables used in the water demand function

Variable	Units	Level	Mean	Std. Dev.	Min	Max
Monthly water usage	Kl/month	HH[1]	19.91729	14.1357	2.03	122
Average water price	R/kl	HH	7.379149	4.766409	0	34.67651
Household size	persons	SAL[2]	3.479083	.7423659	1.333333	6
Household income	R/month	SAL	20,608	17680.77	373.3116	105642.6
Number of rooms	rooms	SAL	4.95763	1.373359	1	9.783069
Average rainfall	Mm	City-wide	35.78	31.88	3.83	94.4
Average temperature	C	City-wide	16.5	3.39786	11	21

[1] HH stands for household
[2] SAL stands for Small Area Layer

5. Water Demand Function Estimation

5.1 Setting up the analysis for the Water Demand Function

As a first step in the Stone Geary function, we need to find the average price for water for the months in which the water price stayed the same (P^W). The average price is calculated by dividing the average cost of water by the average water use on a household level. We can then divide the average household income I by the average price of water P^W.

$$\boldsymbol{Q^W = (1-\beta^W)\gamma^W + \beta^W\left(\frac{I}{P^W}\right) + Z + u1} \qquad \textbf{(Equation 2)}$$

Ordinary least squares regressions assume that errors in the dependent and independent variables are not correlated. However, in the Stone Geary equation above, the relationship between Q^W and P^W is bidirectional. The amount of water used (Q^W) is a predictor of the average price of water (P^W) and not only a response to it. The average price of water influences the level of water usage but the level of water usage also influences the average price of water – and there is no control variable that can address this issue.

This type of issue is commonly known as endogeneity problem. In this case, endogeneity is due to simultaneity (demand and prices are determined simultaneously): X causes Y but Y also causes X. An ordinary least squares regression will not be the optimal model to use because it will produce biased and inconsistent results.

The common way to deal with endogeneity is to use a two-stage least squares technique which will be explained further in the following section.

5.2 Addressing the endogeneity problem with a two-stage approach

We are addressing the endogeneity issue through a control function approach in a two-stage procedure. Control functions model the endogeneity in the error terms.

In the first stage, the endogenous variable $\frac{I}{P^W}$ becomes the dependent variable in the regression model and is regressed on all exogenous and instrumental variables. The chosen instrumental variables need to be (1) correlated with the endogenous variable $\frac{I}{P^W}$ (2) should not affect Q^W directly but through $\frac{I}{P^W}$ and (3) need to be uncorrelated with the error. For this estimation, we used average monthly household income I divided by tariff block price TB^i (where i is equal to the respective tariff block from 1-6) as instrumental variables (see equation 3 below). The exogenous variables in our model are average household size and average number of rooms in the house as well as the weather variables (the same Z variables as in equation 2 in section 4.5).

$$\frac{I}{P^W} = \frac{I}{TB^1} + \frac{I}{TB^2} + \frac{I}{TB^3} + \frac{I}{TB^4} + \frac{I}{TB^5} + \frac{I}{TB^6} + Z + u2 \qquad \textbf{(Equation 3)}$$

We then compute the linear prediction of the dependent variable ($\frac{I}{P^W}$) using an ordinary least squares regression. The error is the difference between the estimation and the prediction of the dependent variable: $\widehat{u2} = \frac{I}{P^W} - \widehat{\frac{I}{P^W}}$.

In the second stage, we then substitute $\frac{I}{P^W}$ with its predicted value ($\widehat{\frac{I}{P^W}}$) from the first stage to estimate the dependent variable (Q^W). The errors from the first model ($\widehat{u2}$) are used as an additional regressor in the second stage.
Here is a brief overview of the terminology:

- *Dependent variable*: Q^W is regressed on the exogeneous and endogenous variables (but not on the instrumental variables).

- *Exogenous variables*: Exogenous variables, such as household size and number of rooms in a house, are independent variables which are included in the first stage and second stage regression model.

- *Endogenous variables*: $\frac{I}{P^W}$ is the dependent variable in the first stage regression and is regressed on all exogenous and instrumental variables. The predicted values from the first stage regression replace the endogenous variable in the second stage.

Instrumental variables: The endogenous variable becomes the dependent variable in the first stage and is regressed on the exogenous and instrumental variables. The predicted values then replace the original values of the endogenous variables in the second stage.

5.3 Correlations between water use and control variables

The dataset included all households that were part of the nudging study between November 2015 and May 2016. The correlations in the sample are shown in Table 5.

Water use and average household size are negatively correlated in the sample. This is contradictory to previous findings in the literature (Arbués, Barberán and Villanúa, 2004; Arbués and Villanúa, 2006; Hoffmann, Worthington and Higgs, 2006; Schleich and Hillenbrand, 2009) which indicated that water use increases with household size. Cape Town (before the drought) however was defined by extremely unequal municipal water usage levels with wealthier households using much more municipal water than poorer households. At the same time, there is a negative relationship between household size and income – lower income families have on average larger families than higher income households. The negative relationship between water use and household size is driven by wealthier households, with smaller household size, using more water than poorer households.

Number of rooms and water use are positively correlated. This result is very straightforward because one would assume that houses with larger number of rooms also have a larger property size overall, potentially with more bathrooms and more garden area.

Average rainfall and water use are negatively related in the sample. During the winter rains, residents use municipal water less (or not at all) for outdoor water purposes such as watering their gardens or topping up their pools (both activities which use excessive amounts of water). Similarly average temperature is positively correlated with municipal water use – households use more water during the hot and dry summer months.

Lastly, indigent status is negatively related with water use. Households that are officially classified as indigent with the City of Cape Town and receive rates rebates and rebates on municipal services use less water than households that do not have this status.

Table 5: Correlations between control variables and water use

	Water use
Average household size	-0.1495
Average number of rooms	0.2514
Average rainfall	-0.1442
Average temperature	0.1811
Indigent status	-0.1748

5.4 Estimation Results

The study estimated a model of residential water demand in Cape Town based on the Stone-Geary utility function. The estimation of the Stone Geary function was done on two levels: the household level and the SAL level. The analysis was conducted on these two levels because most of the control variables used in the regression were only available on a SAL level from the South African Census 2011 and could not be broken down to a lower level. We wanted to assess if using the control variables on a SAL level but estimating the demand function on a household level produces incorrect results.

5.4.1 Estimation results on a household level

The Stone-Geary utility function considers a threshold of water demand that is independent from income levels or price levels and an amount of water that changes with an increase in price.

Municipal water is used for different purposes, some are more essential than others. Water use at the essential level is highly inelastic. Essential water uses such as cooking, drinking, and cleaning cannot be substituted. This fixed quantity of water use is presented as the constant in the regression output. The constant is the threshold of water use below which consumption levels are no longer affected by price. The minimum consumption level is very significant and was estimated to be 17.01 per household per month (when not controlling for temperature and a time trend). This equates to 4.89 kl per person per month (assuming that the average household in our sample has 3.479083 household members). When controlling for temperature and time trend, the threshold drops to 5.67 kl per household per month (or 1.63 kl per person per month).

The first estimation results (excluding temperature data) are strongly in line with the results by Martínez-Espineira and Nauges (2004) who found a minimum consumption level of 4.7 kl per capita per month in the first model specification in their study using water usage data from Seville, Spain. Al-Qunaibet and Johnston (1985) estimated the threshold to be 2.5 kl per capita per month in Kuwait.

Dharmaratna and Harris (2012), however, find the threshold that is unresponsive to changes in water prices to be 4.5 kl per household per month in Sri Lanka (around 1.07 kl per capita per month). These results are close to our second estimation results in this study. They explain their results, which are much lower than previous findings in the literature, that households in developing countries often substitute water supply with alternative sources while households in developed countries rely solely on the piped network. It can be assumed that most households in Cape Town, particularly before the drought, relied on pipe-born supply and very few households would access water through boreholes, rainwater tanks, or natural springs.

On the other hand, Gaudin, Griffin and Sickles (2001) estimated a threshold of 12 to 13.6 kl per capita per month. However, they used water production and not water usage which meant that water losses were also included in their estimation.

The coefficient for income divided by price (incAvPhat in the regression output in Table 6) is very small but significant and has the correct positive sign in both specifications. Since the monthly municipal water bill is relatively small compared to overall household expenses, this small value is not surprising. Other studies, for example Martínez-Espineira and Nauges (2004), found equally small values for this coefficient.

As expected, average household size is negatively related to water usage in the Stone-Geary function. Average number of rooms in a house are significant and positively related to water use, as we anticipated.

Rainfall is also significant and has the expected negative sign while temperature has the expected positive sign. During the warm, dry summer months in Cape Town, households use more water.

The indigent indicator variable is insignificant in the first specification and significant and negative in the second specification.

The overall fit of the model is rather low with an overall R-squared of 0.1352 to 0.1485. This might be because there is a discrepancy between water use level and the explanatory variables – the one is on the household level while the other is on the SAL Census 2011 level. We therefore estimate the same model on the SAL level in the next section.

Table 6: Stone-Geary estimation results (Household level)

VARIABLES	(6) HH_level_ind_rain	(8) HH_level_ind_temp_rain_date
incAvPhat	0.000248***	0.000651***
	(1.03e-05)	(9.95e-06)
Household size	-1.758***	-1.313***
	(0.0281)	(0.0280)
Number of rooms	2.088***	1.547***
	(0.0187)	(0.0185)
Temperature		0.657***
		(0.00378)
Rainfall	-0.0740***	-0.00102***
	(0.000178)	(0.000355)
eincpr	-0.000374***	-0.000365***
	(2.12e-06)	(2.12e-06)
Trend		-0.215***
		(0.00213)
Indigent status	0.0284	-2.394***
	(0.0541)	(0.0530)
Constant	17.01***	5.668***
	(0.135)	(0.159)
Observations	3,175,836	3,175,836
Number of acc_no	342,016	342,016
R-squared: within	0.0564	0.0961
R-squared: between	0.1639	0.1654
R-squared: overall	0.1352	0.1485

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7 presents the estimated income and price elasticities for the sample mean, maximum, and minimum price levels. Calculating price elasticity at the sample mean shows that the elasticity is -0.0334. This suggests that a 10% increase in the average price of water would lead to a decrease in water usage levels of 0.334%. Income elasticities in our sample are (at the mean level) 0.0334 suggesting that a 10% increase in household income would increase water usage by 0.334%.

These results are lower than previous findings in the literature that find water to be price inelastic with elasticity ranging from -0.1 to -0.3. Dharmaratna and Harris (2012) found price elasticities ranging between -0.11 and -0.14 in their study. Martínez-Espineira and Nauges (2004) found average price elasticities of around -0.1 in their study in Spain.

Table 7: Elasticities and thresholds from the Stone-Geary function (household level)

Threshold (in kl)		17.01-5.668
Price elasticity	Mean	-0.0334
	Min	N/A because the lowest price is zero
	Max	-0.0071
Income elasticity	Mean	0.0334
	Min	N/A because the lowest price is zero
	Max	0.0071

5.4.2 Estimation results on a SAL level

When estimating the water demand function for Cape Town before the nudging study on a SAL level instead of the household level, incAvPhat becomes slightly larger. Average household size and average number of rooms has a smaller effect when estimating demand on a SAL level compared to the household level. The coefficient on rainfall and temperature only changes slightly, as would be expected because the weather patterns stay the same when estimating on household or SAL level. The indigent control variable is not included in this estimation because it only exists on a household level and this estimation was done on a SAL level.

The minimum consumption level is very significant and was estimated to be 15.82 per household per month (when not controlling for temperature and a time trend). This equates to 4.55 kl per person per month (assuming that the average household in our sample has 3.479083 household members). When controlling for temperature and time trend, the threshold drops to 4.827 kl per household per month (or 1.387 kl per person per month).

The overall R squared (0.4739) of this model is much higher than the household level estimations.

Table 8: Stone-Geary estimation results (SAL level)

VARIABLES	(6) SAL_level_ind_rain	(8) SAL_level_ind_temp_rain_date
incAvPhat	0.00217***	0.00277***
	(9.77e-05)	(9.78e-05)
Household size	-0.595***	-0.196*
	(0.103)	(0.103)
Number of rooms	0.902***	0.513***
	(0.0766)	(0.0766)
Temperature		0.593***
		(0.0163)
Rainfall	-0.0762***	-0.00711***
	(0.000785)	(0.00153)
eincpr	-0.00231***	-0.00227***
	(6.98e-05)	(6.92e-05)
Trend		-0.223***
		(0.00914)
Constant	15.82***	4.827***
	(0.394)	(0.521)
Observations	51,333	51,342
Number of sal_code	4,416	4,416
R-squared: within	0.163	0.264
R-squared: between	0.5448	0.5488
R-squared: overall	0.4279	0.4681

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9 presents the estimated income and price elasticities for the sample mean, maximum, and minimum price levels. Calculating price elasticity at the sample mean shows that the elasticity is -0. 2345 which is much more in line with previous findings in the literature. This suggests that a 10% increase in the average price of water would lead to a decrease in water usage levels of 2.345%. Income elasticities in our sample are (at the mean level) 0.2345 suggesting that a 10% increase in household income would increase water usage by 2.345%.

Table 9: Elasticities and thresholds from the Stone-Geary function (SAL level)

Threshold (in kl)		15.82-4.827
Price elasticity	Mean	-0.2345
	Min	N/A because the lowest price is zero
	Max	-0.1038
Income elasticity	Mean	0.2345
	Min	N/A because the lowest price is zero
	Max	0.1038

6. Tariff Nudge Interaction

6.1 Estimation

6.1.1 Nordin's Difference

The expenditure function for households consuming block rate priced water is the following, if households respond to marginal prices:

$$\boldsymbol{\pi q} = \boldsymbol{\pi c} + \boldsymbol{\beta}(\boldsymbol{Y} - \boldsymbol{F} + \boldsymbol{D} - \boldsymbol{\pi c} - \boldsymbol{p\gamma}) \qquad \textbf{(Equation 4)}$$

If households respond to the average price, instead of the marginal price, the expenditure function takes to following form:

$$\boldsymbol{\bar{\pi} q} = \boldsymbol{\bar{\pi} c} + \boldsymbol{\beta}(\boldsymbol{Y} - \boldsymbol{F} - \boldsymbol{\bar{\pi} c} - \boldsymbol{p\gamma}) \qquad \textbf{(Equation 5)}$$

The difference between these two expenditure functions is Nordin's difference D. Nordin's difference expresses the refunding to which a household is entitled if they had paid their entire water use at the highest marginal rate, the price in the highest tariff block that the household consumed in in a given month. This adjustment is necessary because the household did not pay the highest marginal rate across the entire bill but different marginal prices for each tariff block. The formula for Nordin's difference is:

$$\boldsymbol{D} = (\boldsymbol{\pi_2} - \boldsymbol{\pi_1})\boldsymbol{b_1} + (\boldsymbol{\pi_3} - \boldsymbol{\pi_2})\boldsymbol{b_2} + \cdots + (\boldsymbol{\pi_j} - \boldsymbol{\pi_{j-1}})\boldsymbol{b_{j-1}} \qquad \textbf{(Equation 6)}$$

The table 5 depicts the concept of Nordin's difference using a simple example tariff structure and an example household consuming 5 kl in tariff block 1 at a price of R1, 5 kl in tariff block 2 at a price of R2, and 2 kl in tariff block 3 at a price of R3. The total amount the household used is 12 kl and the price the household had to pay for this amount is R21.

Table 11: Nordin's Difference tariff structure graph

	Tariff Block 1	Tariff Block 2	Tariff Block 3	
Price in each tariff block	R1	R2	R3	
Water use	5 kl	5 kl	2 kl	=12 kl
Total price per tariff block	R5	R10	R6	=R21

In the example, the marginal price, which is the price in the highest tariff block a household consumed in, in this case tariff block 3, is R3. The average price is R1.75 (R21/12 kl). Nordin's difference D is then calculated by subtracting the actual paid amount (R21) from the amount that the household would have paid if all water use had been priced at the highest marginal rate (= (12kl*R3 = R36). Hence, Nordin's difference is R15.

Average price can also be calculated using Nordin's difference ($\bar{\pi} = \pi - \frac{D}{q}$). In this example, the average price using Nordin's difference therefore is R3-(R15/12kl) = 1.75.

In order to combine the expenditure functions for households using marginal and households using average price when making water use decisions, we need to introduce the parameter k:

$$\boldsymbol{\pi^* q = \pi^* c + \beta(Y - F + (1 - k)D - \pi^* c - p\gamma)} \quad \textbf{(Equation 7)}$$

If a household only uses marginal price, k is 0. The larger k, the more a household uses average price instead of marginal price. If a household only uses average price, k is 1. Note that if k=1, Nordin's difference in equation 4 falls away and the estimation is reduced to equation 2.

Assessing perceived price is important because if the perceived price is higher than the marginal price, updating households price information (for example, through nudges or other kind of information campaigns) could have undesired effects on water use, a water use increase.

6.1.2 Shin's Approach

Households are commonly unaware of their water use during the month and might be confused about the sewerage charges which are often included in the monthly water bill. Water meters are difficult to read, and water use feedback is commonly only given once a month with the monthly water bill and with lack of details.

Nonlinear pricing schemes where goods have different marginal prices depending on how much a household consumes makes it complicated for households to make optimal usage decisions. Shin (1985) developed a model that estimates demand when households do not have perfect information about pricing, for example because the pricing structure is too complex. He assumes that it is costly for consumers to understand the actual tariff pricing schedule in an increasing tariff block structure because prices change with consumption. Shin's price perception model can be used to assess if households respond more to average or marginal prices.

If the marginal costs of calculating the real price are higher than the benefits, households will be imperfectly informed about the true prices they pay. Shin assumed that households would stop finding more information about the price structure they are facing when expected marginal benefit equals expected marginal cost. The perceived price, the price to which the household actually responds, hence lies somewhere in between marginal and average price. Shin therefore described the perceived price as:

$$\boldsymbol{P^* = MP(\frac{AP}{MP})^k}$$ **(Equation 8)**

With k=1 if the household only responds to average price (AP) and k = 0 if the household responds to marginal price (MP). Shin assumes that desired use can be estimated using a log-log model of explanatory variables.

In this analysis, perceived price is defined as the weighted arithmetic average of marginal and average prices (π is marginal price; $\bar{\pi}$ is average price):

$$\boldsymbol{\pi^* = k\bar{\pi} + (1-k)\pi = \pi - \frac{kD}{q}}$$ **(Equation 9)**

This comes from substituting in average price $\bar{\pi} = \pi - \frac{D}{q}$

$$\pi^* = k\left(\pi - \frac{D}{q}\right) + (1-k)\pi$$

$$\pi^* = k\pi - \frac{kD}{q} + \pi - k\pi$$

$$\pi^* = \pi - \frac{kD}{q}$$

In order to derive the final model that we estimate, perceived price π^* is substituted into the expenditure function (equation 7 above).

$$\pi^* q = \pi^* c + \beta(Y - F + (1-k)D - \pi^* c - p\gamma)$$

$$(\pi - \frac{kD}{q})q = (\pi - \frac{kD}{q})c + \beta(Y - F + (1-k)D - (\pi - \frac{kD}{q})c - p\gamma)$$

$$(\pi - \frac{kD}{q})q = \pi c - (\frac{kcD}{q}) + \beta\left(Y - F + (1-k)D - \pi c + \frac{kcD}{q} - p\gamma\right)$$

$$\pi q - \frac{qkD}{q} = \pi c - (\frac{kcD}{q}) + \beta\left(Y - F + (1-k)D - \pi c + \frac{kcD}{q} - p\gamma\right)$$

$$\pi q - kD = \pi c - (\frac{kcD}{q}) + \beta\left(Y - F + (1-k)D - \pi c + \frac{kcD}{q} - p\gamma\right)$$

$$\pi q = \pi c + kD - (\frac{kcD}{q}) + \beta\left(Y - F + (1-k)D - \pi c + \frac{kcD}{q} - p\gamma\right)$$

$$\pi q = \pi c + \left(k - \frac{kc}{q}\right) * D + \beta\left(Y - F + (1-k)D - \pi c + \frac{kcD}{q} - p\gamma\right)$$

$$\pi q = \pi c + \left(1 - \frac{c}{q}\right) * k * D + \beta\left(Y - F + (1-k)D - \pi c + \frac{kcD}{q} - p\gamma\right)$$

6.1.3 Stone Geary's Approach

A growing literature agrees that there exists a subsistence amount of water which is very inelastic to price changes, and thus modelling a water demand function should attempt to distinguish between consumption at this subsistence level and consumption beyond this level (Al-Qunaibet and Johnston, 1985; Gaudin, Griffin and Sickles, 2001; Martínez-Espineira and Nauges, 2004). The Stone-Geary approach is often used to break down water demand into these two parts.

The Stone-Geary function takes into account that there are non-constant price elasticities and that water use is made up of two components. The first is a fixed component that is not affected by changes in prices or income. It varies with family size, habitat characteristics and constitutes an upper bound estimate of basic needs. The second is a variable part that depends on income and tariff parameters. Its specification enables to infer perceived prices (through Shin's formulation or a nested model) and sensitivity of demand to changes in tariff parameters (fixed charge, thresholds of consumption blocks, unit prices within each block). Lastly, econometric methods enable us to infer how water demand functions change with observable characteristics, by examining their effects on these three factors.

6.2 Descriptive results of tariff nudge interaction

Before estimating the change in tariff blocks econometrically, we assessed the shifts across tariff blocks in a descriptive manner. In our first analysis, we looked at what tariff block a household was in in April 2015 and what tariff block the same household was in in April 2016. We assessed how many households stayed in the same tariff block or changed the tariff block they were consuming in (either decreased or increased), and how many tariff blocks they decreased / increased, i.e. if they dropped their water use from block 4 to block 3 or to block 2. We assessed a total of 25 combinations.

We find that most households in the control group remained in the same tariff block (52.86%) and 51.61% of households in the treatment groups remained in the same tariff block.

32.59% of households in the control group decreased the tariff block they were consuming in compared to 34.30% in the treatment groups.

We saw an increase in tariff block among 14.55% of households in the control group and 14.09% treatment group households. However, it needs to be noted that the results are descriptive and do not give any indication on significance.

Very few households increase their water use by more than 1 tariff block. For example, only 0.86% of households in the control group that consumed in tariff block 2 in April 2014 moved more than 1 tariff block (compared to 0.85% in the treatment groups). 5.55% of households moved from TB2 to TB3 in the control and in the treatment groups 5.06% moved from TB2 to TB3. The largest amount of changes happened from TB4 to TB3. 11.77% of households in the control group dropped their water use from TB4 to TB3, compared to 12.16% of households in the treatment groups.

7. Nudge Cost-Benefit Analysis

Green Nudges are increasingly becoming a policy tool used to encourage consumers to act in an environmentally friendly way. These behavioural interventions have become popular as they are able to influence behaviour without changing the price or restricting a consumer's choice set. Green nudges are particularly attractive within low-income countries where the scope to increase tariffs is limited. Their effect is usually measured as the magnitude of behavioural change in relation to their cost effectiveness. Nudges are widely acknowledged to significantly increase resource savings (between 2-5%) at a relatively low cost (Nauges & Whittington, 2019). A common tool used by water utilities when trying to influence consumers to reduce their consumption is to provide them with information through their water bills. However, there are very few papers that evaluate the impact of such interventions through a cost-benefit analysis that includes a full evaluation of the consumer welfare effects of the nudge. There are not many studies that evaluate whether the implementation of behavioural nudges is welfare enhancing.

At the onset of the Cape Town drought, in 2015, the City implemented behavioural nudges. Brick et al. (2017) evaluate the impact of the nudges and find that all treatments significantly reduced water consumption.

This section follows the framework laid out by Nauges & Whittington (2019) to illustrate the costs and benefits of the large-scale behavioural interventions implemented in Cape Town in 2015/2016. The social costs and benefits of behavioural interventions are highly location specific and subject to substantial uncertainty. However, a carefully considered social cost-benefit analysis can drastically change the perceived impact of a behavioural intervention on overall welfare.

Section 2 of this paper will provide a brief overview of some of the existing literature that evaluates the impact of behavioural nudges in the water and energy sectors. The third section gives some context and a brief overview of the behavioural nudges that were implemented to mitigate the drought in Cape Town, South Africa, in 2015/2016. The fourth section will discuss the four main categories of benefits and costs that affect various stakeholders. Section 5 concludes this analysis.

7.1 Literature on cost benefit analysis of green nudges

The applied behavioural literature has demonstrated that nudges are a useful mechanism with which to reduce residential electricity and water consumption (Brick et al., 2017; Datta et al., 2015; Jaime and Carlsson, 2016; Tiefenbeck et al.; 2019). Several types behavioural nudges have been implemented in the literature to reduce water or energy consumption, some common ones are informational nudges, social norms nudges, nudges that appeal to intrinsic motivation, and those that appeal to extrinsic motivation through social recognition or other external rewards (Alcott & Kessler, 2015).

Information provisions are aimed at addressing the lack of knowledge about resource consumption or cost, one of the most common causes of overuse (Ramas et al., 2015). If households are lacking information about their consumption or the tariff structures are complex, providing households with information and saving tips allows them to optimise their water use. Several papers have investigated the effect of providing consumers with information about their water or energy use. Jaime and Carlsson (2016) evaluated several informational treatments, including a treatment which informed consumers about the environmental impact of water use which induced a water use reduction of 4.6% in Colombia. Tiefenbeck et al. (2019) show that real-time feedback on specific activities, such as showering, can reduce water consumption for that target behaviour by 22%.

Social norm messaging is increasingly seen as a useful mechanism for promoting pro-environmental behaviour. For example, a social norms treatment could compare a household's consumption to the average household consumption in the neighbourhood. Datta et al. (2015) investigated the effects of nudges on water consumption in Costa Rica. They found that a descriptive social norm intervention using neighbourhood comparisons reduced water consumption by between 3.7% and 5.6% relative to a control group, while a plan making intervention reduced water consumption by between 3.4% and 5.5%. Ferraro & Price (2013) find that social norm-based appeals reduce water consumption by 4.8% while Pellerano et al. (2017) find that similar social norms nudges in Ecuador yielded a more modest reduction of 1% in energy consumption. Economic incentives on the other hand led to a larger decrease of 14-17% and persisted over time. Nauges & Whittington (2019) review various papers on the effect of behavioural nudges on water consumption and find that the short-term reductions in water use from these interventions tend to be in the range of 2-5%.

Various nudges use both intrinsic and extrinsic incentives to motivate individuals to conserve. Ito et al. (2015) test the effect of both moral suasion and extrinsic economic incentives on household electricity consumption. They found that moral suasion which attempts to influence intrinsic motivation resulted in an 8% reduction in household electricity consumption but that these effects were diminishing over repeated interventions. Economic incentives on the other hand led to a larger decrease of 14-17% and persisted over time.

There is substantial evidence that behavioural nudges are effective in reducing consumption however, there are less studies that evaluate whether nudges are necessarily welfare enhancing. Some studies have gone further than simply estimating the change in water and energy use and assessed the impact of the nudge's interventions using simple cost-effectiveness or cost-benefit analysis. Datta et al. (2015) estimate the benefit-cost ratio of their social norm comparison and their informational treatments, which they found to vary between 6% and 13%.

Although it is common for studies to evaluate the cost effectiveness of nudges, there are few authors that use a theoretical framework to estimate the welfare effects of behavioural interventions. Alcott & Kessler (2015) determine the welfare effects of social comparison reports for energy consumption. They find that social norm interventions are welfare enhancing but that the welfare gains are significantly over estimated when using a standard evaluation approach. Brent et al. (2016) build on the theoretical framework developed by Allcott and Kessler (2015), and designed experiments to explore whether it is the relative moral cost or the information component that drives household's behavioural change. They find that there is significant individual level heterogeneity in willingness to pay for the nudge. They also find the social welfare gains of the nudge in their analysis to be massively overstated by a factor of 3.7. Nauges & Whittington (2019) illustrate a conceptual framework for conducting a cost-benefit analysis of social norms nudges in the municipal water sector. Their framework breaks the cost benefit calculations into four sections. Firstly, they look at the cost of delivery and implementation of the nudge. Secondly, they look at the utility's cost savings due to the reduction in consumption brought about by the nudge. Thirdly, they determine the welfare cost of the nudge to households. Finally, they investigate measuring the value associated with leaving an extra kl of water in the environment.

7.2 Cost Benefit Analysis

According to Nauges & Whittington (2019) four main categories should be included in a cost-benefit analysis. The first category is the cost of delivery of the informational treatment. The second category is the value of resource cost savings to the utility (e.g. water provider) from the social norms study. The third is the welfare effect on households. The fourth is the value of leaving an extra kl of water in the environment. There is a great deal of heterogeneity, and the cost-benefit analysis would vary significantly according to locality.

7.2.1 Cost of delivery

Costs are incurred from printing and mailing the inserts. As the treatments were sent in households' monthly water bills these costs only included the printing of the extra inserts for each household. We assume that the inserts costed approximately R0.25 each. The inserts were sent as part of the monthly municipal bill for 6 months and therefore the cost of delivery was R1.5 in total.

7.2.2 The cost savings to the utility

Behavioural nudges slightly reduce household water consumption. This reduction in consumption results in revenue reduction for the water utility as well as an increase in savings on a household's water bill[1]. The financial gain experienced by households coincides with a financial loss to the utility and therefore they cancel each other out in the cost-benefit analysis.

With the loss in revenue, the water utility will also experience a cost saving from the reduction in the amount of water being produced. The provision of water to consumers is capital intensive and as the water use reduction due to green nudges is generally small and short-lived, there is no reduction in the capital cost to the water utility. The reduction in costs would then come exclusively from the operation and maintenance (O&M) costs of providing households with water.

The City of Cape Town states in their tariff policy document that consumption tariffs for registered charities, public benefit organisations and non-profit organisations will be charged at the Average Cost of Water (The City of Cape Town, 2020). The City defines the Average Cost of Water as the "total current annual cost of the water service (including capital charges but excluding surcharges and contributions to a capital development fund) divided by the total volume of billed water sales for that year." We are, therefore, able to deduce that the cost of delivering one kl of water would be equal to the tariff charged to "Schools / Sport Bodies / Churches / Charities" in the 2015/2016 water consumptive tariff break down, approximately R20.4 (City of Cape Town, 2016b).

We calculate from the 2015/2016 budget that operating expenditure makes up 70% of the annual cost for piped water services. We would not expect the O&M costs to be reduced by 100% as a result of the nudges but, following the example of Nauges & Whittington (2019),

[1] The reduction in revenue experienced by the water utility is equal to R26.46 (0.94% x 23 kl x R20.4 x 6 months = R26.46) on average per treated household.

we assume that the O&M costs were reduced by 25% due to the short run response to the intervention. This results in savings of approximately R3.57 (0.7 x 0.25 x R20.4) per kl of water saved by households. Over the six months in which the intervention was implemented, treated households reduced their consumption by between 0.6% and 1.3% (average of 0.94%). The average consumption at the time of the interventions was approximately 23 kl per household per month (Brick et al., 2017). The average cost saving to the City of Cape Town would, therefore, be approximately R0.77 (0.94% x 23 kl x R3.57) per household per month. Over the six months of the intervention, the City would have saved approximately R4.62 (R0.77 x 6 = R4.62) per household on average.

7.2.3 Welfare effects on households

Most water utilities sell piped water services below their total average cost and rely on subsidies from higher level government to cover the financial deficit (Nauges & Whittington, 2019). This was, however' not the case in Cape Town, as seen in the 2015/2016 budget in which water revenue (R2,931,902) exceeded expenditure (R2,494,663) (City of Cape Town, 2016). A large proportion of these costs came from the provision of free basic water (6 kl per household per month) provided to all households, irrespective of household size or income level, at the time (Parks et al., 2019).

Households will save on their water bills as a result of the reduction caused by the green informative nudges. For most households, however, these savings will be small due to the low price of water at the time. The cost savings of the household corresponds to a reduction in the revenue generated by the water utility and therefore they cancel out in the summation of benefits and costs.

There are various positive and negative ways in which nudges may affect a household's welfare. The outcome strongly depends on household characteristics and the information conveyed in the nudge. There are two main channels through which nudges affect household's welfare (Nauges & Whittington, 2019). Firstly, an informational nudge corrects information failure and enables households to better optimise water use and therefore increases their welfare. Secondly, the social norms nudge imposes a moral tax or benefit due to the social comparison.

When making decisions around how much water to consume, households commonly have imperfect information. Households receive water bills every month, but these bills are often estimated. Households are unaware of how much water specific activities require, and tariffs are generally complex and difficult to understand. Providing households with more precise information about their consumption patterns and tariff structure can help households to optimise their use and increase their overall welfare. It is, therefore, likely that nudges which provide information about consumption to households would have a net positive effect on welfare. These nudges were, however; implemented in a time where the City of Cape Town was already investing in drought communication campaigns to inform households about water conservation during the drought. It is, therefore; likely that many of the households that were part of the water saving tips or tariff graph treatments could have been exposed to similar information without the nudge. We assume that the welfare effects of the four treatments aimed at addressing information failure were negligible.

The moral tax is an estimate of the cost of green nudges to a household's welfare. Nauges & Whittington (2019) mention three ways in which a moral tax from green nudges arises. Firstly, households may feel that the utility is being intrusive by providing the informational nudge. Secondly, the household may feel pressured to reduce their water use when they do not want to do so at the offered price. Thirdly, the household may either feel guilty about consuming above the social norm or they could feel a benefit if learning that they are consuming less than their peers. Alcott and Kessler (2015) assess the welfare effect of social norm nudges in a theoretical model. The model consists of a constant term that simply captures whether a household likes or dislikes the nudge and a second component that depends on how the household's level of water use compares to the social norm. The second component is described as the moral tax of the nudge.

It is difficult to quantify the welfare effect of social nudges as it varies drastically among households depending on the nudge type, the household's consumption level and the household's attitude towards the nudges. It is likely that households that are provided with nudges that address information failure through water saving tips and tariff graphs would experience a positive welfare effect from the nudge. While those households receiving social norm nudges who reduce their water consumption would most likely experience a moral tax. Although we are unable to accurately determine the effect of informational nudges on household welfare, for illustrative purposes we follow the example of Alcott and Kessler (2015) who estimate the moral cost of a social norm intervention to be half the cost saving. In this case the moral cost per kl of water would be half the average price paid per kl of water, which we can assume is equal to half the average cost of water in 2015 or R10.2 per kl (R20.4 x 50%). As Alcott and Kessler (2015) calculate this only based on social norm informational nudges, we will only consider those consumers in the social norms treatment group when calculating this welfare affect in our cost and benefit calculations. Brick et al. (2017) finds that for the social norm's treatment group, the monthly average water consumption was 20.83 kl per month in October 2015. The social norm nudge induced an average reduction in water of 1.13% over the 6-month period of the nudge. We can therefore estimate that the moral cost of the social norm's treatment would be on average R14.4 per household (20.83 kl x 1.13% x 6 months x R10.2). Although this seems significant, we know that only 33034 households out of the 314935 treated households received the social norms nudge. Only 10.5% of the treated households experienced the estimated moral tax associated with a social norms nudge. The average moral cost of the behavioural nudge would therefore be R1.51 per household (R14.4 x 10.5%).

7.2.4 Value of leaving a kl of water in the environment

The third group of stakeholders are those who would experience welfare gains from the effect of the nudges leaving extra water in the environment. The value of the additional water that was kept in the ecosystem is very site specific and subject to significant heterogeneity making it difficult to get an accurate measure of this value. A large benefit of the behavioural nudges is that their combined effect resulted in saving enough water in Cape Town to delay Day Zero by three weeks. This delay had an immensely positive welfare effect on all households residing in Cape Town.

For the purposes of illustration, we follow the example of Nauges & Whittington (2019) and assume that the value of leaving one kl of water in the environment is approximately 5% of the water utility's cost to provide this water. The value of leaving an extra kl of water in the environment would therefore be approximately equal to R1.02 per kl (R20.4 x 0.05 $\approx$ R1.02). Given that the average household residing in Cape Town during the time of the intervention consumed approximately 23 kl of water per month and the behavioural intervention reduced consumption by approximately 0.94% (Brick et al., 2017), the welfare gain created for citizens who value the additional water being kept in the environment would be roughly R1.32 (R1.02 x 23 kl x 6 months x 0.94% = R1.323 $\approx$ R1.32). The assumption that the value of leaving an extra kl of water in the environment would be equal to 5% of the average cost of water is used as an example. Given that there is no accurate way to calculate this value, this value is used to illustrate the conceptual framework that was laid out by Nauges & Whittington (2019). Further research to determine a more accurate measure for the value of leaving a kl of water in the environment is needed. Given the severity of the drought in Cape Town, it is likely that the example given by Nauges & Whittington (2019) is a conservative measure which seems appropriate for lack of a better alternative.

7.2.5 An Illustrative Presentation of the Benefits and Cost of the informational nudges implemented in Cape Town

Table 2 is an illustrative example of all benefits and costs to the three stakeholder groups (owners of the utility, residential households, and the citizens concerned about ecosystem services). As emphasised, this table uses the framework laid out by Nauges & Whittington (2019) to show a comprehensive cost-benefit analysis of behavioural nudges pertaining to water use. There is significant heterogeneity across countries and locations, therefore these calculations are extremely site specific.

Similarly, to Nauges & Whittington (2019) we find it plausible that the welfare effect of these behavioural nudges on households is negative, although quite small. Table 2 illustrates the cost-benefit calculations for different stakeholder groups when we assume that the social norms nudges result in a welfare tax and that the welfare gains from the other nudges are negligible. In Table 3 we assume that there are welfare gains due to warm glow from conservation that at the least counteract the negative welfare effect of the social norm's nudges. The moral cost/ benefit to households is interpretive and could be both positive and negative depending on what assumptions are made about perceptions on the informational nudge. In this case, we used estimates which were based on work done by Allcott and Kessler (2015). In the case of Cape Town, the nudges result in a net benefit to society whether we include a moral tax or not.

The results change significantly depending on the assumptions made about the welfare effects of nudges. Although the cost-benefit calculations presented in the table below are illustrative and the results vary significantly depending on our assumptions, they illustrate the importance of taking the welfare effects of behavioural interventions into account. As stated by both Nauges & Whittington (2019) and Allcott and Kessler (2015), the positive impact of behavioural interventions to reduce water or energy consumption is in many cases overestimated and a comprehensive cost-benefit analysis should be considered before implementation.

Table 12: Cost Benefit Calculations Assuming Welfare Tax

Stakeholder (affected party)	Benefits	Costs	Benefits – Costs
1. Utility owners (taxpayers)			
- Cost of social norms information treatment		≈ R1.5	
- Cost savings from reduced household water use	≈ R4.62		
- Reduced revenues from households		≈ R26.74	
Net change to utility owners	≈ R4.62	≈ R28.24	- R23.62
2. Utility customers (households)			
- Reduced water bills	≈ R26.74		
- Moral costs/benefits		≈ R 1.51	
Net change to utility customers	≈ R26.74	≈ R 1.51	+ R25.23
3. Citizens receiving environmental benefits	≈ R1.32		+ R1.32
Societal Total	≈ R32.68	≈ R29.75	**R2.93**
Benefit-cost ratio ≈ 1.10			

Table 13: Cost Benefit Calculations Assuming no Welfare Tax

Stakeholder (affected party)	Benefits	Costs	Benefits – Costs
1. Utility owners (taxpayers)			
- Cost of social norms information treatment		≈ R1.5	
- Cost savings from reduced household water use	≈ R4.62		
- Reduced revenues from households		≈ R26.74	
Net change to utility owners	≈ R4.62	≈ R28.24	- R23.62
2. Utility customers (households)			
- Reduced water bills	≈ R26.74		
- Moral costs/benefits			
Net change to utility customers	≈ R26.74		+ R25.23
3. Citizens receiving environmental benefits	≈ R1.32		+ R1.32
Societal Total	≈ R32.68	≈ R28.24	**R4.44**
Benefit-cost ratio ≈ 1.16			

7.3 Conclusion

There is a general belief that behavioural interventions in the water sector are a low cost and efficient way to induce a reduction in water resource consumption. The results show that any water planner should carefully consider the welfare effects of behavioural interventions in the water market before implementing such interventions.

This report follows the framework laid out by Nauges & Whittington (2019) to perform a cost benefit analysis of the behavioural interventions implemented during a severe drought in Cape Town, South Africa. An analysis of the impact of these interventions was performed by Brick et al. (2017) and it was found that the behavioural nudges reduced water consumption by 0.6-1.3% across all treatments. As shown by Nauges & Whittington (2019) and Allcott and Kessler (2015), a comprehensive analysis of the cost and benefit of behavioural nudges such as those implemented in Cape Town is important when trying to determine their impact on net welfare. Our results show that the nudges result in a net benefit of R2.93 per treated household. This result depends on assumptions made about the net welfare effect of the interventions and shows that if these welfare effects are not considered, the benefit of such interventions can be significantly overstated.

8. Summary of key findings

This study findings are as follows:

- The study estimated a model of residential water demand in Cape Town based on the Stone-Geary utility function on two levels: the household level and the Small Area Layer (SAL) level. The estimate for the price elasticity of water demand was -0.0334 when using household level data. When looking at the SAL level we get an estimate for the price elasticity of demand of -0.2345. At the household level this study finds the minimum consumption level to be equal to 5.67 kl per household per month, when controlling for temperature and time trend. We find that water use, and average household size are negatively correlated in the sample. The negative relationship between water use and household size is driven by wealthier households, with smaller household size compared to poorer households that use less water. The average number of rooms in a house and water use are positively correlated. Average rainfall and water use are negatively related in the sample while average temperature is positively correlated with municipal water use.

- This study investigated the methodology of estimating the interaction between tariffs and nudges and provides some descriptive statistics evaluating this relationship. The descriptive results suggest that those in the control group were less likely to decrease their tariff block compared to those households that received the nudge. Which suggests that nudges slightly amplify the effect of higher tariffs in getting households to reduce their water consumption to a point that would result in moving down a tariff block. It must be noted that these results are just descriptive and have no indication of significance.

- The study presented an in-depth cost-benefit analysis based on the conceptual model developed by Nauges & Whittington (2019). This model for the cost-benefit analysis of water nudges is based on some restrictive assumptions. Contrary to the water nudges evaluated by Nauges & Whittington (2019), the study showed that even with restrictive assumptions about the value of water left in the environment and the assumption that the nudges have a moral cost, the nudges resulted in a net benefit to society. It was observed that the cost-benefit analysis of these nudges are very location specific and difficult to measure and that the net benefit may be overstated if one does not consider the moral tax associated with social norms nudges.

9. Discussion and Recommendations

This report has provided an overview of all of the work completed for the NEWTS project to date, it includes an estimation of the water demand function, an evaluation of the interaction between tariffs and nudges, and a cost benefit analysis of the nudge program. The nudging study was implemented in November 2015. All households included in this analysis were part of the 2015 nudging study – receiving either one of the eight treatment groups or being part of the control group, which did not receive any messages. An analysis of the impact of these interventions was performed by Brick et al. (2017) and it was found that the behavioural nudges reduced water consumption by 0.6-1.3% across all treatments. This report notes the data sources used for this analysis, the work processes that have been completed so far, including the pre-processing of data and the setup of the analysis.

Previous studies in the context of South Africa, and Cape Town in particular, have revealed that water use is extremely dependent on income levels (Cook, Brühl and Visser, 2020). The drought of 2015-2018 shifted these patterns and the highest income group drastically reduced their municipal water use (Visser and Brühl, 2018; Cook, Brühl and Visser, 2020). In estimating the water demand function, we find that water demand is more price elastic at higher consumption levels. Therefore, those households consuming larger amounts of water will have a higher percentage change in consumption when tariffs increase. Empirically we can see that high consumers reduced their consumption drastically compared to low water consumers during the drought. At the height of the drought, in the summer of 2018, the highest income quintile (previously the highest water consumers) used less municipal water than the lowest income group. When controlling for temperature and time trend the estimated minimum consumption level for households is 5.67 kl per month. This is approximately equal to the free basic water subsidy of 6 kl per household per month.

This report shows that even when the moral cost associated with social norms nudges is considered in the context of the nudges implemented during the Cape Town drought in 2015/2016, this intervention resulted in a net benefit to society. Although the net benefit of these nudges may be overstated when not considering these moral costs, the results suggest that they are still a cost-effective mechanism for water demand side management. This study shows that nudges seem to amplify the effect of increased tariffs in managing water demand, although our results for this interaction are descriptive and do not speak to significance. The water demand function show that there is a minimum consumption level per household which is approximately equal to the 6 kl of free basic water provided to all households and that demand side management mechanisms have a much larger effect on high water consumers.

More research is needed into the interaction between nudges and tariffs for different income groups. Research should also be conducted on estimating the value of the welfare of nudges on households at different consumption levels and the value of water that is left in the environment during severe drought.

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