Understanding the preferences for different types of urban greywater uses and the impact of qualitative attributes

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ABSTRACT

Greywater reuse can allow substantial improvements in the efficiency of potable water systems. However, widespread uptake of greywater reuse depends on its acceptability by the population. Previous studies have assessed the implementation costs of greywater reuse technology, and considered its acceptability in principle. Although cost is clearly very important in terms of adopting/installing the technology, the actual perception of greywater reuse is crucial in driving the acceptability of use and the long-term success of the technology. This study uses discrete choice models to quantify, for the first time, the preferences of different socio-economic groups for greywater of different quality (colour, odour) and for different uses inside homes. A stated choice survey that removed the influence of installation costs was developed, and implemented in Santiago, Chile. Although legislation allows greywater use in Santiago, it does not take place at any meaningful scale. Results show that, in decreasing order of preference, there is an overall acceptance for using high quality treated greywater for toilet flushing, laundry, garden irrigation, hand washing and, shower/bathtub use, but not for drinking. When the quality of appearance in terms of colour and odour gets worse, monetary incentives could be needed even for those uses that do not involve human contact. Gender, age, educational level, water expenditure level, and in particular previous knowledge about greywater reuse, are important determinants of acceptability and thus willingness to pay for greywater use; however, their importance varies according to the type of use. Our results provide important insights for understanding the conditions that would precipitate rapid and wide uptake of greywater reuse in cities, and thereby make better use of limited water resources.

Keywords: Greywater reuse, water reuse preferences, human behaviour, choice modelling

1. Introduction

In recent years, greywater (i.e. the relatively clean waste water from baths, sinks and washing machines) reuse has emerged as a viable and sustainable water management strategy, because: (i) the volume of water that can be recovered presents a significant share of water consumption (Tello *et al*., 2016; Chen *et al*., 2017; Guthrie *et al*., 2017); (ii) the greywater characteristics have reached higher quality standards (Fountoulakis *et al*., 2016); (iii) there are important benefits associated with lower water demand, lower losses in potable water systems and improvements in water allocation (Walsh et al., 2016; Wilcox *et al*., 2016); and (iv) there is a reduction in the energy required for the treatment and distribution of potable water (Lu et al., 2019). However, to become a non-niche water management strategy, greywater reuse needs to be widely accepted by the population, and its welfare benefits for residences and the overall community recognised (Smith *et al*., 2018; Fielding *et al*., 2018).

Several authors have studied the willingness of the population to reuse water (e.g. Adapa, 2018; Fielding et al., 2018; Khan & Anderson, 2018), as well as the characteristics that can influence choices in this area (Hartley, 2006; Hurlimann & Dolnicar, 2016; Smith *et al*., 2018). However, understanding the psychology of the individual is difficult (Dolnicar *et al*., 2011), and that is why studies often rely on aggregate analysis of choices (Fielding *et al*., 2019; Hurlimann & Dolnicar, 2016). Their main limitation is that it is not generally possible to a) understand the specific influence of households' characteristics on the uses projected for the reused water, b) measure the influence of different characteristics of the greywater on acceptability, and c) make predictions about acceptability with changes in water or population characteristics. This highlights the need for improved data collection and econometric analysis methods.

To understand the acceptability of individuals and their choices for water reuse, there are two elementary sources of information: (i) successful local experiences and the population perception of the system (Chen *et al*., 2017b; Woltersdorf *et al*., 2018; Lefebvre, 2018; Khan & Anderson, 2018), and (ii) previous studies related with the acceptability of water reuse (Baumann, 1983; Fielding *et al*., 2019; Gu *et al*., 2015; Smith *et al*., 2018; Wilcox *et al*., 2016). The first source generates new opportunities to create instruments for collecting information about water reuse perceptions (Khan & Anderson, 2018; Lefebvre, 2018). The second is a valuable academic source to understand where policies should focus to achieve greater acceptability of these measures.

Most previous studies have focused attention on attributes associated with the cost of implementing the technologies (Gu *et al*., 2015; Massoud *et al.*, 2018; Oh *et al*., 2018), and found that this could predispose individuals to reject water reuse due to the economic cost involved, especially in the case of individuals who have no previous knowledge or experience about water reuse (Wilcox *et al*., 2016). This is a relevant issue, as negative individual perceptions can affect the implementation of policies oriented to provide alternative water sources and reduce water security problems. Work that seeks to understand acceptability of greywater reuse thus needs to be careful to avoid the influence of the upfront monetary component. Hence, there is a need for studies where this economic issue is controlled, to better characterize and understand individuals' response to other attributes related to the quality of the treated greywater, given past findings about feelings of "disgust" towards greywater (Garcia-Cuerva et al., 2016; Leong, 2016). In this way, although both the cost and disgust are key factors, we want to highlight that while the former is very important in terms of adopting/installing the technology, the disgust factor is crucial in terms of driving the acceptability of use and the long-term success of the technology.

Given the above, the aim of the present paper is to study the potential preferences for greywater reuse, considering specifically which characteristics of greywater are desirable and which are undesirable, net of the impact of installing the technology *per se*. In particular, we address two specific objectives: (1) to determine the willingness to use domestic greywater considering the variation in observable consumer characteristics (e.g. age, education) across households, and (2) to determine if compensation would be required so that the alternatives for reusing greywater are accepted by the population, and how this varies as a function of the appearance of the treated greywater. Given our interest in qualitative attributes and currently inexistent reuse situations, the use of *stated choice* (SC) experiments emerge as a potentially ideal tool for modelling; the SC approach stands out from other methods due to its success and robustness over time when new alternatives are considered under hypothetical scenarios of choice (Bennett & Blamey, 2001; Ortúzar & Willumsen, 2011; Schaafsma *et al*., 2014). SC techniques are used widely across different research areas – for a comprehensive introduction, see Louviere *et al*. (2000) and Rose & Bliemer, (2014). Examples in water research include the work of Rungie *et al* (2014) and Scarpa *et al*. (2012). In our study we make use of SC techniques that allow us to study the preferences of households in carefully constructed hypothetical scenarios, and analyse the resulting data using advanced econometric structures belonging to the family of discrete choice models. The study area is the Metropolitan Region of Santiago, Chile, a location where greywater use, although legally allowed, does not take place at present. The characteristics of the study area plus the uniqueness of the modelling approach and attributes under consideration, make our results potentially valuable not just for this region but also for areas with similar characteristics.

The remainder of this paper is organised as follows. Section 2 discusses the survey work and introduces the econometric methods. The results are presented in Section 3, with conclusions in Section 4.

2. Material and methods

Our work uses data from a stated choice (SC) survey using advanced discrete choice models. In this section, we describe the survey work and the specification of the econometric models.

2.1. Survey overview

A comprehensive survey was designed to understand water use and reuse preferences. The survey form was divided into four sections:

1. *Context of greywater reuse.* Two schematic representations were presented explaining the differences between the types of domestic residual water (grey and sewage) and the operation of a greywater reuse system inside a dwelling (house or apartment). At this stage, respondents were also told that, after treatment, the greywater would be of a quality comparable to mains water and suitable for drinking, no matter what the actual use was.
2. *Greywater reuse.* Six questions with predefined possible answers/ratings were asked to gather information related to the respondent's attitudes (e.g., reactions to the concept of greywater reuse, risk perception, confidence in a greywater reuse system).
3. *Choice experiment.* In this section, the SC questionnaire was presented. This key component of the survey is looked at in more detail below.
4. *Characterization of dwelling and household*. This section had 15 questions related with the number of household members, their socioeconomic characteristics and their dwelling facilities.

2.2. Choice context and experimental design

Our study focuses on understanding individual preferences for greywater reuse, and which characteristics of greywater are desirable and which are undesirable. The choices were therefore framed around a hypothetical setting where the technology was already installed in a property where the respondent currently lived. By asking respondents to consider this hypothetical but plausible scenario, the cost of the technology was thus intentionally removed. This allowed us to study the role of the qualitative characteristics of greywater, net of the impact of installing the technology *per se*. Such a focus on use rather than acquisition is a common application of stated preference (SP) across different fields of research. For example, one of the most common uses of SP looks at the choice of mode of transport, say between private car and public transport. In that context, the focus is on the cost of travel per journey, rather than on the cost of purchasing a car.

Of course, it is important to ensure that respondents can relate to the choice context presented and make decisions that are in line with real world preferences. To this extent, the hypothetical setting was described as follows:

> *"Assume that in your home there is a device to treat greywater with a simple power button to start using it. The technology will not increase your electricity cost as a solar panel provides power. After the greywater treatment is completed, the quality of the treated water is good enough for use inside the home. However, due to treatment, it might not be as visually clear or smell-free as mains water"*.

It should be noted that this setting is not unrealistic. Indeed, the solar power generated by a single panel (between 1kWh/day and 5kWh/day, see Jäger-Waldau, 2019) will exceed the operating needs of the greywater treatment for a one family unit (less than 1kWh/day, cf. Matos et al., 2014). Chile is increasing its deployment of solar energy, where law 20.571 came in force in 2013 to encourage uptake of solar panels in households, and there is a growing sustainable housing industry (Cáceres, et al., 2015; Serpellet al., 2013).

A key issue in the development of a SC survey is the selection of the attributes used to describe the alternatives. Following the findings of (Ilemobade, *et al,* 2013), greywater reuse alternatives were characterized by three level-of-service attributes: *colour*, *odour* and *type of use*, and an economic attribute, the *savings*. In the explanation given to the respondents, it was mentioned that colour and odour were by-products of the treatment, that is, it was not that the technology produces a dark blue colour, but that the chemicals used in the treatment had this as a side-effect (as is the case when using water purification tablets, for example).

In the actual choice scenarios, respondents were presented with three mutually exclusive alternatives. The first two were greywater reuse alternatives, where treated greywater is used for one specific purpose (e.g. toilet flushing) with mains water used for all other purposes. The third alternative was referred to as the *status quo*, that is, mains water for all uses. A core point of SC surveys is that the scenarios force respondents to make trade-offs (i.e., there is not a clear dominant option). This is illustrated in the example scenario shown in Figure 1. While alternative C has the best qualitative levels in terms of colour and odour, it has a disadvantage compared to the other two options in terms of savings. Similarly, there is no dominance between alternatives A and B. One of them has better colour but worse odour and lower savings.

The approach to experimental design for SC is a science in itself and involves decisions about the levels to use for the different attributes, and the way in which these are combined to form meaningful choice scenarios. In our work, the colour and odour attributes varied in three levels, while six *types of use* - associated with the most common residential uses were considered (Table 1). The attribute *savings* was expressed as the monetary equivalent of the water amount that could be recovered monthly if a greywater reuse system was in operation (between 10% and 30% of the household's monthly water expenditure). However, it should be noted that there are a variety of reuse experiences at the household level around the world and water savings levels can vary between 10% and 50% (Chen *et al*., 2017; Fountoulakis *et al*., 2016; Guthrie *et al*., 2017; Wilcox *et al*., 2016; Lambert & Lee, 2018). We then added an intermediary level – the use of three levels was motivated by the fact that the same number was used for the qualitative attributes. Finding an appropriate payment mechanism in SC experiments is not always straightforward (see the discussion in Ortúzar, 2010). We then turned the percentages into actual monetary values, served as a payment mechanism in the experiment. For this, the sample was divided into two mutually exclusive water expenditure groups: low (T1), below 20,000 Chilean Pesos (CLP) per month (approximately US$ 28.8 at the time of data collection) and high (T2), above CLP 20,000 per month.

Attributes	Alternative A TREATED GREYWATER	Alternative B TREATED GREYWATER	Alternative C TAP WATER – ALL USES
Colour caused by treatment	Light blue	Dark blue	Transparent
Odour caused by treatment	Soft chlorine odour	Odourless	Odourless
Uses of treated greywater	Garden irrigation	Washing clothes	
Monthly savings expected on the water bill	Saving US$ 3.00	Saving US$ 8.00	Saving US$ 0.00
	I prefer alternative A ☐	*I prefer alternative B* ☐	*I prefer alternative C* ☐

Figure 1: Example of hypothetical scenario card. Individuals must choose one of three alternatives

The second stage of the experimental design process relates to selecting the combinations of attribute levels for each given choice scenario, for example leading to the scenario presented in Figure 1. For a detailed introduction to experimental design see Bliemer & Rose, 2010. Initially, 60 respondents answered a pilot survey that used an orthogonal design produced in NGENE (ChoiceMetrics, 2012), with 27 individual choice scenarios, subdivided into three blocks, such that, to avoid fatigue, each respondent answered only nine choice situations. Previous experiences had demonstrated that 10 or fewer choice scenarios work well with Chilean respondents (Caussade *et al*., 2005; Rose *et al*., 2009). Subsequently, using the results of models (cf. Section 2.4) estimated on the pilot survey data as priors, a D-optimal (also known as D-efficient) design was generated with the aim of minimizing the standard errors of the parameters to be estimated with the resulting data. This final design comprised 18 hypothetical choice scenarios that were also subdivided into three blocks of six scenarios each, as we noted in the pilot that even nine choice scenarios increased the respondent's burden in this case. Therefore, each respondent only answered six choice scenarios in the final survey. A core aim of the design process is the lack of dominance, hence requiring respondents to make trade-offs, where this is a characteristic of all 18 scenarios used in the survey (six per respondent, split into three blocks).

Table 1. Attributes and levels of treated greywater alternatives in the SC survey

Level	Colour	Odour	Use of treated greywater	Monthly expected savings in water bill	
				Group 1 (T_1) $N_1 = 290$	Group 2 (T_2) $N_2 = 220$
1	Transparent	Odourless	Toilet flushing	US$ 3.00	US$ 8.00
2	Light blue	Soft chlorine odour	Garden irrigation	US$ 6.00	US$ 12.00
3	Dark blue	Strong chlorine odour	Washing clothes	US$ 8.00	US$ 18.00
4			Washing hands		
5			Shower/Tub		
6			Drinking		

2.3. Study Area

Data were collected in the Santiago Metropolitan Region, located in central Chile. This conurbation is the most populated in the country with 7.1 million inhabitants (40% of the Chilean population), who live in an area of 641.4 km^2 administratively divided into 37 municipalities. According to the 2018 census (INE, 2018), women are 51.3% of the population, 69.8% of the inhabitants are individuals between 18 and 64 years of age, and 70.2% of them have primary or secondary educational level.

Average per capita residential demand for water varies between 153 l/day and 290 l/day, where the three largest uses are: 31% for toilet flushing, 30% for showers and 22% for cleaning and laundry. Water supply comes from traditional sources of fresh water such as rivers and groundwater wells (Meza *et al*., 2014).

However, the Santiago Metropolitan region could potentially be affected by water security problems, and although the water system appears to be robust in terms of city supply, it is fairly fragile to external factors such as climate and geology (Ministerio del Interior y Seguridad Publica, 2014).

The analysis and modelling were based on the results of a *face-to-face* survey conducted on a random sample of 606 households in 29 municipalities within the Santiago Metropolitan region. After data cleaning, a sample of 510 households were retained for the analysis, of which 290 households (N_1) and 220 households (N_2), respectively, belonged to the low and high water expenditure groups previously defined (Table 1). Table 2 shows a summary of the data according to the socio-demographic characteristics used in our analysis. These characteristics replicate those reported by INE (2018) for the actual population, although more women participated in the survey.

Table 2: Overview of socio-demographic characteristics of survey respondents

Characteristic	Level	Share (%)	Census 2017 (%), *taken from INE (2018)*
Gender	Female	65.3	51.3
	Male	34.7	48.7
Age	18 - 54 years	55.9	69.8
	55-64 years	19.0	
	65 years and over	25.1	10.8
Education	Primary or secondary education	64.1	70.2
	Technical college	15.5	29.8
	University	20.4	
Water expenditure level	Below 20,000 CLP/month	56.7	N/A
	Above 20,000 CLP/month	43.3	N/A
Previous grey-water knowledge	None or low	71.4	N/A
	Middle or high	28.6	N/A

2.4. Specification of discrete choice models

Our survey aimed to study the impact of a variety of characteristics on preferences, including qualitative attributes, the type of use, and the monetary implications. We employed econometric methods belonging to the family of discrete choice models, and specifically those based on random utility theory, to help us disentangle these different influences on choice. In these models, the probability of choosing a specific option amongst mutually exclusive alternatives increases in the presence of desirable characteristics and decreases in the presence of undesirable characteristics. The extent to which individual characteristics are desirable/undesirable is determined during model estimation. For an in-depth overview of choice modelling techniques, see the theoretical discussions in Ortúzar & Willumsen, (2011, Chapters 7–9) and Train (2009), while a coverage of application areas is available in (Hess & Daly, 2014).

Our modelling work considered the estimation of progressively more flexible specifications, especially in terms of socio-demographic effects. The final specification was an Error Components Mixed Logit model (Train, 2009), capturing the correlation across choices made by the same respondent (i.e. the so-called pseudo panel effect). The models used a detailed utility function with numerous socio-demographic and water use interactions (Ortúzar & Willumsen, 2011, chapter 8, pp. 279).

In random utility models, each alternative has an associated "utility function", which is a latent construct describing the appeal of the alternative to the individuals; these functions have two components: (i) a systematic or representative utility, which is typically a linear function of the attributes weighted by unknown parameters that represent marginal utilities; (ii) an error term that serves to treat data deficiencies, the effect of unknown variables, etc. This error term can have different forms yielding different model specifications (Ortúzar & Willumsen, 2011; Train, 2009). The higher the utility, the more likely the alternative is to be chosen. Undesirable attributes (e.g. darker colour in our case) decrease the utility of an alternative while desirable attributes (e.g. higher savings) increase it. The impact of each attribute is captured through its associated parameter. The values for these parameters are estimated through a maximum likelihood process. The expectation is that negative parameter values are obtained for undesirable attributes and positive parameter values for desirable attributes. The absolute size of the parameters gives an indication of the importance of the various individual attributes in shaping the decision-making process. As mentioned above, these parameters were allowed to vary across decision makers as a function of their socio-demographic characteristics.

In our models, the utility for alternative j (where $j = 1,..3$) for respondent n in choice scenario t ($U_{j,n,t}$) is given by:

$$U_{j,n,t} = \delta_j + \underline{\beta}_n \underline{X}_{j,n,t} + \xi_{j,n} + \varepsilon_{j,n,t} \qquad (1)$$

This utility function contains two error terms. The first, $\xi_{j,n}$, is identically and independently distributed (IID) across alternatives and respondents according to a normal $N(0, \sigma)$ distribution, where σ is estimated, and serves to treat the pseudo panel effect. The second term, $\varepsilon_{j,n,t}$, is IID across alternatives and observations, and follows a type I extreme value distribution. In the absence of the first error component, this specification would be a simple Multinomial Logit model (Train, 2009). For both error terms, the variance is the same across alternatives (σ^2 for $\xi_{j,n}$, and $\frac{\pi^2}{6}$ for $\varepsilon_{j,n,t}$), but while $\varepsilon_{j,n,t}$ varies across all choices, $\xi_{j,n}$ is kept constant across the choices for the same respondent, thus capturing the potential correlation among them.

Two sets of parameters were estimated. The first was an alternative specific constant (δ_1), which was included in the utility of the left-most alternative with a view to capturing any positional bias in how respondents choose between alternatives; this parameter is associated with a value 1 for the left-most alternative and zero for the others (and $\delta_j = 0$, for $j \neq 1$). The remaining set of parameters ($\underline{\beta}$) capture the influence on utility of the various possible levels of the attributes describing the alternatives. The vector $\underline{X}_{j,n,t}$ groups together the various characteristics (or attributes) of alternative j, as faced by respondent n in choice scenario t:

- The type of water use, which has seven levels; namely, the six types of grey water uses and using mains water for all purposes. As shown in Table 1, only the first six levels are possible for the first two alternatives, while only the final level is possible for the third alternative. This attribute is treated as categorical, with mains water use as reference (i.e., its parameter $\beta_{mains\ water}$ is fixed to zero).
- The colour attribute, which has three levels, namely clear, light blue and dark blue. All three levels are possible for the first two alternatives, while only the first level is possible for the third alternative. This attribute is also treated as categorical, and the best level (which also applies to mains water) is used as reference ($\beta_{clear} = 0$).
- The odour attribute, which also has three levels, namely odourless, light chlorine and strong chlorine. Again, all three levels are possible for the first two alternatives, while only the first level is possible for the third alternative. This attribute is also treated as categorical, and the best level (which also applies to mains water) is used as reference ($\beta_{odourless} = 0$).
- The savings attribute, which is treated as a continuous variable.

We allowed for differences across socio-demographic groups by considering five characteristics, with two levels each. One level was used as reference and an additional parameter was estimated to measure the shift in utility for the other level in each case. The five characteristics were: Gender (male as the base); Age (55 and over as the base); Education (high education as the base); Water expenditure level (low as the base), and Previous knowledge of greywater use (low as the base). The grouping used here were determined after initial testing with a more detailed model specification that showed, for example, negligible differences between the various age groups below 55. Hence, there are 32 different combinations of types or socio-demographic profiles that are summarised in Table 3, which also shows the weight for each profile. Each row corresponds to one combination of gender, education, age and previous knowledge, with a further split into low (T_1 profiles 1 to 16) and high (T_2 profiles 17-32) water expenditure groups.

For each model attribute, we tested for differences in sensitivities according to the five socio-economic characteristics described above. In addition, for gender, education, age and previous knowledge, we tested whether the impact of these characteristics on preferences was different for the low (T_1) and high (T_2) water expenditure groups.

Table 3: Socio-demographic profiles of respondents

Profile for T_1 respondents	**Profile for T_2 respondents**	**Gender**	**Education**	**Age**	**Previous knowledge**	**Share of respondents (%)**	
						T_1	**T_2**
1	**17**	Female	Basic education	Below 55	Low	9.02	7.84
2	**18**				High	1.57	2.55
3	**19**			Over 55	Low	11.18	5.88
4	**20**				High	4.12	2.75
5	**21**		Higher education (includes technical college and university level)	Below 55	Low	7.06	4.71
6	**22**				High	2.16	1.76
7	**23**			Over 55	Low	1.76	0.78
8	**24**				High	0.59	1.57
9	**25**	Male	Basic education	Below 55	Low	4.51	3.92
10	**26**				High	1.37	0.78
11	**27**			Over 55	Low	3.73	2.35
12	**28**				High	1.76	0.78
13	**29**		Higher education (includes technical college and university level)	Below 55	Low	2.94	2.35
14	**30**				High	2.16	1.18
15	**31**			Over 55	Low	1.18	2.16
16	**32**				High	1.57	1.96

Remember that $\underline{\beta}_n$ is a vector of parameters for respondent n, that groups together his/her parameters associated with the impact of the different explanatory variables. In particular, the utility component for respondent n for attribute l (which could be either the continuous *savings* attribute or one of the levels of a categorical variable) is given by one of the elements in $\underline{\beta}_n$, say $\beta_{n,l}$, as follows:

$$\beta_{n,l} = \beta_l + \Delta_{hc,l} z_{n,hc} + \sum_{m=1}^{4} z_{n,m} \left(\Delta_{\mathrm{m,l}} + \Delta_{\mathrm{m,l,hc}} z_{n,hc} \right) \quad (2)$$

In this equation, the sum over m refers to the four characteristics other than water expenditure level (gender, age, education and previous greywater experience), as will become clear now. The different terms in Equation (2) are as follows:

- β_l captures the value of the parameter for attribute l for a respondent in the base category for all the socio-demographic variables;
- $\Delta_{hc,l}$ captures a shift in this base value for respondents in the high expenditure group (T_2), where the socio-demographic variable $z_{n,hc} = 1$ if respondent n falls into that group (and 0 otherwise);
- The remaining four socio-demographic characteristics are captured by $z_{n,m}$, where, for example, $z_{n,1} = 1$ if respondent n is female (and zero otherwise). $\Delta_{\mathrm{m,l}}$ captures the shift in the sensitivity to attribute l for a respondent who has the socio-demographic characteristic $z_{n,m}$, while $\Delta_{\mathrm{m,l,hc}}$ captures an additional additive shift if that respondent also belongs to the high water expenditure group (T_2).

3. Results and discussion

All our models were estimated using Apollo v 0.0.9 (Hess & Palma, 2019), through simulated maximum likelihood and using 500 Halton draws (Ortúzar & Willumsen, 2011, Chapter 8). The estimation process for discrete choice models consists of finding the parameter values that best explain the choices in the data, where this is achieved by maximising the log-likelihood of the model[1].

Alongside values for the parameters, estimation of a choice model also produces standard errors. These are related to the steepness of the log-likelihood function around convergence. The value of the standard error for a parameter is approximately double the expected loss in log-likelihood if we move one standard error from the estimate. In line with standard choice modelling practice, we used these standard errors to compute t-ratios for individual parameters, given by the ratio between the estimate and its standard error. They are a single parameter test and are derived from the fact that the maximum likelihood estimates are asymptotically normally distributed (see for example sec. 8.4.1.1 in Ortúzar & Willumsen, 2011). The value for a t-ratio tells us with what confidence level we can reject the null hypothesis that a parameter is equal to zero. This confidence level depends on whether we are conducting one-sided or two-sided tests, where the 95% confidence level for a one-tailed test is 1.64, and 1.95 for a two-tailed test.

Our specification searches tested many different versions of the model, gradually adding additionally socio-demographic effects. The variable selection process in these cases normally considers both formal statistical tests, relating to whether new parameters lead to significant improvements (i.e., t-ratios to test

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[1] Each observed choice has a probability in the model, and the log-likelihood is the sum across all observations of the logarithms of the probabilities of the chosen alternatives. Thus, in a purely deterministic model the log-likelihood would be 0 (with all choices having a probability of 1), while in a purely random model, the log-likelihood would be $N \cdot \log\left(\frac{1}{J}\right)$, where J is the number of alternatives. The latter is known as the log-likelihood at zero - LL(0). A measure of the goodness of fit of a choice model is given by the adjusted ρ^2 measure (McFadden, 1974), which shows how far estimation has moved from LL(0) towards a perfect model, with adj. $\rho^2 = 1 - \frac{LL(\beta)-K}{LL(0)}$, where LL(β) is the log-likelihood at convergence, and K is the number of estimated parameters. While there are no absolute guidelines, values in the range of 0.2 to 0.4 are typically seen as providing a very good fit.

the null hypothesis of the parameter being zero, and likelihood ratio tests for improvements in model fit) and more informal (but even more important) tests such as examining the sign of the estimated coefficient, to judge whether it conforms to *a priori* notions or theory. Given the limited sample sizes available in most analyses, it is good practice to retain parameters that provide important insights (notably for socio-demographic effects) with lower levels of confidence, given that each socio-demographic level will only apply to a smaller set of the data (cf. page 278 in Ortúzar & Willumsen, 2011, and also the more general points on significance in Amrhein et al., 2019).

Our final specification includes 40 parameters; 32 have a t-ratio that rejects the null hypothesis of no difference from zero at or above the 95% level of confidence; the remaining eight parameters were retained as they provided valuable insights into socio-demographic effects. Numerous other effects were tested during the specification searches but were not retained due to a lack of statistical importance and behavioural insights. This final specification has a log-likelihood of -2,524.65 and an adjusted ρ^2 of 0.24, offering the best fit of all specifications tested after accounting for the number of parameters.

3.1. Overview of results

Before looking at the results in detail, we first provide an overview at the sample level. As the 32 socio-demographic profiles had different levels of representation in our sample, we calculated a weighted average of the different utility components. The weighted average value for the parameter associated with attribute l is given by $\widehat{\beta_l} = \sum_{k=1}^{K} w_k \beta_{k,l}$, where weight $w_k = {}^{N_k}/_{N}$, N is the total number of respondents in the sample, N_k is the number of respondents in segment k of our sample, and $\beta_{k,l}$ is the utility associated with attribute l for respondents in segment k. This incorporates any socio-demographic shifts, as described above in Equation (2).

The weighted average of the 32 profiles for the different components of utility are shown in Table 4. The results show that utility decreases with an increase in the colour beyond light blue (which is no different from clear) and/or any odour level, and that the water bill savings have an important positive influence.

Furthermore, (i) compared to only using mains water, greywater reuse within the home is perceived positively in most cases; (ii) in contrast with past work, the outdoor use of greywater (i.e. garden irrigation) is not the favourite use for respondents (despite only 17% of respondents having no garden at all), and (iii) reusing water in garden irrigation is valued similarly to reusing water for laundry. On the other hand, it is also important to note that the level of exposure seems to influence reuse preferences, especially in those uses that require most and least human contact (drinking and toilet flushing, respectively); this is consistent with results reported elsewhere (Aitken *et al*., 2014; Fielding *et al*., 2018; Massoud *et al*., 2018; Oh *et al*., 2018).

Table 4. Weighted average of utility function components across socio-demographic groups

General description	**Weighted estimate**
Light blue (vs. clear)	0.000
Dark blue (vs. clear)	-0.427
Light chlorine (vs. no odour)	-0.399
Strong chlorine (vs. no odour)	-1.064
Toilet flushing (vs. no grey water use)	1.116
Garden irrigation (vs. no grey water use)	0.457
Washing clothes (vs. no grey water use)	0.475
Washing hands (vs. no grey water use)	0.096
Shower/Tub (vs. no grey water use)	0.109
Drinking (vs. no grey water use)	-1.087
Savings	0.106

3.2. Detailed estimation results

We now explore the influence of socio-economic characteristics in more detail, with a full breakdown of the discrete choice model results in Table 5. The most influential socioeconomic characteristics are gender, age, educational level and level of knowledge about greywater reuse. Among these characteristics, two stood out in all uses: (i) being female, for its strong negative influence (especially in households with high water expenses), and (ii) previous knowledge about reuse for its strong positive influence.

Position of alternative: The constant associated with the left-most alternative received a negative value. Thus, all other things being equal, out of the two reuse alternatives in each choice scenario, the second was chosen more often than the first, despite both having been randomised across choice situations in the survey. So, apparently, the left-most alternative is perceived as less desirable on the basis of its position (given that the third, and right-most alternative, was always the *status quo*), justifying the use of the alternative specific constant.

Water appearance: Concerning colour and odour, an increase in level causes a decrease in the utility for the affected alternative. However for colour, only the change to dark blue matters, while high levels of odour seem to influence utility more than colour. The negative perception of dark blue colour was found to be a bit stronger in the case of respondents whose houses had lower water expenses.

Savings: Water bill reductions increase the utility of respondents, as expected. Also, the marginal utility (i.e. the per unit value) of increases in savings is larger for people whose households had lower water expenses, although this shift is only significant at lower levels of confidence (87 for a one-sided test). In part, this could be due to these respondents being more cost sensitive (and hence also using less water). However, the finding is also in line with much evidence in the choice modelling literature about non-linear sensitivities to money (see Gaudry *et al*, 1989 and a more recent discussions in Hess *et al*., 2017). Indeed, the cost savings presented to respondents in the high expenditure group were larger, and our finding suggests that the per unit value of a saving is smaller in these cases.

Uses: A key interest in the analysis of results lies in the different types of greywater reuse, where there is extensive heterogeneity across socio-demographic groups, as shown in the numerous interactions with socio-demographics in Table 5. For all six uses, the values must be interpreted relative to the reference of using mains water for all uses (with a utility fixed to 0 as the base). A detailed investigation of the socio-demographic shifts will follow in our discussion of probabilities and monetary valuations. For now, we only highlight two key findings. Firstly, there is a positive and statistically significant influence of past knowledge for all six types of uses, meaning that the utility of any greywater reuse option, compared to using mains water, is higher for respondents with previous knowledge of greywater reuse. Other characteristics, most notably gender and level of education, have quite differing effects across uses, where this also differs between the low and high consumptions groups. Despite greywater being of notably better quality (i.e. without faecal matter and other pollutants) than wastewater, these findings echo studies into wastewater reuse that identify age (Probe Research Inc., 2017), gender (Baghapour *et al*., 2017; Gibson & Burton, 2014), educational level (Garcia-Cuerva *et al*., 2016; Gu *et al*., 2015; Wester *et al*., 2015), and previous knowledge (Dolnicar *et* al., 2011; Fielding & Roiko, 2014; Goodwin *et* al, 2018) as important characteristics.

For example, the utility for reusing water in ***toilet flushing*** is positive for all respondents. However, it is lower for female respondents in the high water expenditure group (T_2) and for respondents with low education, compared to those in the reference group, although this negative impact of low education is weaker in the high water expenditure group.

Correlation across choices: Another important result is that the standard deviation of the normal errors incorporated to deal with the pseudo panel effect is highly significant (t-ratio: 20.31). This indicates a strong correlation in the responses across the six scenarios for the same respondent.

Table 5. Detailed estimates of discrete choice model parameters

Attrib.	General description	Estimate	Robust std error	Robust t-ratio
	Log-likelihood at zero (for all parameters = 0)	-3361.754		
	Final Log-likelihood (at convergence)	-2524.648		
	Adjusted ρ^2	0.2371		
	Constant for left most alternative	**-0.489**	**0.080**	**-6.10**
Colour	**Clear or light blue**	0	*-Fixed-*	
	Dark blue	-0.430	0.091	-4.72
Odour	**Odourless**	0	*-Fixed-*	
	Light chlorine	-0.400	0.100	-4.01
	Strong chlorine	-1.156	0.135	-8.58
	… shift for high-water expenditure group	0.208	0.186	1.12†
	Savings on water bill	0.138	0.030	4.55
	… shift for high-water water expenditure group	-0.076	0.033	-2.33
Toilet flushing	**Base parameter**	**1.463**	**0.354**	**4.13**
	… shift for female	0.476	0.309	1.54†
	… shift for female and high-water expenditure group	-1.289	0.510	-2.53
	… shift for low education	-1.266	0.326	-3.89
	… shift for low education and high-water expenditure	0.695	0.415	1.68†
	… shift for previous knowledge	0.928	0.379	2.45
	… shift for previous knowledge and high expenditure	0.491	0.521	0.94†
Garden Irrigation	**Base parameter**	**1.087**	**0.321**	**3.39**
	… shift for female	0.453	0.279	1.62†
	… shift for female and high-water expenditure	-2.009	0.487	-4.13
	… shift for low education	-1.550	0.303	-5.11
	… shift for low education and high-water expenditure	1.184	0.376	3.15
	… shift for previous knowledge	1.105	0.311	3.56
Washing Clothes	**Base parameter**	**0.717**	**0.306**	**2.34**
	… shift for female and high expenditure	-1.312	0.453	-2.89
	… shift for age below 55 and high-water expenditure	0.612	0.280	2.19
	… shift for low education	-0.639	0.254	-2.52
	… shift for previous knowledge	1.022	0.363	2.82
	… shift for previous knowledge and high-water expenditure	0.690	0.487	1.42†
Washing hands	**Base parameter**	**0.009**	**0.247**	**0.03**
	… shift for female and high-water expenditure	-0.581	0.408	-1.42†
	… shift for previous knowledge	0.364	0.335	1.08†
	… shift for previous knowledge and high-water expenditure	1.132	0.511	2.21
Shower/ Tub	**Base parameter**	**0.734**	**0.264**	**2.78**
	… shift for female and high-water expenditure	-1.519	0.412	-3.69
	… shift for low education	-0.592	0.242	-2.45
	… shift for previous knowledge and high-water expenditure	1.355	0.429	3.16
Drinking water	**Base parameter**	**-1.435**	**0.335**	**-4.28**
	… shift for female	0.763	0.342	2.23
	… shift for female and high-water expenditure	-2.134	0.529	-4.03
	… shift for age below 55 and high-water expenditure	0.773	0.365	2.12
	… shift for previous knowledge and high-water expenditure	1.894	0.467	4.06
	Standard deviation of error component (σ)	1.686	0.083	20.35

† Parameter not significant at the 95% level of confidence

3.3. Predicted uptake for single type of greywater reuse

We now look at the six possible options for greywater reuse and calculate the predicted uptake of greywater for a single use instead of mains water. This shows the split in probability according to our model, between using mains water for all uses, or using greywater for a specific activity. Separate calculations were made with four levels of savings in the water bill, between 0% and 30% (in steps of 10%), two levels of colour (clear/light blue and dark blue) and three levels of odour (odourless, light odour, strong odour). We then computed the weighted probability for each type of reuse (compared to mains water) across the 32 respondent profiles.

Table 6 considers four differing cases of greywater characteristics. The first corresponds to the best possible situation, where the treated greywater is clear/light blue, odourless, and the monthly savings are 30% on the mains water bill. The second considers the same appearance of the treated greywater as before, but with no savings. The third considers the worst treated greywater appearance (i.e. dark colour, strong chlorine odour), but maximum savings (30%), and the final case is the worst one in terms of both water appearance and savings (0%).

Table 6. Predicted uptake for greywater vs mains water depending on greywater quality and savings

	Use of treated greywater	**Clear/light blue water and odourless**		**Dark water colour and strong chlorine odour**	
		Maximum Savings	No savings	Maximum Savings	No savings
		Case 1	**Case 2**	**Case 3**	**Case 4**
1	Toilet flushing	84.7%	72.6%	58.7%	41.5%
2	Garden irrigation	74.0%	59.0%	44.6%	29.4%
3	Clothes washing	75.2%	60.1%	44.9%	29.0%
4	Washing hands	70.0%	52.2%	36.0%	21.0%
5	Shower/Tub	69.3%	52.8%	37.3%	22.3%
6	Drinking	43.9%	27.6%	16.8%	8.8%

The results show clear differences across the six possible types of greywater use, with some uses predicted to have a substantial share in a binary choice against using mains water. These probabilities correctly decrease if the condition of the treated water worsens in terms of odour and colour, and also if the savings on the water bill are reduced. Moreover, if we analyse the influence of the variation in savings on the probability of choice, there is a decrease in the probability of choice between 12.1 and 17.8% for the best treated greywater conditions (i.e. Case 2 *vs* Case 1). Conversely, for the worst greywater conditions, offering the maximum monetary incentive (30%) could achieve an increase between 8 and 17.2% (case 3 *vs* case 4). The changes in probability also differ across uses. In particular, given the best possible conditions of treated greywater and savings, the probability of choice varies between 84.7% and 43.9%. However, if instead of having the best treated water appearance and maximum savings, we had the worst treated greywater appearance and no savings, a decrease of up to 49 percentage points would occur (i.e. for washing hands, there is a drop from 70% to 21%). On the other hand, the smallest percentage decrease when comparing these 'best' and 'worst' cases, occurs for drinking, where the percentage goes down from 43.9% to 8.8%.

The 8.8% share for drinking in Case 4 (i.e. the worst treated greywater conditions in terms of odour, colour and savings) may seem a bit counterintuitive. This has to be understood on the basis of the models being probabilistic, where even undesirable alternatives have a non-zero probability. Given sample size requirements, the survey design process assumed a generic response to water quality across uses, i.e. did not allow us to then later estimate an interaction between quality and use, meaning that the shift in utility as a result of lower quality is the same across uses. Although the directionality is expected to be the same, it is unlikely that the impacts will be exactly equal, which could partly explain this result. To further analyse this issue, the probabilities for each of the 32 profiles were computed for case 4. These are shown in Figure 2 alongside the corresponding weights in the data (i.e. what share of the data a given profile represents), and the weighted average in the probabilities. The highest probability of greywater reuse for drinking is for men in the high water expenditure group, aged under 55 and with prior knowledge about greywater reuse. These respondents cover two socio-demographic profiles (26 and 30) but only represent 1.96% of all respondents.

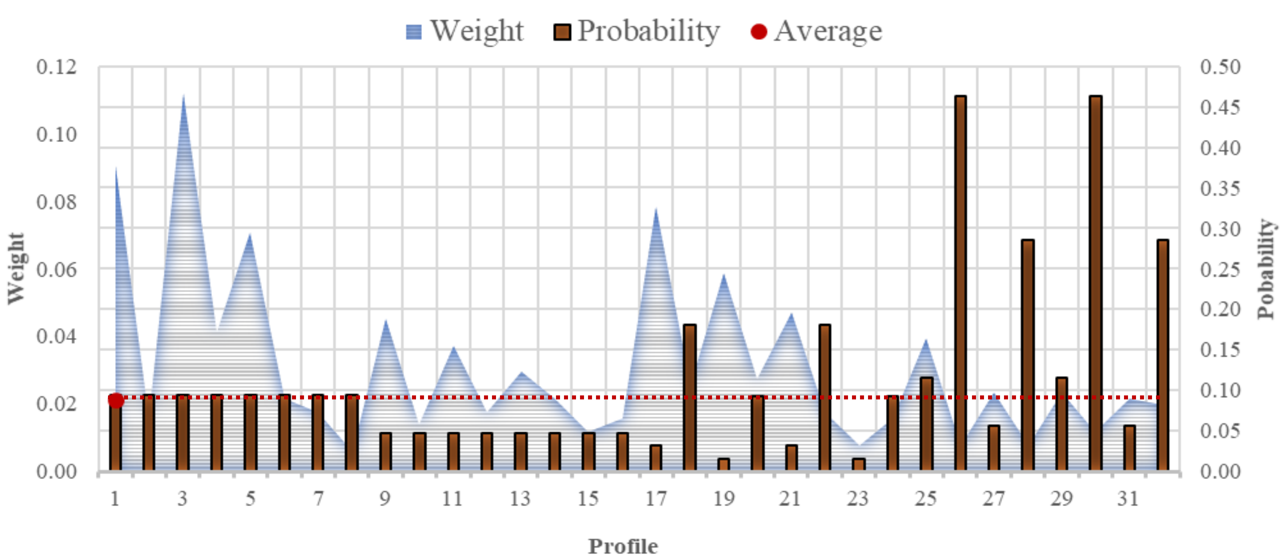


Figure 2. Representativeness of different profiles and associated probabilities of using treated greywater for drinking in Case 4 shown in the table 7 (worst odour and colour, and no savings)

3.4. Monetary valuation

Finally, we provide a monetary representation of the acceptability of using greywater inside the home using the marginal rate of substitution between the utility for a given type of greywater reuse and the monthly savings ($\beta_{savings}$); see the discussion about willingness-to-pay (WtP) in Sillano & Ortúzar, (2005). For linear-in-parameters utility functions, the WtP is given by the ratio of the corresponding utility parameters, and its interpretation thereof depends on the sign of the numerator. For example, for toilet flushing, the monetary valuation is given by:

$$MV_{toiletflushing} = {\beta_{Toilet\ flushing}}/{\beta_{savings}}. \quad (3)$$

As $\beta_{bathroom\ discharge}$ is positive, the monetary valuation is positive too. Notwithstanding the possibility of asymmetric responses to money gains and losses, this would imply that respondents would be willing to incur extra charges for such a reuse. Despite the fact that only savings are included in the survey, we can thus interpret this as a willingness-to-pay. The problem of finding an adequate payment mechanism in choice experiments is sometimes quite challenging (Ortúzar, 2010); we are confident that the use of savings in this case is appropriate, and is not dissimilar for example from looking at increased income in some other studies (e.g. Beck & Hess, 2016). Our example here looked at a generally desirable attribute. On the other hand, for generally undesirable options, such as using grey water for drinking, the numerator would be negative, and the marginal rate of substitution would also be negative. This would imply that respondents would need a monetary incentive to accept such greywater reuses.

WtP values were first calculated for each of the 32 profiles and for three cases, namely clear/light blue colour and odourless greywater, clear/light blue colour and strong chlorine odour, and dark blue greywater with a strong chlorine odour. We then expressed these monetary valuations as a percentage of the monthly water expenditure for the specific group (using CLP 20,000 for T_1 and CLP 40,000 for T_2).

Table 7 presents the weighted average across the 32 profiles for these valuations. The results indicate that, for the best appearance conditions of treated greywater, people are willing to pay monthly between 1.7% and 18.7% of the water service bill. This WtP is applicable for all uses except drinking, where a compensation of 18.3% of the value spent on the water bill would be required.

Table 7: Monetary valuation of the different treated greywater uses as share of monthly expenditure

	Uses	**Clear/light blue water, odourless**	**Clear/light blue water, strong chlorine**	**Dark blue water, strong chlorine**
1	Toilet flushing (vs. no greywater use)	18.7%	0.93%	-6.3%
2	Garden irrigation (vs. no greywater use)	7.6%	-10.20%	-17.4%
3	Washing clothes (vs. no greywater use)	8.0%	-9.83%	-17.0%
4	Washing hands (vs. no greywater use)	1.7%	-16.09%	-23.3%
5	Shower/Tub (vs. no greywater use)	1.7%	-16.13%	-23.3%
6	Drinking (vs. no greywater use)	-18.3%	-36.11%	-43.3%

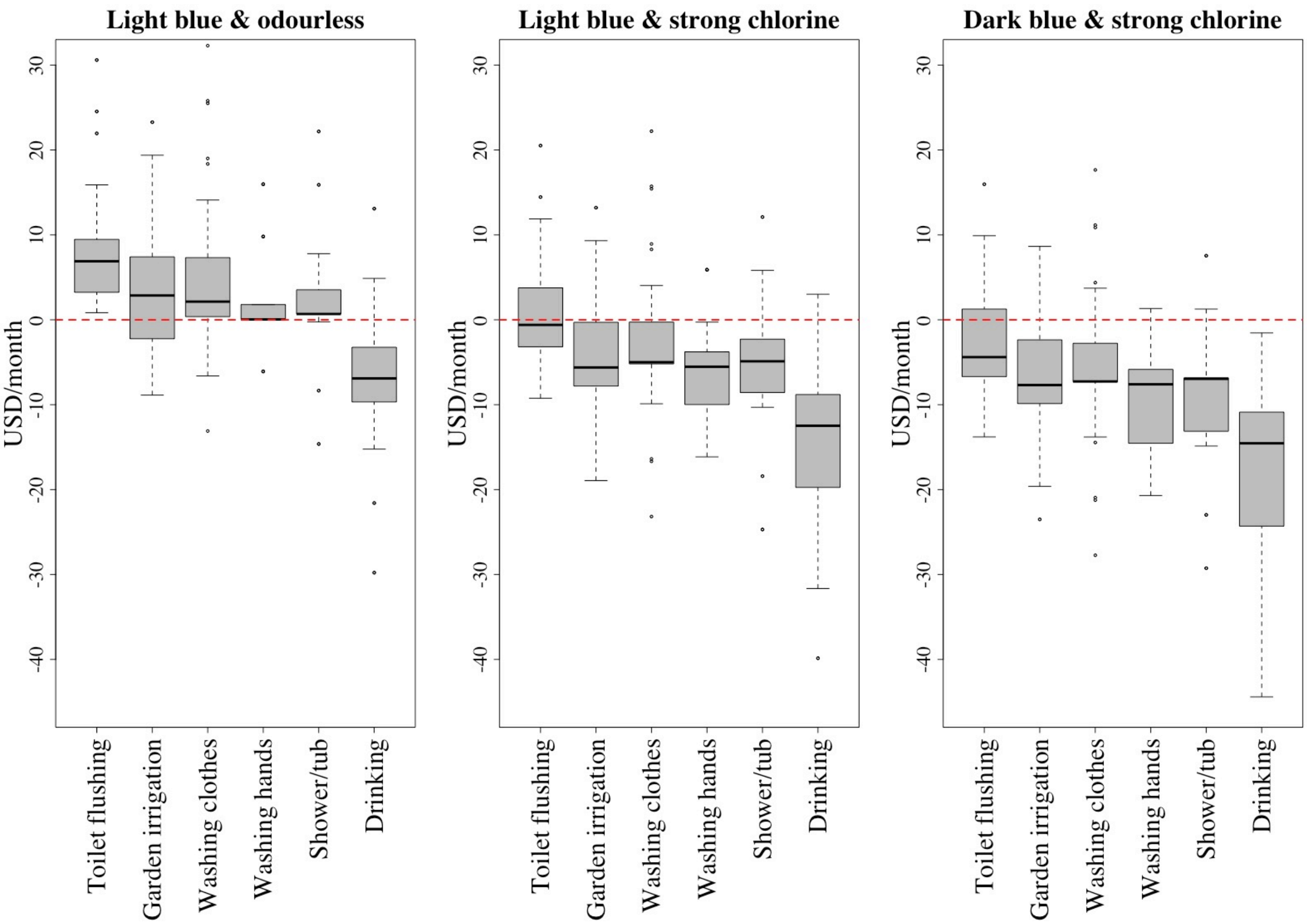
If we instead consider the case of the worst appearance conditions of treated greywater (dark colour and strong chlorine odour), respondents would require, on average, a monthly compensation between 6.3% and 43.3% of the value they pay monthly for their water service. Again, the compensation expected by respondents varies according to the level of contact they would have with the greywater and remains highest for drinking. For qualitative water appearance in between these two extreme cases, as shown in the middle column, the valuations are similarly intermediate values between the best and worst cases.

The results in Table 7 are weighted averages across the different socio-demographic groups and thus do not show the heterogeneity in valuations across different types of consumers. To provide further insights into this heterogeneity, Figure 3 shows box-plots for the distribution of the actual valuations (i.e. in monetary terms rather than expressed as a percentage of the water bill), highlighting the extent of heterogeneity in valuations across individuals (given the vertical spreads of the boxplots), across uses, and also as a function of three different conditions of supply of treated greywater in the home (clear/light colour and odourless, clear/light colour and strong colour, and dark colour and strong odour).

In the first graph, we note that in the cleanest water case, most respondents have a positive monetary valuation for using greywater for all uses except drinking. However, in this case we want to highlight the fact that although garden irrigation is an indirect and out of home use (in terms of human contact), almost half of the respondents (47.65%) would require financial compensation to decide to reuse water for this purpose. Detailed inspection of the results shows that the group with the most negative valuations for this use are women in the high consumption group without past knowledge of water reuse, where this is especially negative for those with low education. Only 33% of respondents without past knowledge of greywater reuse have a positive valuation for using the highest quality greywater for garden irrigation. For drinking, we obtain negative valuations for 95.29% of respondents, where the valuations are only positive for male respondents in the high consumption group with past knowledge of water reuse, where this is especially positive for those aged under 55. Other striking socio-demographic effects include the fact that all men have positive valuations for using greywater for washing clothes, washing hands and shower/tub (in addition to toilet flushing, which is positive for all respondents), all respondents with past knowledge have a positive valuation for all uses except shower/tub and drinking, and the valuations for all uses except drinking are positive for over 85% of respondents with high education.

In the second graph, we can see how the monetary valuation is affected if the treated water presents strong levels of chlorine odour even though the colour remains clear/light blue. Given this situation, the direct uses (washing hands, shower and drinking) show negative valuations for over 95% of respondents. The share of respondents with a positive valuation remains high for toilet flushing, at 42.9%, where the affected groups are primarily those respondents with higher levels of education (85% of those respondents) and past knowledge (89% of those respondents). The highest valuation is obtained for men with high education and past experience in the high expenditure group. Education and past knowledge also matter for garden irrigation (where the monetary valuation is positive for 64% of high education respondents) and washing clothes (where the monetary valuation is positive for 60% of respondents with past experience).

Figure 3: Distribution of monetary valuations across respondents and as a function of water quality



Finally, the third graph shows how the monetary valuations would be distributed if the treatment caused the greywater to present a dark colouration and a strong chlorine odour. As expected, the economic valuation becomes negative for the vast majority of respondents, which indicates that people would expect compensation if these were the conditions. However, it is interesting to see that among the respondents there is a percentage of people who, even under these water conditions, would be willing to pay for reusing greywater for the different uses. The monetary valuation for using greywater for toilet flushing remains positive for 89% of respondents with past knowledge of greywater reuse, but only 19% of those without past knowledge. Looking at garden irrigation and washing clothes, which obtain similar shares of positive valuations (11.18% and 12.94%, respectively), all the affected respondents fall into the higher education category, with the exception of men in the high expenditure group who also have past knowledge of greywater reuse.

From these results, we want to highlight that some of the socio-demographic effects are striking in their impact. Looking at the case of greywater with the best possible qualitative appearance, those respondents with past knowledge of greywater reuse are more than three times as likely to have a positive utility for reusing greywater for garden irrigation than those with low or no past knowledge, while men are over 60% more likely than women to have a positive utility for reusing greywater for showering and 42% more likely in the case of washing hands. Looking at the worst qualitative appearance, those with high education are over three times as likely to have a positive utility for using greywater for washing hands or showering than those with low education, while men are over five times as likely as women to have a positive utility in the case of garden irrigation, and over three times as likely in the case of washing clothes.

4. Conclusions, limitations and future research directions

This study has investigated the potential preferences for, and acceptability of, domestic greywater reuse, considering specifically qualitative attributes that could impact the desirability of greywater reuse. We calculate monetary valuations on the basis of the results from an econometric analysis. Our survey was designed to remove the bias related to the cost of installation, which is highly influential in decision making, and to focus respondents' attention on the qualitative attributes of this new source of water supply, both in terms of the appearance, odour, and the type of reuse. Indeed, any successful deployment of treated greywater reuse technology would be conditional on a priori identifying those households most willing to actually use the treated greywater.

Quantifying the influence exerted by attributes of a potential source of water supply on this acceptability is crucial to understand how effective greywater reuse codes and policies - such as the one currently approved in Chile - might be. Our results show clear evidence that although in the city of Santiago most people do not have previous experience about water reuse, they may be willing to reuse treated greywater for a variety of direct and indirect purposes. This is however conditional on the treated greywater having a similar quality as mains water in terms of colour and odour. If changes occur in the colour or odour levels of the treated greywater, our model predicts that the acceptability of reusing water would decrease considerably, even for indirect uses. In addition, the preferences vary extensively across socio-demographic groups.

Our findings provide a reference for starting to establish more effective broadcast messages about decentralized water systems. The findings relating to the importance of knowledge about greywater reuse (which does not necessarily imply personal experience of using greywater) suggest that broadcasting campaigns in TV advertisements, newspapers, and social networks, highlighting the potential reuse inside the home, can have a positive impact on the acceptability of greywater reuse for direct and indirect uses. Given the findings in relation to qualitative attributes, such campaigns should also focus on the quality of treated greywater, thus decreasing the influence of the disgust factor and increasing acceptability.

These types of information campaigns are of course most successful when targeting individuals who are more likely *a priori* to accept greywater reuse. In this context, the findings on heterogeneity are key, and the resulting disaggregated information (i.e. predicted acceptability at the level of individual households) could be used to predict which areas have the highest potential for reuse based on census zoning information. These results can form part of a comprehensive water management plan, allowing policy makers to focus efforts and propose incentives in areas where the acceptability is greater, and allow to alleviate the pressure of water resources through the use of alternative water sources. For example, the places where the diffusion campaigns can be more effective in the study zone are those areas where the population has higher education levels (information available in census data).

As with any study, there are limitations to highlight and opportunities for future research to explore.

Firstly, although we based our hypothetical choice scenarios on real situations (Domnech & Saurí, 2010; Ilemobade et al., 2013; The Guardian[2], 2014; Wester et al., 2016), inevitably for the participating individuals this was still a hypothetical situation. As with any such survey, without direct experience individuals can interpret qualitative attributes differently (section 3.4.2.7, Ortúzar & Willumsen, 2011). For example, the odour attribute had three levels (odourless, slight chlorine odour, strong chlorine odour), and although most individuals have some experience of the smell of chlorine (e.g. swimming pool), what constitutes a light or strong level of chlorine can vary between individuals and this cannot be measured by the modeller (e.g. two individuals in the same pool, may find the same chlorine odour to be strong or light). While previous studies have shown that results from this type of stated preference survey are a good tool to obtain prior information about goods or services that do not yet exist (Louviere et al., 2000), future work should seek to validate the perceptions and behaviour on real data.

Secondly, this study has looked specifically at the situation where a grey water reuse system is already installed and thus provides important insights into the acceptability of water reuse and its potential uses. This is a first step and demonstrates the immediate interest in greywater reuse for new properties and the

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[2] https://www.theguardian.com/lifeandstyle/2014/jul/21/greywater-systems-can-they-really-reduce-your-bills

potential for wider uptake in existing properties. The next step is to understand the costs of implementing and operating widespread greywater reuse systems, and the affordability of these systems for residential and commercial properties, especially in the context of existing homes being considered retrofitted, where the marginal cost would be higher than for new builds.

Finally, different cultural, spiritual and socio-economic values of water in different places mean that our results may not be universally applicable. Any transfer of this approach to other locations should, therefore, undertake a similar process of setting up a pilot survey to establish relevant local factors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Amrhein, V., Greenland, S. & McShane, B. (2019). Scientists rise up against statistical significance. *Nature* **567**, 305-307 doi: 10.1038/d41586-019-00857-9

Adapa, S. (2018). Factors influencing consumption and anti-consumption of recycled water: evidence from Australia. *Journal of Cleaner Production* **201**, 624–635. doi.org/10.1016/J.JCLEPRO.2018.08.083

Aguas Andinas (2016). Reporte de Sustentabilidad. Retrieved from www.aguasandinas.cl (in Spanish)

Aitken, V., Bell, S., Hills S. & Rees, L. (2014). Public acceptability of indirect potable water reuse in the south-east of England. *Water Science and Technology: Water Supply* **14**, 875–885 doi.org/10.2166/ws.2014.051

Baghapour, M.A., Shooshtarian, M.R. & Djahed, B. (2017). A survey of attitudes and acceptance of wastewater reuse in Iran: Shiraz City as a case study. *Journal of Water Reuse and Desalination* **7**, 511–519 doi.org/10.2166/wrd.2016.117

Baumann, D.D. (1983). Social acceptance of water reuse. *Applied Geography* **3**, 79–84 doi.org/10.1016/0143-6228(83)90007-3

Beck, M. & Hess, S. (2016). Willingness to accept longer commutes for better salaries: understanding the differences within and between couples. *Transportation Research Part A: Policy and Practice* **91**, 1-16 https://doi.org/10.1016/j.tra.2016.05.019

Bennett, J. & Blamey, R. (eds.) (2001). *The Choice Modelling Approach to Environmental Valuation.* Edward Elgar, Cheltenham.

Bliemer, M.C.J. & Rose, J.M. (2010). Construction of experimental designs for mixed logit models allowing for correlation across choice observations. *Transportation Research Part B: Methodological* **44**, 720–734 doi.org/10.1016/j.trb.2009.12.004

Bliemer, M.C.J. & Rose, J.M. (2014). Stated choice experimental design theory: the who, the what and the why. In S. Hess & A.J. Daly (eds.), *Handbook of Choice Modelling.* Edward Elgar, Cheltenham.

Cáceres, G., Nasirov, S., Zhang, H., & Araya-Letelier, G. (2015). Residential solar PV planning in Santiago, Chile: incorporating the PM10 parameter. *Sustainability* **7**, 422–440 https://doi.org/10.3390/su7010422

Caussade, S., Ortúzar, J. de D., Rizzi, L.I. & Hensher, D.A. (2005). Assessing the influence of design dimensions on stated choice experiment estimates. *Transportation Research Part B: Methodological* **39**, 621–640 doi.org/10.1016/J.TRB.2004.07.006

Chen, Z., Wu, Q., Wu, G. & Hu, H.Y. (2017). Centralized water reuse system with multiple applications in urban areas: lessons from China's experience. *Resources, Conservation and Recycling* **117**, 125–136 doi.org/10.1016/j.resconrec.2016.11.008

ChoiceMetrics (2012). Ngene User Manual & Reference Guide. Retrieved from www.choice-metrics.com

Dolnicar, S., Hurlimann, A. & Grün, B. (2011). What affects public acceptance of recycled and desalinated water? *Water Research* **45**, 933–943 doi.org/10.1016/J.WATRES.2010.09.030

Domnech, L. & Saurí, D. (2010). Socio-technical transitions in water scarcity contexts: public acceptance of greywater reuse technologies in the Metropolitan Area of Barcelona. *Resources, Conservation and Recycling* **55**, 53–62 https://doi.org/10.1016/j.resconrec.2010.07.001

Fielding, K.S., Dolnicar, S. & Schultz, T. (2019). Public acceptance of recycled water. *International Journal of Water Resources Development* **35**, 551–586 doi.org/10.1080/07900627.2017.1419125

Fielding, K. S. & Roiko, A.H. (2014). Providing information promotes greater public support for potable recycled water. *Water Research* **61**, 86–96. https://doi.org/10.1016/j.watres.2014.05.002

Fountoulakis, M.S., Markakis, N., Petousi, I. & Manios, T. (2016). Single house on-site grey water treatment using a submerged membrane bioreactor for toilet flushing. *Science of the Total Environment* **551–552**, 706–711 doi.org/10.1016/j.scitotenv.2016.02.057

Garcia-Cuerva, L., Berglund, E.Z. & Binder, A.R. (2016). Public perceptions of water shortages, conservation behaviours, and support for water reuse in the U.S. *Resources, Conservation and Recycling* **113**, 106–115 doi.org/10.1016/j.resconrec.2016.06.006

Gaudry, M.J.I., Jara-Diaz, S.R. & Ortúzar, J. de D. (1989). Value of time sensitivity to model specification. *Transportation Research Part B*: *Methodological* **23**, 151–158 doi.org/10.1016/0191-2615(89)90038-6

Gibson, F.L. & Burton, M. (2014). Salt or sludge? Exploring preferences for potable water sources. *Environmental and Resource Economics* **57**, 453–476 doi.org/10.1007/s10640-013-9672-9

Goodwin, D., Raffin, M., Jeffrey, P., & Smith, H. M. (2018). Informing public attitudes to non-potable water reuse – the impact of message framing. *Water Research* **145**, 125–135 https://doi.org/10.1016/j.watres.2018.08.006

Gu, Q., Chen, Y., Pody, R., Cheng, R., Zheng, X. & Zhang, Z. (2015). Public perception and acceptability toward reclaimed water in Tianjin. *Resources, Conservation and Recycling* **104**, 291–299 doi.org/10.1016/j.resconrec.2015.07.013

Guthrie, L., De Silva, S. & Furlong, C. (2017). A categorisation system for Australia's integrated urban water management plans. *Utilities Policy* **48**, 92–102 doi.org/10.1016/j.jup.2017.08.007

Hartley, T.W. (2006). Public perception and participation in water reuse. *Desalination* **187**, 115–126 doi.org/10.1016/j.desal.2005.04.072

Hess, S. & Daly, A. (2014). *Handbook of Choice Modelling*. Edward Elgar, Cheltenham.

Hess, S., Daly, A., Dekker, T., Cabral, M.O. & Batley, R. (2017). A framework for capturing heterogeneity, heteroskedasticity, non-linearity, reference dependence and design artefacts in value of time research. *Transportation Research Part B: Methodological* **96**, 126-149 doi.org/10.1016/j.trb.2016.11.002

Hess, S. & Palma, D. (2019). Apollo: a flexible, powerful and customisable freeware package for choice model estimation and application. *Journal of Choice Modelling* **32**, 100170 doi.org/10.1016/j.jocm.2019.100170

Hurlimann, A. & Dolnicar, S. (2016). Public acceptance and perceptions of alternative water sources: a comparative study in nine locations. *International Journal of Water Resources Development* **32**, 650–673 doi.org/10.1080/07900627.2016.1143350

INE (2018), Memoria del Censo 2017. Instituto Nacional de Estadísticas (INE), https://www.censo2017.cl/memoria/, accessed online 7 April 2020.

Ilemobade, A.A., Olanrewaju, O.O. & Griffioen, M.L. (2013). Greywater reuse for toilet flushing at a university academic and residential building. *Water SA* **39**, 199-210 http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1816-79502013000300003&lng=en&tlng=en.

Jäger-Waldau, A. (2019). PV Status Report 2019, EUR 29938 EN. Publications Office of the European Union, Luxembourg, ISBN 978-92-76-12608-9, doi:10.2760/326629, JRC118058.

Khan, S.J. & Anderson, R. (2018). Potable reuse: experiences in Australia. *Current Opinion in Environmental Science & Health* **2**, 55–60 doi.org/10.1016/J.COESH.2018.02.002

Lambert, L. A. & Lee, J. (2018). Nudging greywater acceptability in a Muslim country: comparisons of different greywater reuse framings in Qatar. *Environmental Science and Policy* **89**, 93–99. https://doi.org/10.1016/j.envsci.2018.07.015

Lefebvre, O. (2018). Beyond NEWater: an insight into Singapore's water reuse prospects. *Current Opinion in Environmental Science & Health* **2**, 26–31 doi.org/10.1016/J.COESH.2017.12.001

Leong, C. (2016). The role of emotions in drinking recycled water. *Water* **8**, 548. https://doi.org/10.3390/w8110548

Louviere, J.J., Hensher, D.A. & Swait, J.D. (2000). *Stated Choice Methods: Analysis and Application*. Cambridge University Press, Cambridge.

Lu, Z., Mo, W., Dilkina, B., Gardner, K., Stang, S., Huang, J. C. & Foreman, M.C. (2019). Decentralized water collection systems for households and communities: household preferences in Atlanta and Boston. *Water Research* **167**, 115134 doi.org/10.1016/j.watres.2019.115134

Massoud, M.A., Kazarian, A., Alameddine, I. & Al-Hindi, M. (2018). Factors influencing the reuse of reclaimed water as a management option to augment water supplies. *Environmental Monitoring and Assessment* **190** doi.org/10.1007/s10661-018-6905-y

Matos, C., Pereira, S., Amorim, E. V., Bentes, I. & Briga-Sá, A. (2014). Wastewater and greywater reuse on irrigation in centralized and decentralized systems—an integrated approach on water quality, energy consumption and CO2 emissions. *Science of the Total Environment* **493**, 463-471 https://doi.org/10.1016/j.scitotenv.2014.05.129

McFadden, D. (1974). Conditional logit analysis of qualitative choice behavior. In P. Zarembka (ed.), *Frontiers in Econometrics*. Academic Press, New York.

Meza, F.J., Vicuña, S., Jelinek, M., Bustos, E. & Bonelli, S. (2014). Assessing water demands and coverage sensitivity to climate change in the urban and rural sectors in central Chile. *Journal of Water and Climate Change* **5**, 192–203 doi.org/10.2166/wcc.2014.019

Ministerio del Interior y Seguridad Publica (2014). Análisis de la situación hídrica en Chile, propuestas y políticas. Gobierno de Chile. Retrieved from http://aih-cl.org/articulos/Analisis-de-la-situacion-hidrica-en-Chile-Gobierno-de-Chile-(mayo-2014).pdf (in Spanish)

Oh, K.S., Leong, J.Y.C., Poh, P.E., Chong, M.N. & Von Lau, E.E. (2018). A review of greywater recycling related issues: challenges and future prospects in Malaysia. *Journal of Cleaner Production* **171**, 17–29 doi.org/10.1016/j.jclepro.2017.09.267

Ortúzar, J. de D. (2010). Estimating individual preferences with flexible discrete choice models. *Food Quality and Preference* **21**, 262-269 doi.org/10.1016/j.foodqual.2009.09.006

Ortúzar, J. de D. & Willumsen, L.G. (2011). *Modelling Transport*. John Wiley & Sons, Chichester.

Probe research INC. (2017). Water Issues Public Opinion Poll. Retrieved from https://www.sdcwa.org/sites/default/files/2017 SDCWA Poll Complete Report.pdf

Rose, J.M., Hensher, D.A., Caussade, S., Ortúzar, J. de D. & Jou, R.C. (2009). Identifying differences in willingness to pay due to dimensionality in stated choice experiments: a cross country analysis. *Journal of Transport Geography* **17**, 21–29 doi.org/10.1016/J.JTRANGEO.2008.05.001

Rungie, C., Scarpa, R. & Thiene, M. (2014). The influence of individuals in forming collective household preferences for water quality. *Journal of Environmental Economics and Management* **68**, 161-174 doi.org/10.1016/j.jeem.2014.04.005

Scarpa, R., Thiene, M. & Hensher D.A. (2012). Preferences for tap water attributes within couples: an exploration of alternative mixed logit parameterizations. *Water Resources Research* **48**, W01520, doi:10.1029/2010WR010148, 2012

Schaafsma, M., Brouwer, R., Liekens, I., & de Nocker, L. (2014). Temporal stability of preferences and willingness to pay for natural areas in choice experiments: a test-retest. *Resource and Energy Economics* **38**, 243–260 https://doi.org/10.1016/j.reseneeco.2014.09.001

Serpell, A., Kort, J. & Vera, S. (2013). Awareness, actions, drivers and barriers of sustainable construction in Chile. *Technological and Economic Development of Economy* **19**, 272–288 https://doi.org/10.3846/20294913.2013.798597

Sillano, M. & Ortúzar, J. de D. (2005). Willingness-to-pay estimation with mixed logit models: some new evidence. *Environment and Planning A: Economy and Space* **37**, 525-550 doi.org/10.1068/a36137

Smith, H.M., Brouwer, S., Jeffrey, P. & Frijns, J. (2018). Public responses to water reuse – understanding the evidence. *Journal of Environmental Management* **207**, 43–50 doi.org/10.1016/J.JENVMAN.2017.11.021

Tello, P., Mijailova, P. & Chamy, R. (eds.) (2016). *Uso Seguro del Agua para el Reúso.* AIDIS & UNESCO Retrieved from http://www.aidis.org.br/pdf/AIDIS-Uso_seguro_del_agua_26_sep.pdf (in Spanish).

Train, K.E. (2009). *Discrete Choice Methods with Simulation*. Cambridge University Press, Cambridge.

Walsh, C.L., Blenkinsop, S., Fowler, H.J., Burton, A., Dawson, R.J., Glenis, V., Manning, L.J., Jahanshahi, G. and Kilsby, C.G. (2016). Adaptation of water resource systems to an uncertain future. *Hydrology and Earth System Science* **20**, 1869–1884. https://doi.org/10.5194/hess-20-1869-2016.

Wester, J., Timpano, K.R., Çek, D., Lieberman, D., Fieldstone, S.C. & Broad, K. (2015). Psychological and social factors associated with wastewater reuse emotional discomfort. *Journal of Environmental Psychology* **42**, 16–23 doi.org/10.1016/J.JENVP.2015.01.003

Wester, J., Timpano, K.R., Çek, D. & Broad, K. (2016). The psychology of recycled water: factors predicting disgust and willingness to use. *Water Resources Research* **52**, 3212–3226 https://doi.org/10.1002/2015WR018340

Wilcox, J., Nasiri, F., Bell, S. & Rahaman, M.S. (2016). Urban water reuse: a triple bottom line assessment framework and review. *Sustainable Cities and Society* **27**, 448–456 doi.org/10.1016/J.SCS.2016.06.021

Woltersdorf, L., Zimmermann, M., Deffner, J., Gerlach, M. & Liehr, S. (2018). Benefits of an integrated water and nutrient reuse system for urban areas in semi-arid developing countries. *Resources, Conservation and Recycling* **128**, 382–393 doi.org/10.1016/j.resconrec.2016.11.019