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Abstract

We design a survey to provide quantitative evidence about household demand for qualitative aspects of tap water supply. We focus on two characteristics that are of importance for households: water hardness and aesthetic quality in terms of taste, smell and appearance. Our survey elicits expenditures on products that improve the overall experience of these characteristics of tap water quality, and administration targets a representative sample of the population in England and Wales. For water hardness, our results show that around 14% of households employ at least one water softener device or purchase products such as softening tablets or descaling agents. For the aesthetic quality of tap water, around 39% of households report some averting behaviour, the most common being the use of filtering devices, purchase of bottled water, or addition of squash or cordial. To study how expenditures on these products vary with the level of service quality, we match household data to highly disaggregated records on regional water hardness (in mg $CaCO3/l$) and aesthetic quality, as measured by the regional rate of complaints to the water service supplier. Our econometric analysis suggests that households' decision to incur averting expenditures varies with service quality in a statistically and economically significant manner, providing novel evidence that households actively respond to non-health related aspects of tap water quality.

Keywords: Water demand; Tap water quality; Water hardness; Revealed preferences; Averting behaviour; Cost-benefit analysis; Economic surveys.
JEL Codes: Q25, Q53, C83, L95, D13.

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1 Introduction

The regional monopoly and regulated price control structure of the water sector in England and Wales means it is not possible to directly observe consumers' preferences for the specific components of the services they receive. These aspects of service provision include, for example, the reliability of water supply, the frequency of hosepipe bans, and the aesthetic quality of tap water in terms of taste, smell and appearance. Because the regulatory framework requires water utilities to periodically produce business plans that reflect consumer preferences for maintaining and improving service levels, this presents a challenge. Consequently, the past decade has seen the widespread application of stated preference methods to elicit consumer preferences and support investment planning with the application of cost-benefit analysis (e.g. Willis et al., 2005; Lanz and Provins, 2015).

There are, however, also opportunities to apply revealed preference methods, exploiting consumption decisions for marketed products to infer consumers' preferences for related non-marketed goods (see Young, 2005). This includes cases in which products are purchased in response to insufficient quality of certain aspects of household water supply. Loosely speaking, the averting behaviour or defensive expenditure method suggests that variation in private expenditures associated with changes in service quality provide evidence about the demand for service quality (e.g. Courant and Porter, 1981; Smith and Desvousges, 1986; Smith, 1991; Dickie, 2003).[1] For instance, consumers can respond to service failures such as unpleasant taste or smell of tap water by purchasing products such as water filters and bottled water. These products are assumed to be purchased so long as the value of the disamenity that is avoided is larger than the marginal expenditure on these products. Importantly, it is implied that if the quality of tap water was adequate, consumers would not make averting expenditures. Therefore, in this model an improvement in service quality is associated

[1] The theoretical foundation for the averting behaviour approach is based on the canonical model of household production, in which households combine commodities purchased on the market with other inputs (notably non-market amenities and their time) to produce goods that they value for consumption (Becker, 1965; Grossman, 1972). When incurring averting expenditures, households trade-off the disamenity of under-provision of a public good with the costs of investments to protect themselves against under-provision. In the context we consider, households may select their preferred level of service by combining the quality of water at the tap with market goods that are either complements (such as filters) or substitute products (such as bottled water).

with a reduction in averting behaviour and therefore lower expenditures on substitute and complement products.

In this paper we design a household survey focusing on averting behaviour for two specific characteristics of tap water supply, namely water hardness and aesthetic quality in terms of taste, smell and appearance. Hard water (via scaling) can damage and significantly reduce the lifetime of water-using appliances, implying notable costs to households. Whilst the level of hardness is a characteristic of the raw water source and is determined by the geology of the area from which water is abstracted (specifically the presence of calcium and magnesium in aquifers), it can be mitigated by investments by the water company in treatment plants or at the individual household level.[2] In addition, the aesthetic characteristics of tap water are important to consumers, and this dimension of service provision is directly related to investments by utility companies (e.g. the frequency of cleaning of water mains or their replacement).

The survey, which was administered in England and Wales, covers a wide geographical area supplied by different water services suppliers. It elicits detailed information on households' perceptions of tap water quality, the type of products purchased in relation to water hardness and aesthetic quality of tap water, and the motivations for doing so. Results from the survey on households' attitudes, motivations and behaviour provide clear evidence that consumers do purchase market goods in response to qualitative aspects of tap water. For water hardness, around 14% of respondents report some form averting behaviour. For aesthetic quality, almost 40% of respondents relate their use of marketed products to issues concerning the quality of tap water, although average annual expenditures per household are lower than for water hardness.

Survey responses are augmented with detailed data on regional tap water quality, which is sourced from company reporting to the Drinking Water Inspectorate (DWI) for England and Wales,[3] and includes physical data on average water hardness and the rate of customer

[2] However, while it is possible to reduce water hardness during the treatment process, water companies in England and Wales do not currently do this.

[3] This data refers to water supply zone (WSZ), which are geographical areas in which water supply is from the same source(s), so that quality can be assumed to be the same for all households within the same zone.

complaints to water service suppliers in relation to the taste, smell and appearance of tap water. This rich set of data enables us to explore whether averting expenditures vary systematically with the local level of service provision, as well as relevant households' characteristics.[4] Variation in averting expenditures are modelled with a Tobit model (Tobin, 1958), an approach which is standard in the literature (e.g. Um et al., 2002), as well as a more flexible alternative suggested by Cragg (1971). The latter model allows separate consideration of the (binary) decision to incur averting expenditures and, conditional on observing positive averting expenditures, the level of expenditures.

Our results provide evidence that households' averting behaviours respond to our measure of objective service quality, which is in line with standard applications of the method in the context of health risks (see for example Gerking and Stanley, 1986, and Deschenes et al., 2012, on air quality, and Zivin et al., 2011, on water pollution).[5] Quantitatively, we find that, at the mean of the sample, a 10% reduction in water hardness (measured in mg of calcium carbonate, $CaCO3$) is associated with a GBP 1.00 – 1.30 reduction in yearly averting expenditures depending on the model used to analyse the data. With respect to aesthetic quality, we find that averting behaviour is mainly driven by the taste and smell of tap water rather than issues with its appearance. At the mean of the sample, a one point reduction in the number of taste/smell complaints per thousand of customers is associated with a GBP 13.31 – 15.95 reduction in averting expenditures, again depending on the model used. Therefore, overall, we find that households purchase market products as a response to non-health risk related aspects of tap water quality, and do so in an economically significant manner.

[4] Note that customer complaint data provides a convenient measure of relative performance of suppliers and is readily collected by all water utilities in England and Wales. It therefore provides a policy-relevant starting point to use in conjunction with averting expenditures, although we acknowledge that it is not an ideal measure of service quality.

[5] Because objective quality only affects behaviour through perception, some authors relate averting expenditures to subjective rating (or quality perception); see Abrahams et al. (2000) for an application to water health risks. Such an approach is, however, problematic because replacing objective service provision with subjective perception makes marginal benefits difficult to interpret when assessing the socially optimal provision of public goods. Moreover, as initially noted by Whitehead (2006), there is a potential endogeneity issue associated with the use of self-reported rating (see also Adamowicz et al., 2014; Bontemps and Nauges, 2016). In a companion paper, Lanz and Provins (2016), we contribute to this literature by proposing a general solution to the use of perceived quality, and we illustrate our approach with data derived from our survey. In the present paper, the econometric analysis rather focuses on providing evidence about the internal validity of responses to our survey instrument, using a more standard model relating averting expenditures to objective quality.

The quantitative evidence derived from our survey is novel from at least two perspectives. First, whereas a large literature has focused on failures in relation to tap water quality standards and risks to human health (Abdalla et al., 1992; Larson and Gnedenko, 1999; Abrahams et al., 2000; McConnell and Rosado, 2000; Yoo and Yang, 2000; Wu and Huang, 2001; Um et al., 2002; Rosado et al., 2006; Lee and Kwak, 2007; Jakus et al., 2009; Zivin et al., 2011; Dupont and Jahan, 2012), we study averting behaviour in a context where risks to human health are negligible.[6] Therefore, to the best of our knowledge, our survey provides the first quantitative evidence on the demand for non-health dimensions of tap water quality. Because improving tap water services requires costly and long-lived investments, quantitative evidence about such preferences is of importance for most developed countries (Whittington and Hanemann, 2006). Second, our survey work represents the first application of a revealed preference approach in the context of water service regulation in the UK. On the one hand, our survey data provide quantitative evidence about the economic benefits associated with service improvements, which can be compared against investment costs to improve the level of services. On the other hand, as we discuss in more detail below, our results provide an interesting counter-point to the challenges raised by the widespread use of stated preference methods, notably discrete-choice experiments (see e.g. Ofwat, 2016a,b).

The remainder of the paper proceeds as follows. In Section 2 we present the details of our survey instrument. Section 3 describes the main results from the administration of our survey, including spatial coverage of the sample, a summary of the extent of averting behaviour by sampled households, and pairwise correlations between averting behaviour, service ratings, and our measures of objective service quality. Section 4 reports the econometric analysis of averting expenditures in relation to objective service provision. Section 5 discusses our results in the context of the wider regulatory environment in England and Wales, and provides some concluding comments.

[6] In England and Wales, compliance with UK and European drinking water standards across 39 parameters was 99.96% in 2012 (DWI, 2013). Note however that *perceived* health risks associated with tap water consumption (which, for example, could be triggered by aesthetic quality issues) may motivate averting behaviour.

2 Description of the survey instrument

The development of the survey material proceeded in two phases. First, questions on households' consumption of tap water and extent of averting behaviour in relation to water hardness and aesthetic quality of tap water were trialled in a national omnibus survey. Based on a sample size of approximately 2,000 respondents, results indicated that alternatives such as bottled water and filtering tap water represented averting behaviours for approximately 20 to 30 percent of households. In the second step the survey instrument was tested via an online pilot with a sample of approximately 200 respondents.

The structure of the final survey features several sections, starting with a screening question on respondents' responsibility for paying the household's water bills.[7] Respondents who are screened-in are asked a number of warm-up questions to record the number of people in the household and their age, as well as their consumption of tap water both for drinking and for other uses. We then ask about potential averting behaviours, such as the use of a jug/kettle with filter, tap/under sink filter, bottled water, squash and cordial, as well as water softener appliances and products such as softening tablets. Respondents who indicate the use of a specific product are directed to follow-up questions on their uses of these products (e.g. drinking, food preparation, etc.), associated expenditures (both one-off and recurring amounts), and frequency of purchases. In order to ascertain whether these purchases represent an averting behaviour, we ask about their motivations for the purchases, including reasons related to concerns about the taste, smell and colour of tap water, health concerns, advice from third parties (water companies, medical professionals, media, advertising, etc.), and other potential factors such as convenience.

We then ask follow-up questions about experiences of tap water, including problems with the taste, smell and colour of tap water (including chlorine or musty taste, cloudy appearance, sediment, brown/orange colouring, etc.), perceptions regarding its quality (e.g. hardness, impurities, mineral content of substitutes, etc.) and health risks (e.g. risk of illness, contaminants and pollutants, lead in supply pipes, the addition of fluoride, chemicals used to

[7] A copy of the final survey was made available for the peer-review process, and can be obtained from the authors upon request.

treat drinking water, etc.), as well as advice received about consumption of tap water from a water company (e.g. 'boil water' notices, 'do not drink' notices). We then elicit the respondent's ratings of the tap water supply at their home in several dimensions: taste, smell, appearance, hardness, and overall quality. The survey concludes with background questions about the respondent household, including how long they have lived at their current address, their previous place of residence, whether they have a water meter, their annual water services bill amount, as well as questions about the health status of all members of the household.

We administered the survey through an online market-research platform providing us access to a panel of over 300,000 individuals, which is designed to facilitate nationally representative fieldwork. This allows us to draw a representative sample by setting up quotas on a number of key characteristics of the respondents, namely age, gender, and social class. The survey was administered in November and December 2012, and potential participants were contacted by drawing a random sample of panel members (conditional on the quotas) with the following email message: "We are conducting a survey on water services and tap water. If you would like to take part please click this link." The response rate to our invitation was around 1 in 6, and, by construction, the quotas imply that our sample is broadly representative of the population of England and Wales.[8] Our sampling procedure also exploits information about the location of respondents. Specifically, a geographically representative sample of 1,000 respondents was targeted for England and Wales, and a further 3,500 respondents were sampled from within the supply areas of seven water services suppliers in England and Wales (approximately 500 respondents per company).[9] This was to enable company-specific results to be estimated for these suppliers. For the econometric analysis, we employ weights to obtain results that are representative of the population of England and Wales.

In order to support the analysis of household's averting behaviour, data resulting from

[8] We acknowledge that there is a potential for sample selection, with households dissatisfied with their water services potentially more likely to participate in the survey. However, the generality of the invitation message should mitigate any bias specific to water hardness and aesthetic quality issues.

[9] A total of nine water service suppliers in England and Wales participated in the study. For seven companies, an additional sample of 500 respondents was targeted. Note that the nationally representative sample of approximately 1,000 households also includes respondents from other water service suppliers.

survey administration are augmented by a range of data on local tap water quality and hardness service levels. This data mainly allows us to study how averting behaviour elicited with the survey varies with the level of service provided across different areas. The data refers to highly disaggregated WSZs, for which we can assume that source water quality is the same as water supplied is typically from a single treatment works. For each WSZ, we have data on water hardness expressed as mg $CaCO3/l$, the number of customer contacts (complaints) relating to taste/smell of tap water, and its appearance, and the population within the WSZ. We match survey respondents to their WSZ through their home postcode.

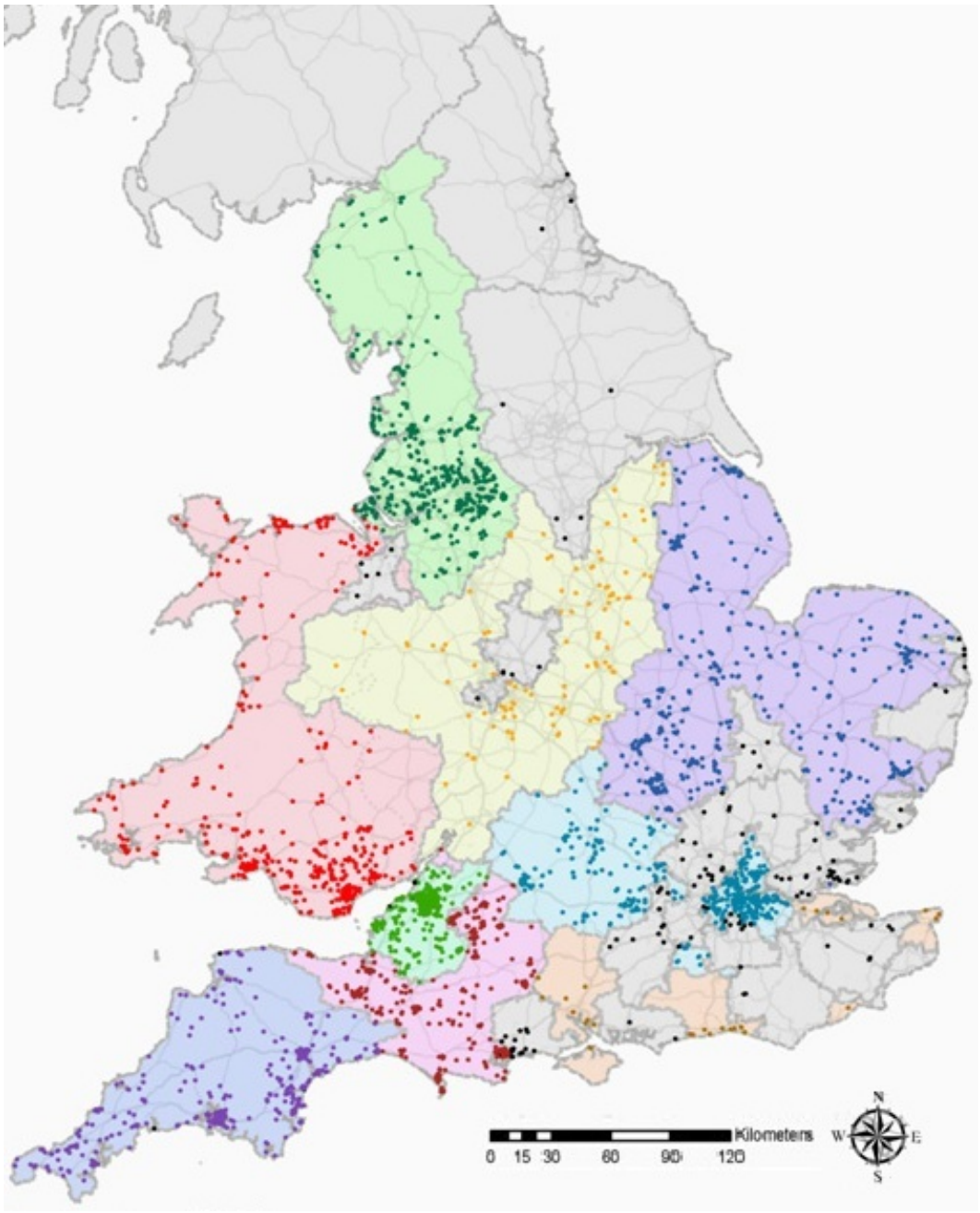
3 Descriptive results from the survey

A total of 4,520 households were sampled via the online survey. This comprised of 1,056 respondents in the nationally representative 'base' sample, and a further 3,464 households in the combined company-specific sample. The geographical composition of the sample is reported in Figure 1. Summary statistics for socio-demographic characteristics are provided in Appendix A.

Table 1 reports average household ratings for hardness, taste, smell, and appearance of tap water from the overall pooled sample and individual company areas. The majority of households (74%) rated their tap water overall to be in the range 'adequate' – 'good' on a 5-part Likert scale. For the aesthetic quality of tap water, both the pooled sample average and individual companies subsamples show that appearance of tap water receives the highest rating, followed by its smell and then taste. Moreover, households' perception of aesthetic quality does not vary significantly across companies, there is substantial variation in the rating of water hardness.

Averting behaviour by households is summarised in Table 2 across the overall pooled sample (N=4,520). Starting with water hardness, just over 1 in 10 respondents report some form of defensive or mitigating actions; the most common being the use of water softener products for washing machines, dishwashers and kettles. Averting behaviour in relation to aesthetic quality is more prevalent, as almost 4 in 10 households report some form of averting action. The most common averting behaviour is the use of a jug with a filter (18.4%) followed

Figure 1: Spatial composition of the sample, England and Wales



by the purchase of bottled water (16.3%).

Results reported in Table 2 exploit responses to the follow-up questions in order to identify relevant averting behaviour and expenditures. In particular, only 1 in 3 households cite deficient aesthetic quality as the main reason for undertaking the reported actions. Dislike

Table 1: Household rating of tap water – water hardness and aesthetic quality

	Hardness[a]	Taste[b]	Smell[b]	Appearance[b]
Overall pooled sample	3.4	3.6	3.7	4.0
Company 1	2.4	3.8	3.9	4.2
Company 2	4.2	3.5	3.7	3.9
Company 3	4.0	3.5	3.7	4.0
Company 4	4.2	3.4	3.6	3.9
Company 5	2.5	3.7	3.7	4.1
Company 6	4.0	3.5	3.7	4.0
Company 7	2.2	3.5	3.7	4.0

Notes: Pooled sample includes all observations (N = 4,520). Individual company samples: N between 487 and 503. [a]Ratings for hardness are based on the scale 'very soft' (=1), 'soft' (=2), 'medium' (=3), 'hard' (=4), and 'very hard' (=5). [b]Ratings for taste, smell and appearance of tap water are based on the scale: 'bad' (=1); 'poor' (=2); 'adequate' (=3); 'good' (=4); and 'excellent' (=5).

of the taste and smell of tap water (27%) is the most frequent response, while dislike of the appearance of tap water is cited as a motivation by relatively few households (5%), and ranked lower in considerations than the temperature of tap water (7%), for example. The second most common motivation is the convenience of bottled water, with 1 in 4 respondents stating this as being a reason for their behaviour (the re-use of bottles was stated by 12% of respondents). Following this, respondents who reported that their purchases of bottled water were solely due to convenience factors or the re-use of bottles are not included in the analysis of averting behaviour.

A key motivation for averting behaviour is found to be the perception of the quality of marketed products, which is split between a general view that they are better quality than tap water (23%) or that they are healthier than tap water (about 18%). Relatively few respondents stated that these products represented 'value for money' (6%), but a greater number stated that their purchases and/or actions were formed largely out of habit (13%). Finally less than 2% of respondents stated that advice not to drink tap water had influenced their use of marketed products.

Turning to our results for averting expenditures, we first note that a small fraction of respondents who reported averting behaviour were not able to state the associated expen-

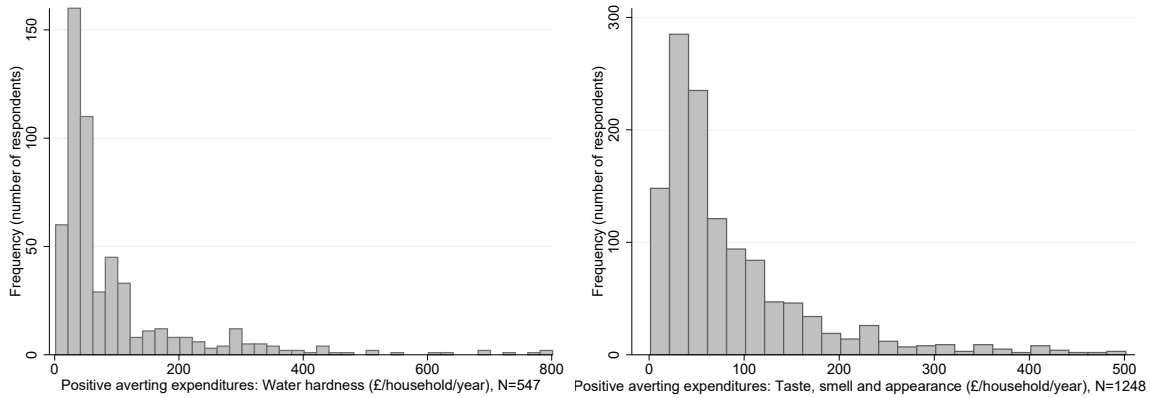
Table 2: Averting behaviour – water hardness and aesthetic quality

	Averting behaviour	Averting expenditures		
	% respondents	% respondents	Mean (GBP/yr)	Median (GBP/yr)
Water hardness				
Water softener device (total)	5.1	3.5	149.5	60.0
Ion exchange unit[a]	3.0	2.0	233.5	160.0
Chemical conditioning unit[a]	0.8	0.4	77.7	37.5
Physical conditioning unit[a]	1.5	1.1	18.7	15.0
Water softener products (total)	9.9	9.7	66.3	48.0
Tablets/powder	8.1	7.9	51.6	36.0
Kettle descaler	4.9	4.5	24.7	12.0
Limescale remover	4.5	4.3	28.7	24.0
TOTAL[c]	13.9	12.1	94.4	50.0
Aesthetic quality				
Filtering devices (total)	26.0	21.6	71.0	40.0
Jug with filter[a]	18.4	16.9	60.4	39.0
Kettle with filter[a]	2.8	2.4	63.9	25.0
Tap/under-sink filter[a]	4.0	3.4	75.8	50.0
Fridge with dispenser[a,b]	2.8	1.9	134.9	107.5
Water dispenser/purifier[a]	1.0	0.8	138.2	69.5
Other filtering appliances[a]	0.2	0.2	44.6	38.0
Bottled water	16.3	11.0	87.9	60.0
Purification tablets	0.4	0.3	55.7	42.0
Cordial/squash	7.3	6.1	59.3	48.0
TOTAL[c]	38.7	27.6	91.7	60.0

Notes: Table reports averting behaviour and expenditures for the pooled sample (N = 4,520). The first column reports the proportion of respondents who engage in averting behaviour, the second column is the proportion of respondent who report positive averting expenditures. The difference between the first two columns reflect the share of respondents who were not able to report amounts spent on specific products. The third and fourth columns report mean and median expenditures, respectively, for those respondents with positive averting expenditures. [a]Denotes assumption that capital expenditures are annualised over a five year period; [b]Only a fraction of the one-off purchase cost potentially represents averting behaviour hence expenditure on fridges with dispenser is excluded from the calculation of total annual average expenditure. [c]Total figures account for multiple averting behaviours by the respondents, including annualised one-off purchase amounts.

ditures. This is shown as the difference between the first and second columns of Table 2. These respondents are excluded from the analysis focusing on expenditures. For respondents who report positive averting expenditures related to water hardness (N=547), we observe that these households spend on average approximately GBP 94 per year in response to hard-

Figure 2: Distribution of households' annual averting expenditures



ness of tap water, with a median value of GBP 50 per household per year.[10] For respondents with positive expenditures related to aesthetic quality of tap water (N=1,248), average annual averting expenditure is approximately GBP 92 per household per year, while the median value is GBP 60 per household per year. The distribution of annual household averting expenditure is presented in Figure 2 for hardness and aesthetic quality. Notice that, while the proportion of households with aesthetic quality related expenditures is greater than the proportion for water hardness, individual amounts are smaller.

Table 3 reports pairwise (polyserial) correlation coefficients for respondents' tap water quality ratings and averting behaviour related to the hardness of tap water. It shows that respondents who rate their tap water to be 'hard' are more likely to undertake averting actions related to hardness of tap water. Moreover, we observe that respondent hardness rating is strongly correlated to average water hardness (mg $CaCO3/l$) in the relevant WSZ. This suggests that the respondents have well-formed perceptions of water hardness, an important pre-requisite for applying the averting behaviour method.

Turning to the aesthetic quality of tap water, Table 4 reports (polyserial) correlation coef-

[10] This represents the sum of all averting expenditures across all products, where capital outlays are spread equally over a 5 year period, which was found to be the typical life span for appliances considered. Capital expenditures could be annualised using alternative assumptions, although implications for the results are minor.

Table 3: Pairwise correlation coefficients – hardness of tap water

	Averting behaviour	Hardness rating	Hardness[a] (mg $CaCO3/l$)
Averting behaviour	1	–	–
Hardness rating	0.49***	1	–
Hardness[a] (mg $CaCO3/l$)	0.39***	0.67***	1

Notes: Table reports pairwise polyserial correlation coefficients, pooled sample. *Denotes statistical significance at the 10% level; **Denotes statistical significance at the 5% level; *** Denotes statistical significance at the 1% level. [a] Average hardness (mg/l $CaCO3$) at the WSZ level.

Table 4: Pairwise correlation coefficients – aesthetic quality of tap water

	Averting behaviour	Taste rating	Smell rating	Appearance rating	Taste/smell complaints[a]	Appearance complaints[a]
Averting behaviour	1	-	-	-	-	-
Taste rating	-0.54***	1	-	-	-	-
Smell rating	-0.47***	0.86***	1	-	-	-
Appearance rating	-0.33***	0.73***	0.72***	1	-	-
Taste/smell complaints[a]	0.09**	-0.11***	-0.09***	-0.09***	1	-
Appearance complaints[a]	-0.04	0.03	0.01	0.01	0.21***	1

Notes: Table reports pairwise polyserial correlation coefficients, pooled sample. *Denotes statistical significance at the 10% level; **Denotes statistical significance at the 5% level; *** Denotes statistical significance at the 1% level. [a] Consumer contacts (complaints) per capita at the WSZ level.

ficients related to averting behaviour, service ratings, and the number of complaints in WSZ areas (number of complaints per 1,000 customers). As expected, respondents who report higher quality ratings are less likely to engage in averting behaviour, whereas a higher rate of complaints is associated with an increased likelihood of averting behaviour (although the latter relationship only holds for taste/smell complaints). In fact, it appears that the rate of complaints in relation to the appearance of tap water is also not strongly correlated with any of the other rating variables. This suggests that complaints with respect to taste and smell of tap water provide a more appropriate measure of service quality relative to appearance.

4 Econometric analysis of averting expenditures

The main objective of our econometric analysis is to provide evidence about the internal validity of responses to our survey instrument, quantifying the relationship between averting expenditures and the level of service provision. Relating variation in an objective measure of service provision to the observed level of averting expenditures represents a standard application of the averting behaviour method (see e.g. Deschenes et al., 2012, and other papers cited in the introduction). The marginal effect of service quality on averting expenditures provides a measure of the marginal benefit, from the perspective of a representative household, of an improvement in the level of service. In addition, our analysis controls for a number of households' characteristics that might influence averting behaviours, such as socio-economic (e.g. household income), demographic (e.g. household composition), and other contextual factors (e.g. the length of residence in the current dwelling).

The dependent variable in the regression analysis is total averting expenditures (i.e. expenditures on products improving water hardness and aesthetic quality that are explicitly related to service failures).[11] We treat averting expenditures as a corner solution outcome, and use both a Tobit model (Tobin, 1958) and Craggs' (1971) two-tier model to represent the conditional expectation of expenditures. Importantly, the two models share the same underlying distributional assumptions, although they differ in that the Cragg model allows the processes determining the probability of positive averting expenditure and the amount observed (when larger than zero) to be driven by different determinants. Note that the Cragg model reduces to the Tobit model when the parameters of the two processes are constrained to be the same.[12]

The key covariate in the regression analysis is the measure of the level of service, i.e.

[11] For each individual, we sum expenditures across all product categories reported in Table 2. As noted previously, capital expenditures are annualised over a five year period, and for recurring expenditures we use information from the respondents as to the frequency of purchases within a year. Respondents who did not report averting expenditures are excluded form the analysis, and we also exclude expenditures on fridges with a water dispenser.

[12] Formally, the Tobit model is nested in the Cragg model, and the latter combines a probit model for the binary decision to incur averting expenditures or not, and a truncated normal regression to model positive expenditures. See Wooldridge (2010, p. 692). Marginal effects in the Cragg model are derived using the Stata command by Burke (2009).

the quality of tap water. In the present setting, our measure of objective service provision is average water hardness measured in mg $CaCO3$ per litre and the rate of complaints related to taste / smell and appearance (the number of complaints per thousand of customers). In the following analysis, we therefore assume that these two measures of service can be taken as exogenous.[13] First, it is highly unlikely that these water services characteristics enter household's location decisions, which rules out spatial sorting and associated endogeneity of objective provision. Second, tap water quality regulation in England and Wales enforces strict compliance with European drinking water standards (see DWI, 2013), and information about WRZ boundaries and characteristics of associated treatment plants are typically not known by households. This makes an association between the service level for non-risk related features of water supply and local socio-economic outcomes very unlikely. Finally, the measures we consider are relevant from the perspective of regulation and resource management, and since they correlate with self-reported rating variables (see Table 3 and 4) they are taken as good candidates to assess consistency of our averting expenditure data within the averting behaviour model.

Estimation results for averting expenditure in response to the hardness of tap water are presented in Table 5. Specification I is the standard Tobit model, for which we report both the parameter estimates and marginal effects evaluated at the mean of the sample. Specification II is the Cragg two-tier model, for which we report parameter estimates for the selection equation (a probit model where the dependent variable is equal to one when averting expenditure are positive, zero otherwise), and a truncated normal model (explaining the level of expenditures when these are greater than zero). We further report marginal effects associated with each variable, evaluated at the mean of the sample. For both the Tobit model and the Cragg model, marginal effects account for both the effect of each covariate on the probability of positive expenditures and on the amount spent. Therefore, marginal effects computed from the Tobit and Cragg models are consistent and can meaningfully be compared. For both models we also include a set of households characteristics to control for key

[13] The exogeneity of our measures of objective provision is discussed extensively in Lanz and Provins (2016).

Table 5: Hardness of tap water – Averting expenditures model

	(I) Tobit model		(II) Cragg two-tier model		
	Parameters	Marginal effects	Selection equation parameters	Expenditure equation parameters	Full model marginal effects
MG $CaCO3/l$	1.066***	0.078***	0.004***	1.207	0.059*
	(0.192)	(0.015)	(0.001)	(0.874)	(0.031)
INCOME	1.025**	0.075**	0.005*	-0.211	0.054
(GBPx1,000)	(0.477)	(0.034)	(0.003)	(1.213)	(0.037)
AGE	6.282***	0.460***	0.024***	6.576	0.334*
(in years)	(1.486)	(0.092)	(0.006)	(5.740)	(0.182)
FEMALE	-11.698	-0.853	0.011	23.740	0.360
(=1)	(26.522)	(1.902)	(0.117)	(91.713)	(1.499)
HEALTHY[a]	-7.949	-0.575	-0.063	-65.927	-1.365
(=1)	(28.201)	(2.025)	(0.128)	(108.332)	(1.984)
HOSPITALISED[b]	-28.873	-1.926	-0.110	220.811	0.922
(=1)	(38.920)	(2.380)	(0.175)	(148.407)	(2.347)
RESIDENCY[c]	1.705	0.125	0.010	-25.241*	-0.130
(in years)	(2.743)	(0.198)	(0.012)	(13.229)	(0.208)
HOME OWNER	103.851	7.812	0.404	-347.930	1.143
(=1)	(64.766)	(5.061)	(0.283)	(231.163)	(4.134)
RESIDENCY x OWNER	-6.681*	-0.489*	-0.029*	23.916	-0.096
	(3.716)	(0.265)	(0.016)	(15.440)	(0.242)
BILLS	60.011	4.391	0.212	-356.321	-1.104
(GBPx1,000)	(80.389)	(5.934)	(0.379)	(357.654)	(5.180)
FAMILY SIZE	-3.397	-0.249	-0.042	57.217	0.090
(# person)	(14.336)	(1.054)	(0.064)	(47.173)	(0.843)
INFANTS	58.251	5.286	0.285	-166.038	1.592
(# < 2 y.o.)	(80.034)	(8.749)	(0.395)	(258.129)	(5.256)
CONSTANT	-900.457***		-3.564***	-654.443	
	(149.598)		(0.431)	(565.320)	
σ	238.250***		196.729***		
	(28.216)		(52.987)		
Log-likelihood	-841.7		-762.7		
AIC	1711.4		1579.0		
BIC	1780.5		1712.6		
(Pseudo) R^2	0.048		0.123		
N	1,029		1,029		
N corner	901		901		

Notes: Marginal effects evaluated at the mean of the sample, and combine the effect of each covariate on the probability positive expenditures and on the amount spent (conditional on expenditures being non-negative). Robust standard errors reported in parenthesis. [a] Self-assessed health better than someone with the same age. [b] Hospitalisation in the previous year. [c] Length of residence at current home. *Denotes statistical significance at the 10% level; **Denotes statistical significance at the 5% level; *** Denotes statistical significance at the 1% level. Observations are weighted for representativeness.

potential determinants of averting expenditures.[14]

Estimates from Specification I indicate that averting expenditures are positively related to the measure of water hardness and household income. This is important as it provides confidence that the results from the survey conforms with prior expectations. Specification II further reveals that these two variables mainly influence the decision of whether or not to incur averting expenditures, rather than the amount spent, as signified by statistical (in)significance of the respective parameters in the expenditure equation. Note, however, that the sample of respondents with positive averting expenditures, on which the expenditure equation is estimated, is relatively small (N=128), which penalises the precision of our estimates. We also find that most of the socio-demographic determinants included in the analysis are not statistically significant, which demonstrates that there is significant unobserved heterogeneity. Respondent age is an exception, with older respondents being more likely to report positive expenditures in relation to water hardness than younger respondents. This is possibly due to greater experience of the effect of hard water on the lifetime of consumer appliances.

We also note that goodness-of-fit measures favour the more flexible two-tier specification, even when penalised for the fact that the number of estimated coefficient is almost two times larger (i.e. the BIC is lower in Specification II). Our measure of the marginal benefit associated with a reduction of water hardness is very similar across the two specifications. At the mean of the sample, a reduction of water hardness by 1 mg $CaCO3$ per litre is associated with a reduction in averting expenditures by around GBP 0.08 per household per year for the Tobit model, and GBP 0.06 in Cragg's two-tier model.

Econometric results for averting expenditures in relation to the aesthetic quality of tap water are presented in Table 6. As for water hardness, specification I is a standard Tobit model, for which we report both parameter estimates and marginal effects evaluated at the mean of the sample. Specification II is the Cragg model, for which we report coefficient es-

[14] Note that the sample size is lower than the total pooled sample, as respondents who did not indicate their household income and averting expenditures are excluded from the analysis, and because of missing postcode information precluding the matching of household-level data to regional (WSZ) data. Balance tests across subsamples do not reveal any statistically significant differences in means, suggesting no sample selection problems (at least for the household characteristics we observe).

Table 6: Aesthetic quality of tap water – Averting expenditure model

	(I) Tobit model		(II) Cragg two-tier model		
	Parameters	Marginal effects	Selection equation parameters	Expenditure equation parameters	Full model marginal effects
COMPLAINTS:	55.223**	15.947**	0.451***	3.834	13.312*
TASTE/SMELL	(23.388)	(6.713)	(0.155)	(10.510)	(7.298)
COMPLAINTS:	-4.452	-1.286	-0.030	8.955	-0.493
APPEARANCE	(2.810)	(0.814)	(0.021)	(12.409)	(0.766)
INCOME	-0.013	-0.004	0.002	0.112	0.057
(GBPx1,000)	(0.267)	(0.077)	(0.002)	(1.023)	(0.060)
AGE	-0.263	-0.076	0.005	-4.106	-0.035
(in years)	(0.762)	(0.222)	(0.004)	(3.084)	(0.187)
FEMALE	-38.246**	-11.206**	-0.079	-217.553**	-11.816**
(=1)	(15.294)	(4.571)	(0.089)	(85.699)	(5.832)
HEALTHY	-5.420	-1.551	-0.018	49.621	1.636
(=1)	(16.474)	(4.665)	(0.093)	(70.142)	(4.250)
HOSPITALISED	38.903*	12.776*	0.371***	109.973	15.646**
(=1)	(20.954)	(7.684)	(0.136)	(94.526)	(7.910)
RESIDENCY	-0.603	-0.174	-0.013	8.318	-0.003
(in years)	(1.332)	(0.385)	(0.008)	(5.773)	(0.358)
HOME OWNER	43.471	13.382	-0.023	190.005	7.634
(=1)	(37.025)	(12.160)	(0.183)	(126.156)	(8.072)
RESIDENCY x OWNER	-0.382	-0.110	0.011	-11.910	-0.199
	(1.834)	(0.530)	(0.010)	(7.411)	(0.460)
BILLS	-34.136	-9.858	-0.237	225.853	2.969
(GBPx1,000)	(45.292)	(13.089)	(0.287)	(203.063)	(12.085)
FAMILY SIZE	3.894	1.124	-0.023	113.115**	4.285
(# person)	(6.979)	(2.020)	(0.045)	(44.168)	(2.771)
INFANTS	-25.951	-6.784	0.179	-401.291	-12.329
(# < 2 y.o.)	(48.912)	(11.531)	(0.374)	(280.524)	(17.362)
FEMALE x INFANTS	91.600	36.864	0.301	266.467	20.450
	(65.371)	(34.164)	(0.563)	(286.288)	(21.769)
CONSTANT	-66.605		-0.724***	-488.292**	
	(42.468)		(0.267)	(232.464)	
σ	144.174***		196.533***		
	(9.755)		(32.529)		
Log-likelihood	-2436.6		-2398.2		
AIC	4903.8		4859.4		
BIC	4983.9		5013.4		
(Pseudo) R^2	0.008		0.023		
N	1,074		1,074		
N corner	735		735		

Notes: Marginal effects evaluated at the mean of the sample, and combine the effect of each covariate on the probability positive expenditures and on the amount spent (conditional on expenditures being non-negative. Robust standard errors reported in parenthesis. [a] Self-assessed health better than someone with the same age. [b] Hospitalisation in the previous year. [c] Length of residence at current home. *Denotes statistical significance at the 10% level; **Denotes statistical significance at the 5% level; *** Denotes statistical significance at the 1% level. Observations are weighted for representativeness.

timates associated with both the decision of whether or not to incur averting expenditures (selection equation) and the level of averting expenditures (expenditure equation). We also report marginal effects evaluated at the mean of the sample, which combine the impact of each variable on the probability of positive expenditures and the level of expenditures. As before, all models include a set of explanatory variables related to households characteristics.[15]

Specification I indicates a positive association between the rate of complaints for taste and smell and averting behaviour, but not for complaints concerning the appearance of tap water (the latter estimate has the wrong sign but is not statistically different from zero). This result mirrors the correlation patterns reported in Table 4 and is consistent with the observation that the appearance of tap water has the highest rating among all three aesthetic quality attributes (see Table 1). As for water hardness, Specification II suggests that the effect of aesthetic quality mainly occurs through changes in the probability of incurring averting expenditures, although the sample for the expenditure equation (N=339) is again significantly smaller than that for the selection equation. This of course affects the precision of estimates in the expenditure equation. We also find that whether a respondent has been hospitalised in the year leading up to the study is associated with a higher probability of averting behaviour, but with little discernible effect on the level of expenditures. However, a key driver of expenditure is the number of persons living in the household.

Our estimate of the benefit associated with a marginal reduction of the rate of taste and smell complaints is again consistent across the two models. For the Tobit model, it is around GBP 16 per household per year, while for the Cragg two-tier model it is slightly above GBP 13 per household per year. Comparing goodness-of-fit statistics, we observe that the AIC and the pseudo-R^2 improve with the more flexible two-tier model, although the BIC (which penalises for the number of coefficient estimated) suggests otherwise. Therefore, evidence for preferring one model over the other is ambiguous, and the fact that welfare estimates are very similar across models is reassuring.

[15] The sample size is again smaller than the total pooled sample size, as observations with missing income and averting expenditures are omitted, and missing postcode information precludes matching households to their WSZ and associated complaint rate. As for water hardness, this could raise concerns about sample selection, although we do not find statistically significant differences in (observed) households characteristics across subsamples.

5 Discussion and conclusion

The survey developed in this paper represents the first application of an averting behaviour approach to the estimation of the demand for tap water quality in England and Wales. It quantifies households' preferences in relation to the hardness and the aesthetic quality of tap water (taste, smell and appearance). In contrast to previous applications of the averting behaviour and defensive expenditure approach, which focus on health risks associated with tap water consumption, we consider qualitative (non-health risk related) aspects of tap water supply. In this setting, consumer behaviour is driven by preferences for tap water quality, along with a host of other lifestyle and convenience factors. Evidence from our large-scale national survey eliciting complementary information on households' motivations for their averting behaviours suggests that household's experience of hard water and aesthetic quality is a key determinant of decisions to purchase and use averting products. Although our estimated models do not account for a significant part of the variance of observed averting expenditures, our analysis confirms that averting behaviour does vary with the level of service.

From a water sector investment planning perspective, results from our survey provide evidence about the benefit to household consumers of improved levels of service. The regulatory framework in England and Wales requires that water utilities develop business plans that deliver the greatest benefit for customers subject to several constraints, including the cost of maintaining and improving services, and the affordability of overall bills. Information on household preferences and the demand for improved service levels is therefore an important input to the development of business plans in order to understand the 'value for money' of potential investments and service improvements. Indeed cost-benefit analysis principles underlie the investment modelling and optimisation processes that shape company's business plans (see for example UKWIR, 2010).[16]

Our study also provides a counter-point to the application of stated preference studies in

[16] Anecdotally, the cost of reducing water hardness at the treatment plant level is typically very high; however unit cost estimates for reducing water hardness are not publicly available and are confidential information in the context of the regulatory price control process. Hence it is not possible to provide an indicative view on how our marginal benefit estimates compare to indicative marginal costs of investment for water utilities.

water sector in the UK. Whilst the results detailed here should not be interpreted as 'benchmarks' against which stated preference values should be assessed, they do provide a basis for judging how expressed preferences for improved tap water quality align with observed consumer behaviour in relation to marketed products (e.g. Carson et al., 1996). First, with respect to separate components of tap water aesthetic quality, stated preference studies that provide higher values for taste (and smell) of tap water, over issues concerning the appearance could be seen as reliable. Second, our results also highlight that averting expenditures are, at the margin, fairly modest amounts in terms of the overall household income and expenditure, but represent a significant proportion of water bills.[17]

There are, however, a number of key distinctions between values estimated from our survey data and those that may be derived from stated preference studies. In particular, our application focuses on water services as a private good: it captures only consumer preferences for improving services/avoiding service failures that have a direct impact on households' consumption of tap water. By contrast, estimates from the averting behaviour method do not capture preferences related to the public good benefits of water services, nor potential non-use motives stemming from the benefits derived by other households. The public good aspect of water services is in fact a significant component of the seminal work by Willis et al. (2005).

We conclude by highlighting that, for some households (roughly 1 in 8 in our data), consumption decisions are to some extent formed out of habit. Hence potential improvements in tap water quality that could be delivered by water service providers might not result in changes in consumer behaviour, either due to an explicit decision to continue to purchase alternative products, or due to inertia and habits. While this consideration is largely irrelevant to the application of revealed preference methods (as inputs to cost-benefit analysis and investment appraisal), the question as to whether households would actually change their behaviour if service levels improved would be an interesting topic area for future research.

[17] At the time of the survey administration, water services bills (excluding sewerage services) were around GBP 180 per household per year (Ofwat, 2013).

Appendix A Socio-demographic composition of the full sample

	%		%
Gender		*Gross household income*	
Female	50.1	Under 5,000 per year	2.6
Male	49.9	5,000 to 9,999 per year	4.5
Respondent age		10,000 to 14,999 per year	7.3
18-29 years	13.6	15,000 to 19,999 per year	7.7
30-39 years	18.6	20,000 to 24,999 per year	8.5
40-49 years	17.3	25,000 to 29,999 per year	8
50-59 years	19.7	30,000 to 34,999 per year	5.3
60-69 years	23.3	35,000 to 39,999 per year	5
70+ years	7.5	40,000 to 44,999 per year	5.1
		45,000 to 49,999 per year	4
Socio-economic group		50,000 to 59,999 per year	6.2
A	13.2	60,000 to 69,999 per year	3.5
B	23.6	70,000 to 99,999 per year	5.2
C1	30.5	100,000 and over	2
C2	12.8	Don't know	0.8
D	9.7	Prefer not to say	3.7
E	9.5		
		Household water and wasterwater bill	
Household size		Less than GBP 150 per year	8.6
1	17.8	GBP 151 to GBP 200 per year	11.1
2	46.8	GBP 201 to GBP 250 per year	11.7
3	14.4	GBP 251 to GBP 300 per year	11.3
4	14.5	GBP 301 to GBP 350 per year	9.1
5	3.8	GBP 351 to GBP 400 per year	9.7
6	1.7	GBP 401 to GBP 450 per year	5.3
7	0.1	GBP 451 to GBP 500 per year	4.4
8 or more	0.3	GBP 501 to GBP 550 per year	3.9
Prefer not to say	0.7	GBP 551 to GBP 600 per year	2.4
		Over GBP 600 per year	3.9
Household members aged 0 – 17 y.o.		Don't know	18.6
0	75.3		
1	10.8		
2	9.8		
3	2.2		
4	0.8		
5	0.2		
6 or more	0.1		
Prefer not to say	1		

Notes: SEG = socio-economic group. Market Research Society definitions are: A = professionals, very senior managers, etc.; B = middle management in large organisations, top management or owners of small businesses, educational and service establishments; C1 = junior management, owners of small establishments, and all others in non-manual positions; C2= skilled manual labourers; D = semi-skilled and unskilled manual workers; E = state pensioners, casual and lowest grade workers, unemployed with state benefits only.

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