THE GRADUATE INSTITUTE GENEVA

CENTRE FOR INTERNATIONAL ENVIRONMENTAL STUDIES

Research Paper 23

ESTIMATING THE DEMAND FOR TAP WATER QUALITY: AVERTIVE EXPENDITURES ON SUBSTITUTES FOR HARDNESS AND AESTHETIC QUALITY

B. LANZ AND A. PROVINS

Estimating the demand for tap water quality: Avertive expenditures on substitutes for hardness and aesthetic quality*

Bruno Lanz† Allan Provins‡

This version: March 2016

Abstract

This paper uses avertive expenditures to estimate the demand for qualitative aspects of tap water supply. We focus on two characteristics that are of importance for water consumers: water hardness and aesthetic quality in terms of taste, smell and appearance. To elicit expenditures on substitute products, we survey households in England and Wales. For water hardness, around 14% of households employ at least one water softener device, with mean and median yearly expenditure around £95 and £50 respectively. Substitutes for the aesthetic quality of tap water mainly include bottled water, water filter devices, or adding squash or cordial before drinking. Overall 39% of respondents report at least one such behaviour, with mean and median yearly expenditure around £92 and £60 respectively. These are substantial amounts given a yearly average household bill of £186 for water services. Matching household data to highly disaggregated records on regional water hardness, our econometric analysis suggests that a 10% reduction in water hardness is associated with a £1.50 reduction in avertive expenditures. We also exploit geographic variation in the aesthetic characteristics of tap water, and correlate self-reported quality ratings to expenditures. We find that a one-fifth increase in the rating of water taste is associated with a £19 reduction in yearly expenditures.

Keywords: Avertive expenditures; Water quality; Regulated industry; Revealed preferences; Non-market valuation; Willingness to pay.
JEL Codes: L9, D1, Q2, Q5, D1.

---

*We would like to thank Ian Bateman, Diane Dupont, Scott Reid, seminar participants at the Ecole Polytechnique Fédérale de Lausanne and WCERE meeting in Istanbul for helpful comments on this work. Excellent research assistance was provided by Martin Baker and Lawrie Harper-Simmonds. The research presented in this paper is based on a study undertaken for a consortium of water companies, and we thank the participating water companies for allowing us to access their data. The views expressed in this paper and any remaining errors are those of the authors alone.

†Department of Economics and Centre for International Environmental Studies, Graduate Institute of International and Development Studies, Geneva, Switzerland; Chair for Integrative Risk Management and Economics, ETH Zurich; Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology. Maison de la Paix P1-633, Chemin de Eugène Rigot 2, 1202 Geneva, Switzerland; Tel: +41 22 908 62 26; email: bruno.lanz@graduateinstitute.ch.

‡Economics for the environment consultancy (eftec), London UK. E-mail: allan@eftec.co.uk.

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. This includes aspects such as the reliability of tap water supplies and its aesthetic quality, in terms of taste, smell and appearance. This presents a challenge for water utilities since the regulatory framework requires that they periodically produce business plans that reflect consumer preferences for maintaining and improving service levels. Consequently the past decade has seen the widespread application of non-market stated preference methods to elicit consumer preferences and support investment planning and the application of cost-benefit analysis across the sector (e.g. Willis et al., 2005).

There are, however, also opportunities to apply revealed preference methods. Specifically, in instances where consumers' preferences for water services can be inferred from their consumption of related market goods (Young, 2005). This includes the case where products can be purchased to substitute for deficient quality of certain aspects of water services. Here the expenditure on the substitute(s) can be used to infer the demand for its quality via avertive behaviour or defensive expenditure methods (e.g. Courant and Porter, 1981; Smith and Desvousges, 1986; Smith, 1991; Dickie, 2003).[1] In relation to tap water supply, consumers can respond to service failures such as unpleasant taste or smell by purchasing substitute products such as bottled water. Substitutes will be purchased so long as the avertive expenditure is less than the value of the disamenity that is avoided and would otherwise be experienced. Importantly, it is assumed that if the quality if tap water was adequate, consumers would not make avertive expenditures. Thus if the experienced quality level improves, private expenditures associated with avertive behaviour can be expected to decline.

The relationship between the quality of tap water provision and the level of expenditure on substitute products provides a basis for estimating the demand for the quality of tap water. Identification requires observing variation in both the quality of tap water and avertive expenditures by consumers. Our paper employs data from a household survey administered in

[1] The theoretical foundation for this approach is based on the canonical model of household production functions, where individuals trade-off the disamenity of under-provision of a public good with the costs of investments to protect themselves against such disamenity (Becker, 1965; Grossman, 1972).

England and Wales, covering a wide geographical area and spanning different water services suppliers. We focus on two specific characteristics of tap water supply, namely water hardness and the 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 mainly determined by the geology of the area from which it 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.

Similarly, the aesthetic characteristics of tap water are important to consumers, as evidenced by the breadth of substitute products that are readily available. The survey collates data on the avertive and defensive expenditures by households in relation to these aspects of tap water supply, along with supporting information on households' perceptions of tap water quality and their motivations for incurring avertive expenditures. The survey responses are augmented by detailed data on regional variations in tap water quality, including customer complaints to water service suppliers concerning the taste, smell, appearance and hardness of tap water, along with physical data on water hardness. The resulting data enable us to exploit regional variations in the level of service provision in order to identify the impact of service quality on avertive expenditure.

Our investigation is novel from a number of perspectives. First, whereas a large literature has focused on failures in relation to tap water quality standards and consequential human health risks (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 examine avertive expenditures in a context where risks to human health are negligible.[2] To our knowledge this paper is the first to examine the extent to which demand for tap water quality is motivated by broader non-health related consumer preferences.[3] Be-

[2] In England and Wales, compliance with strict UK and European drinking water standards across 39 parameters was 99.96% in 2012 (DWI, 2013).

[3] In a companion paper, Lanz (2015) uses data from the same survey to study the role of endogenous water quality perception. On this issue see also Adamowicz et al. (2014) and Bontemps and Nauges (2016) for avertive behavior studies, and Whitehead (2006) and Orgill et al. (2013) for contingent valuation studies. In the present paper we focus on the broader results from the survey, and we come back to the issue of quality perception below.

cause improving tap water quality for households requires costly and long-lived investments, this is of importance for most developed countries (Whittington and Hanemann, 2006). Second, it represents the first application of a revealed preference approach in the context of water sector investment planning in the UK, providing an interesting counter-point to the challenges raised by the widespread use of stated preference methods (e.g. Lanz and Provins, 2012).

The analysis of respondents' attitudes, motivations and purchasing behaviour provides clear evidence that consumers do substitute between tap water quality and related market goods. As expected these purchasing decisions and the amount of expenditure are motivated by perceptions of tap water quality and by the desire of households to mitigate tap water service failures. Overall, almost 40% of the respondents related their use of substitutes – either in full, or in part – to issues concerning the aesthetic quality of tap water. For water hardness, a much lower proportion of respondents – 14% in total – report avertive behaviour in relation to the hardness of tap water, although, on average, annual expenditures are higher. In relation to the average annual bill for water services, the estimated average household avertive expenditures are substantial. These are around £90 per household per year, which is roughly 50% the annual water services bill amount.[4] However this represents less than 1% of average weekly household expenditure.[5] Overall it suggests that while households are actively responding to variation in service levels concerning tap water quality, the actual burden imposed on most is relatively minor in terms of their overall budget constraint.

This very rich dataset can also be used to estimate an avertive cost function and derive household willingness to pay (WTP) for quality improvements (see e.g. Abdalla et al., 1992; Um et al., 2002, for similar approaches). All else equal, households with harder tap water spend more on substitute products, and we find that a 10% reduction in water hardness (measured in mg of calcium carbonate, CaCO3) is associated with a £1.50 reduction in avertive expenditures. Using self-reported ratings, WTP for a one unit decrease (from the average rating) in the hardness of tap water is £6 per household per year. Estimated values differ significantly across water supply regions, ranging from £1 to £15 per household per

[4] National average for metered and unmetered customers is approximately £186 per household per year (Ofwat, 2013).

[5] Average weekly household expenditure on main commodities and services in England and Wales was reported to be £483.60 in 2011 (ONS, 2012).

year, in line with the observed level of water hardness in these areas. Concerning aesthetic quality, a 1-point increase in taste rating is associated with a decline in expenditures of almost £19 per household per year, all else equal. Avertive expenditures are found to increase with household income and household size, but the effect is relatively small (though statistically significant); £0.13 per household per year for every additional £1,000 in income, and £2 per person for household size. A more significant driver of household expenditure is the presence of infants in the household, which is associated with an increase in expenditure of almost £12 per household per year.

The remainder of this paper is structured as follows. In Section 2 we provide an overview of our survey instrument. Section 3 describes our data sample and reports avertive expenditures for substitutes for tap water hardness and aesthetic quality. Section 4 reports the econometric analysis and estimated marginal WTP for improvements in the provision of these aspects of tap water. Section 5 concludes.

2 Survey instrument

The survey instrument was developed via an iterative design process, and the testing of the survey instrument comprised two main parts. First, questions intended to elicit data on household consumption of tap water, substitute products and the extent of avertive behaviour by households 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 avertive behaviours for approximately 20 to 30 percent of households. In the second step the full implementation of the survey instrument was tested via an online pilot with a sample of approximately 200 respondents.

The final survey instrument is structured as follows. After a screening question on respondents' responsibility for paying the household's water bills, a set of warm-up questions focus on the composition of the household (number of people and age groups) and their consumption of tap water for drinking and other uses (e.g. washing machine, dishwasher). Information on the consumption of substitutes for tap water by the respondent's household is then elicited, including water filters (e.g. a jug/kettle, tap/under sink filter, fridge dispenser), bottled water, squash and cordial, water softener devices (that remove calcium and

magnesium ions from tap water) and other products (e.g. tablets, powders and coils).

For the substitutes selected, respondents are then filtered to follow-up questions in which they indicate the specific product types they use/purchase, their substitute uses of these products (e.g. drinking, food preparation, washing, watering plants, etc.) and their expenditures, including one-off amounts (e.g. purchase of the jug with a filter) and regular amounts (e.g. bottled water, replacement filter cartridges), as well as the frequency of purchases. Following this respondents are asked to indicate why their household uses substitutes to tap water, including reasons related to the aesthetic quality of tap water (taste, smell and colour), health concerns, advice from water company, medical professional and other sources (media, advertising, etc.), and other preferences (e.g. convenience, temperature of tap water).

The survey then asks about more specific experiences and perceptions, including experience of problems with the taste, smell and colour of tap water (e.g. chlorine taste, musty taste, cloudy appearance, sediment, brown/orange colouring. etc.), perceptions regarding the quality of tap water (e.g. hardness, impurities, added mineral content of substitutes, etc.) and health issues (e.g. risk of illness, contaminants and pollutants, lead in supply pipes, fluoride, chemicals used to treat tap water, etc.), as well as advice received about consumption of tap water (e.g. 'boil water' notice, 'do not drink' notice from a water company). Respondents then give their rating of the tap water supply at their home, in terms of its taste, smell, appearance, and hardness, and overall quality. The survey concludes with questions about the respondent's 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 and wastewater bill amount, as well as their own health status and the health status of others in their household.

The survey was administered online in November and December 2012 via a panel of over 300,000 individuals. A representative sample of 1,000 respondents was targeted, based on national averages for age, gender, social class and type of newspaper (upmarket, mid-market, red-top, no newspaper). Information on the socio-economic and demographic characteristics of the respondent household was provided by the online panel provider. In addition, to the nationally representative sample a further 3,500 respondents within the supply areas of seven water services suppliers in England and Wales (approximately 500 respondents per

company) was targeted.[6] This was to enable company-specific results to be estimated for these suppliers.

Responses to the survey instrument are augmented by a range of data collated from participating water companies to support the analysis of household's avertive behaviour. This provides alternative measures of tap water service levels alongside the self-reported ratings of households. In order to be consistent across water service providers, the data is taken from regulatory reporting requirements specified by the Drinking Water Inspectorate (DWI) for England and Wales. We use data at the water supply zone (WSZ) level which typically has a resident population around 30,000.[7] This includes the number of customer contacts (complaints) relating to water hardness, taste/smell of tap water, and its appearance. We also collate data on water hardness in each WSZ expressed as mg $CaCO3/l$ and the population within the WSZ. We then uniquely match survey respondents to their WSZ through their home postcode.

3 Sample description

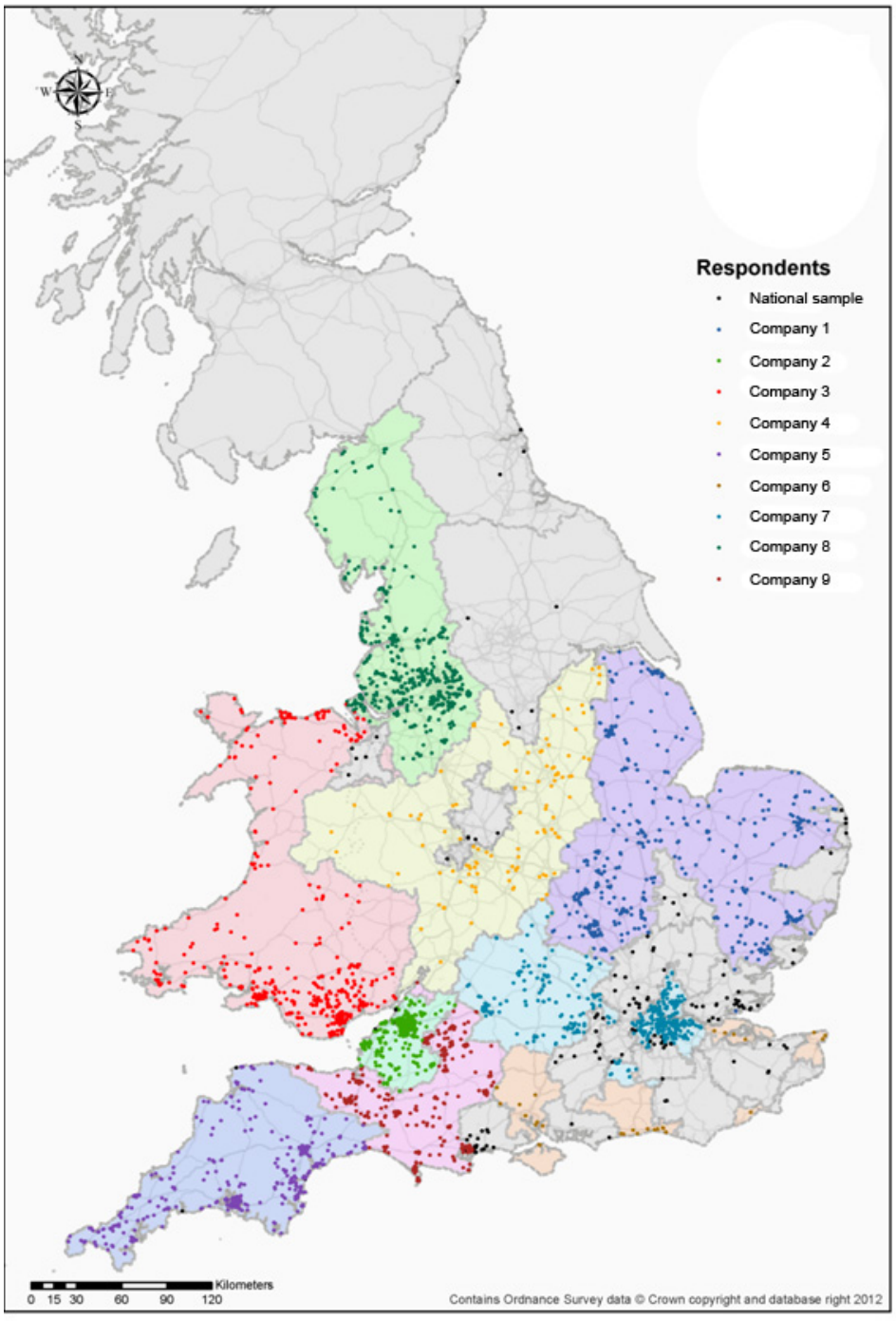
A total of 4,638 households were sampled via the online survey. This comprised of 1,087 respondents in the nationally representative 'base' sample, and a further 3,551 households in the combined company-specific sample. The geographical composition of the sample is reported in Figure 1. Summary statistics for the socio-demographic characteristics are reported 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. In all cases for the aesthetic quality of tap water – the pooled sample average and individual companies – the appearance of tap water receives the highest rating, followed by its smell and then taste. While households' perception of quality does not vary

[6] 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.

[7] In each WSZ water supplied typically stems from a single treatment works, so that for all customers in a WSZ water quality can be assumed to be the same.

Figure 1: Spatial composition of the sample



significantly across companies, there is a substantial variation in the rating of water hardness.

Avertive behaviour by households is summarised in Table 2 across the overall pooled sample. Just over 1 in 10 respondents report some form of defensive or mitigating actions;

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: n = 4,638. Individual company samples: n between 500 and 600. [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).

the most common being the use of additive water softener products for washing machines, dishwashers and kettles. Avertive behaviour and expenditures in relation to aesthetic quality is more prevalent. Almost 4 in 10 households report some form of avertive behaviour in relation to the aesthetic quality of tap water, while around 3 in 10 report actual expenditures. The most common avertive behaviour is the use of a jug with a filter (18.4%) followed by the purchase of bottled water (16.3%).

Evidence reported in Table 2 concentrates on those respondents whose purchases of substitute products is an avertive behaviour, as identified by follow-up questions. This is especially important for substitutes for aesthetic quality, as only 1 in 3 households cite it as the main reason for undertaking substitute actions. Nevertheless, this was the most commonly reported motivation, with a dislike of the taste and smell of tap water (27%) being the most frequent response. Dislike of the appearance of tap water was stated to be a motivation by relatively few households (5%) and ranked lower in considerations than the temperature of tap water (7%). The second most common motivation concerns the convenience of bottled water, with 1 in 4 respondents stating this as being a reason for purchasing a substitute product. The re-use of bottles was stated by 12% of respondents. Thus aside from respondents stating no purchases of substitutes, the main group of respondents excluded from the analysis of avertive expenditures are those who reported that their purchases of bottled water were solely due to convenience factors or the re-use of bottles. We also omit purchases of a 'fridge with water dispenser' because it represents relatively large expense that is not exclusively an

Table 2: Avertive behaviour – water hardness and aesthetic quality

	Avertive behaviour	Avertive expenditures		
	% resp.	% resp.	mean, £/yr	median, £/yr
Water hardness				
Water softener device (total)	5.1	3.5	149.5	60.0
Ion exchange unit	3.0	2.0	233.5	160.0
Chemical conditioning unit	0.8	0.4	77.7	37.5
Physical conditioning unit	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[a]	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[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

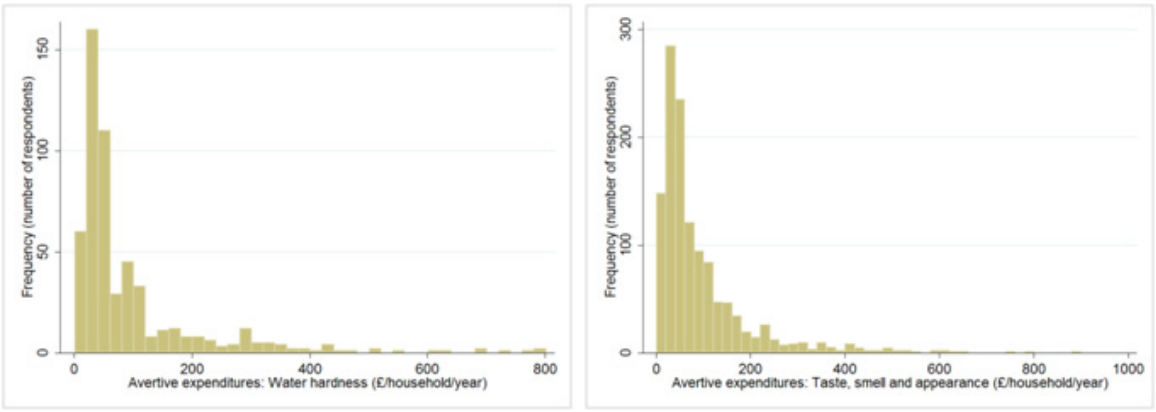
Notes: The difference in percentages between the stated avertive behaviour and stated expenditure reflects the proportion of 'don't know' responses for the latter. Respondents who were not able to state the amount spent on substitutes were omitted from calculations of annual average expenditures (rather than treated as 'zero' expenditure). Pooled sample N = 4,520. [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 avertive behaviour hence expenditure on fridges with dispenser is excluded from the calculation of total annual average expenditure. [c]Total figures account for multiple behaviours by respondents. Values include annualised one-off purchase amounts.

avertive behaviour.

A key motivation for avertive behaviour is the perception of the quality of substitute 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 (approx. 18%). Relatively few respondents stated that substitutes represented 'value for money' (6%), but a larger number stated that their purchases and/or actions were formed largely out of habit (13%). Finally less than 2% stated that advice not to drink tap water had influenced their use of substitute products.

For the full pooled sample, average annual avertive expenditure in response to hardness of tap water is approximately £94 per household per year, with a median value of £50 per

Figure 2: Distribution of household annual avertive expenditure (N = 4,520)



household per year. This is the sum of all avertive 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.[8] Using a similar approach, average annual avertive expenditure in relation to the aesthetic quality of tap water is approximately £92 per household per year. The median value is £60 per household per year. The distribution of annual household avertive expenditure is presented in Figure 2 for the hardness and aesthetic quality, respectively. While the proportion of households with aesthetic quality related expenditures is greater than the proportion for water hardness, the individual amounts are smaller. Conversely, fewer respondents have expenditures related to hardness, but the actual amounts are on average larger.

Table 3 reports pairwise correlation coefficients for respondents' tap water quality ratings and avertive behaviour related to the hardness of tap water. Respondents who rated their tap water to be 'hard' are more likely to undertake avertive behaviour related to hardness of tap water. The respondent's hardness rating is strongly correlated to average water hardness (mg $CaCO3/l$) in the water supply zone. This suggests that respondent's rating is a good indicator of actual water hardness. Moreover, the customer complaint rate at the WSZ level is correlated with both the subjective rating of hardness (respondent rating) and objective rating (average hardness).

[8] Obviously capital expenditures could be annualised using other approaches, although implications for the results are minor.

Table 3: Pairwise correlation coefficients – hardness of tap water

	Avertive behaviour	Hardness rating	Hardness contacts[a]	Hardness[b] (mg $CaCO3/l$)
Avertive behaviour	1	-	-	-
Hardness rating	0.29***	1	-	-
Hardness contacts[a]	0.13***	0.25***	1	-
Hardness[b] (mg $CaCO3/l$)	0.23***	0.66***	0.36***	1

Notes: *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; [b]Average hardness (mg/l $CaCO3$) at the water resource zone level.

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

	Avertive behaviour	Taste rating	Smell rating	Appear. rating	Taste/smell complaints[a]	Appear. complaints[a]
Avertive behaviour	1	-	-	-	-	-
Taste rating	-0.42***	1	-	-	-	-
Smell rating	-0.35***	0.79***	1	-	-	-
Appearance rating	-0.25***	0.64***	0.64***	1	-	-
Taste/smell complaints[a]	0.07	-0.1***	-0.09***	-0.08	1	-
Appearance complaints[a]	-0.03	0.03	0.01	0.01	0.21***	1

Notes: *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.

Pairwise correlation coefficients for aesthetic quality of tap water are reported in Table 4. As expected, respondents who report higher quality ratings are less likely to engage in avertive behaviour. The correlations between avertive behaviour and customer complaint rates (taste and smell, and appearance) are not statistically significantly different from zero, although correlations between the number of contact about taste/smell respondent's rating of tap water taste and odour are negative and highly statistically significant. For appearance correlations are very close to zero and not statistically significant at conventional levels.

4 Estimation of the avertive expenditure function

The objective of the econometric analysis is to estimate an avertive expenditure function based on the characteristics of households, including the hardness of tap water / aesthetic quality of tap water, socio-economic factors (e.g. household income), demographic factors

(e.g. household composition), and other contextual factors (e.g. whether the household is a metered customer or not). Following Um et al. (2002), the measurement of quality is based on both the subjective rating (or perception) of water hardness and aesthetic quality, and an objective measure. In particular, we use the 5-part Likert scale for hardness, taste, smell and appearance of tap water. 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; Lanz, 2015). As an alternative, we use the number of customer contacts in the WSZ related to water hardness, taste and smell jointly, and appearance. For water hardness, we also use the $CaCO3$ content at the WSZ level, which provides a fully objective assessment of the hardness of tap water.

The dependent variable in the regressions are total expenditures on substitutes for water hardness and aesthetic quality only where these are explicitly reported to be due to a service failure, and thus represent avertive behaviour for either hardness or aesthetic quality.[9] We treat the avertive expenditures as a corner solution outcome, assuming that households with zero expenditures optimally chose this amount, and we use a tobit model to represent the conditional expectation of expenditures. Formally, denote household avertive expenditure by Y, and consider an associated latent variable Y^* which we model as a function of a vector X of K household characteristics:

$$Y^* = \beta' X + \varepsilon \,, \tag{1}$$

where β is a vector of K parameters to be estimated from the data where and ε is a vector of independent and identically distributed errors. Observed avertive expenditures are then:

$$Y = max(0, Y^*) \,. \tag{2}$$

Expected avertive expenditures conditional on the vector of covariates X, denoted by $E(Y|X)$,

[9] In other words, for each individual, we sum expenditures across all product categories reported in Table 2. As mentioned 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. Further, we exclude respondents who did not report avertive expenditures (rather than treating these as zeros) and exclude expenditures on fridges with a water dispenser from the analysis.

can be decomposed into two parts:

$$E(Y|X) = P(Y > 0|X) \cdot E(Y|X, Y > 0)\,. \tag{3}$$

This reflects the fact that changes in covariates (for example an increase in the perceived quality of tap water) will impact both the decision of whether to incur expenditures on substitute products (or the fraction of households with positive avertive expenditures), as measured by $P(Y > 0|X)$, and the average amount spent by households who decide to incur expenditure, denoted $E(Y|X, Y > 0))$. It follows that the marginal effect of X on average expenditures $E(Y|X)$ is a highly non-linear function of the estimated parameters. Marginal effects are denoted $\frac{\partial E(Y|X)}{\partial X}$ and evaluated at the mean of the sample. These provide the basis for establishing household WTP for improvements in the hardness and aesthetic quality of tap water (see Um et al., 2002).

Tobit model results for avertive expenditure in response to the hardness of tap water are presented in Table 5. Model I uses the respondents' self-reported assessment of water hardness measured by a 1–5 continuous variable. Model II also considers subjective quality rating but with a set of dummies for each step on the Likert scale (the default value is level 3 'medium'). Model III uses measured water hardness in mg of $CaCO3$ per litre. Model IV uses the number of customer contacts (complaints) about water hardness. All models include a set of households characteristics and dummies for the company-specific subsamples.[10]

Across all specifications, avertive expenditure is positively related to the measure of water hardness and household income. The only exception is in model IV where the number of contacts within a particular area is not associated with an increase in households' expenditure on water hardness substitutes. Model II suggests that the rating of water hardness has a non-linear effect on expenditures, as we detect no statistically significant differences in expenditures for households who rated tap water hardness as 'very soft', 'soft' relative to those who rated it as 'medium'. However, annual avertive expenditures are, on average, £13

[10] The sample size for the model I and model II is 3,111. This is lower than the total pooled sample as those respondents who did not indicate their household income or avertive expenditures are excluded. Similarly, the sample size for model III is 1,306 and model IV 1,447 due to missing postcode information and impossibility to match 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 on all household characteristics we observe).

Table 5: Hardness of tap water – tobit model

Independent variables	Model I – Linear		Model II – Non linear		Model III – Measured hardness		Model IV – Contacts	
	β	$\frac{\partial E(Y\|X)}{\partial X}$	β	$\frac{\partial E(Y\|X)}{\partial X}$	β	$\frac{\partial E(Y\|X)}{\partial X}$	β	$\frac{\partial E(Y\|X)}{\partial X}$
Hard. rating (1-5)	76.70***	6.11***	-	-	-	-	-	-
Hard. rating: v.soft	-	-	-0.85	-0.06	-	-	-	-
Hard. rating: soft	-	-	-9.89	-0.71	-	-	-	-
Hard. rating: hard	-	-	142.40***	13.39***	-	-	-	-
Hard. rating: v.hard	-	-	205.30***	24.61***	-	-	-	-
WSZ CaCO3 in mg/l	-	-	-	-	1.00**	0.08**	-	-
Hard. contacts	-	-	-	-	-	-	83.83	5.57
Hh income ('000£)	1.21***	0.10***	1.10***	0.08***	1.66**	0.13**	1.69**	0.11**
Hh size (no.)	9.24	0.74	7.32	0.54	13.86	1.1	12.28	0.82
Meter (y=1)	-10.51	-0.84	-9.63	-0.7	31.05	2.48	44.79	3.02
Age (in years)	4.21***	0.34***	4.14***	0.30***	5.43***	0.43***	6.10***	0.41***
Female (=1)	-15.97	-1.26	-21.54	-1.56	-18.5	-1.46	-19.08	-1.26
Infants (=1)	-6.21	-0.49	13.01	0.95	18.29	1.52	-36.97	-2.25
Years of res.	-0.3	-0.02	-0.6	-0.04	0.36	0.03	0.56	0.04
Home own. (y=1)	8.28	0.66	6.98	0.51	45.3	3.64	27.78	1.86
Company 1	-99.46**	-6.11***	-90.72**	-5.20***	-91.81	-6.72	-251.80***	-13.21***
Company 2	43.41	3.86	49.50*	4.13	132.3	14.02	81.11	6.54
Company 3	13.51	1.12	12.04	0.91	3.35	0.27	-3.42	-0.23
Company 4	63.30**	5.96*	63.30**	5.51*	171.10**	18.36*	152.40**	13.53
Company 5	-179.60***	-9.17***	-153.60***	-7.64***	-	-	-329.60***	-12.58***
Company 6	21.04	1.77	21.48	1.67	5.00	0.40	-1.04	-0.07
Company 7	-59.22	-4.03	-75.37*	-4.48**	-19.8	-1.51	-169.7	7.78**
Constant	-890.30***	-	-692.3	-	-1,125	-	-952.4	-
N	3,111		3,111		1,306		1,447	
F-test (p-value)	0.00***		0.00***		0.00***		0.00***	

Notes: *Denotes statistical significance at the 10% level; **Denotes statistical significance at the 5% level; *** Denotes statistical significance at the 1% level.

per household per year higher for households rating their tap water as 'hard', and £26 per household per year higher for households rating their tap water as 'very hard'. Model III confirms that expenditures are higher in areas with higher $CaCO3$ concentrations, even when controlling for company (or service area) dummies.

We further find that most of socio-demographic determinants are not statistically significant. Respondent age is an exception, with older respondents reporting higher expenditures in relation to hardness than younger respondents. This is possibly due to greater experience of the effect of hardness on the lifetime of consumer appliances. In addition, statistical significance of company dummy variables suggests that some of the variation in expenditure is accounted for by the level of water hardness in different regions. In particular Company 1 and Company 5 households have statistically significant lower expenditures than the base case (all other water companies). In contrast households supplied by Company 4 have statistically significantly higher expenditure than all other companies. This pattern is consistent underlying geology of the company water supply areas.

Tobit model results for avertive behaviour in relation to the aesthetic quality of tap water are presented in Table 6. As for water hardness, model I uses 1–5 values representing respondents' subjective rating of taste, smell and appearance, and model II uses a set of dummies for each step on the Likert scale (the default value is level 3 'adequate'). Model III uses the number of customer contacts about taste and smell and appearance. As before, all models include a set of households characteristics and dummies for the company-specific sub-samples.[11]

Model I shows that households who perceive tap water quality to be high report, on average, lower avertive expenditures. The taste rating is observed to be the most important factor in determining avertive expenditures, followed by the smell rating, while the coefficient for appearance is not statistically significantly different from zero. This result is in line with the fact that appearance has the highest rating among the three aesthetic quality attributes (see Table 1), and the lowest incidence of experienced service failure for households (despite some degree of collinearity between these variables, as suggested by Table 4).

[11] The sample size again varies across specification. For model I and model II N=2,945, as observations with missing income and avertive expenditures are omitted, while the sample size for model III is 1,250 due to missing postcode information, which prevented us to match households to their WRZ 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.

Table 6: Aesthetic quality of tap water – tobit model

Independent variables	Model I – Linear		Model II – Non-linear		Model III – Complaint rates	
	β	$\frac{\partial E(Y\|X)}{\partial X}$	β	$\frac{\partial E(Y\|X)}{\partial X}$	β	$\frac{\partial E(Y\|X)}{\partial X}$
Taste rating (1-5)	-65.86***	-18.68***	-	-	-	-
Taste rating: bad	-		62.00***	21.97**	-	-
Taste rating: poor	-		46.33***	15.23***	-	-
Taste rating: good	-		-104.60***	-27.60***	-	-
Taste rating: excel.	-		-140.60***	-28.35***	-	-
Smell rating (1-5)	-14.93**	-4.24**	-	-	-	-
Smell rating: bad	-		71.90**	26.47*	-	-
Smell rating: poor	-		44.03***	14.48***	-	-
Smell rating: good	-		-2.45	-0.69	-	-
Smell rating: excel.	-		-5.42	-1.52	-	-
T&S contacts	-		-	-	66.96**	19.17**
App. rating (1-5)	-3.13	-0.89	-	-	-	-
App. rating: bad	-		50.38	17.27	-	-
App. rating: poor	-		44.35**	14.77*	-	-
App. rating: good	-		2.06	0.59	-	-
App. rating: excel.	-		4.42	1.26	-	-
App. contacts	-		-	-	-1.3	-0.37
Hh income ('000£)	0.46***	0.13***	0.44***	0.13***	-0.12	-0.03
Hh size (no.)	7.84**	2.23**	7.36**	2.09**	6.74	1.93
Meter (y=1)	15.03**	4.27**	15.71**	4.46**	21.78	6.28
Age (in years)	0.87**	0.25**	0.78*	0.22**	1.06*	0.30*
Female (=1)	-18.33**	-5.17**	-18.80***	-5.30***	-29.64**	-8.41**
Infants (=1)	41.64*	11.81*	39.64*	11.24*	59.27	20.26
Years of res.	0.04	0.01	0.03	0.01	-0.58	-0.17
Home own. (y=1)	4.04	1.15	5.06	1.44	7.9	2.27
Company 1	-22.39	-5.94	-24.1	-6.36*	-52.23	-13.84*
Company 2	14.16	4.18	13.28	3.91	33.41	10.57
Company 3	-16.17	-4.37	-18.56	-4.98	-51.41*	-13.56**
Company 4	-7.81	-2.17	-8.49	-2.35	-23.5	-6.36
Company 5	-24.55*	-6.48*	-25.35*	-6.67*	-54.88*	-13.72**
Company 6	2.23	0.64	2.69	0.77	-39.88	-10.18
Company 7	-39.90***	-10.03***	-38.89***	-9.79***	-73.6	-16.90**
Constant	149.50***	-	-94.45***	-	-150.80***	-
N	2,945		2,945		1,250	
F-test (p-value)	0.00***		0.00***		0.00***	

Notes: *Denotes statistical significance at the 10% level; **Denotes statistical significance at the 5% level; *** Denotes statistical significance at the 1% level.

Turning to model II, results suggest some degree of non-linearity in the relationship between aesthetic ratings and average expenditures. For the taste attribute, respondents are most sensitive to an improvement from 'adequate' to 'good' (a reduction in expenditure of around £28 per household per year) and by a deterioration from 'adequate' to 'poor' (an increase in expenditure of about £15 per household per year). The difference in average expenditures between respondents who rate the taste of tap water as 'good' or 'excellent' is less than £1 per household per year, and around £6 per household per year for a change from 'poor' to 'bad.' For smell and appearance ratings, expenditures are mostly driven by 'bad' and 'poor' ratings, since dummies for ratings above 'adequate' are not statistically significant.

In model I and II, household income and household size are positively related to expenditures on aesthetic tap water quality substitutes, and both coefficient estimates are highly statistically significant. For every additional £1,000 of household income, all else equal, avertive expenditures increase by just £0.13 per year. The increase in expenditure by household size is £2 per person. A quantitatively more important driver of household expenditure is the presence of infants in the household, which is associated with a marginal effect of £12 per household per year. Finally, only customers from Company 5 and Company 7 are found to report statistically lower avertive expenditures compared to those of other companies (all else equal), which suggests that differences in annual expenditure on substitutes are mainly captured by household-level characteristics.

Model III suggests that households in a WSZ with a high number of contacts in relation to taste and smell are more likely to report higher avertive expenditures, although no statistically significant relationship is found for complaints related to the appearance of tap water. This reflects the fact that appearance is generally found to be less of an issue relative to taste and odour problems.

5 Conclusion

This study is the first application of an avertive 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 of tap water and the aesthetic quality of tap water (taste, smell and appearance). In contrast to previous applications of avertive behaviour and defensive

expenditure approach, health risks concerning the quality of tap water are not a primary concern. Rather, consumer preferences are driven by the perception and experience of tap water quality, along with a host of other lifestyle and convenience factors.

We implement a large-scale national survey that elicits complementary information on households' motivations for their avertive behaviours. We find that aesthetic quality of tap water experienced by households is a key determinant of decisions to purchase and use substitute products, and avertive expenditures vary in accordance with the ratings of these aspects of tap water. Whilst the observed expenditure on substitutes represents a small proportion of the household budget, it is proportionately large in comparison to the average water services bill.

From a water sector investment planning perspective, we find that customer complaint data is likely to be a limited indicator of the level of service experienced by households. This is of relevance, as in the absence of more objective measures of tap water quality in terms of its taste, smell and appearance, the performance of water utilities has in part been measured via aggregated customer complaint rates. A notable exception is taste and odour, as WSZ-level complaints in this category were found to be related to household-level expenditures targeting improved aesthetic quality.

The study also provides a counter-point to the application of stated preference studies in water sector in the UK, particularly since opportunities to compare values from alternative methods are limited. 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 substitute 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 may be seen as reliable. Second, the study also highlights that expenditure on substitute products and estimated WTP values are fairly modest amounts in terms of the overall expenditure by households, but represent a significant share of water bills.

There are, however, a number of key distinctions between values estimated by our study and those that may be provided by stated preference studies. In particular our application focuses on water services as a private good. It captures only consumer preferences for improv-

ing services/avoiding service failures that have a direct impact on households' consumption of tap water. By contrast, we do not capture preferences that relate 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 is in fact a significant component of the seminal work by Willis et al. (2005). Moreover, valuations presented in terms of changes in customer perceptions (e.g. ratings of tap water quality) are not directly tractable for cost-benefit analysis without understanding of how investments would change customer ratings.

We close by highlighting that, for some households (roughly 1 in 8 in our data), consumption decisions are to some extent largely 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 an explicit decision to continue to purchase alternatives or due to inertia and habits. While this consideration is largely irrelevant to the application of revealed preference methods as a way to estimate values associated with non-market goods (as inputs to cost-benefit analysis and investment appraisal), the question as to whether households would actually change their behaviour if service levels improved remains an interesting research area.

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 £150 per year	8.6
1	17.8	£151 to £200 per year	11.1
2	46.8	£201 to £250 per year	11.7
3	14.4	£251 to £300 per year	11.3
4	14.5	£301 to £350 per year	9.1
5	3.8	£351 to £400 per year	9.7
6	1.7	£401 to £450 per year	5.3
7	0.1	£451 to £500 per year	4.4
8 or more	0.3	£501 to £550 per year	3.9
Prefer not to say	0.7	£551 to £600 per year	2.4
		Over £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.

References

Abdalla, C., B. Roach, and D. Epp (1992) "Valuing environmental quality changes using averting expenditures: An application to groundwater contamination," *Land Economics*, 68 (2), pp. 163 – 169.

Abrahams, N., B. Hubbell, and J. Jordan (2000) "Joint production and averting expenditure measures of willingness to pay: Do water expenditures really measure avoidance costs?" *American Journal of Agricultural Economics*, 82(2), pp. 427 – 437.

Adamowicz, W., D. Dupont, P. Lloyd-Smith, and C. Schram (2014) "Endogeneity of risk perceptions in water expenditure models." Working paper.

Becker, G. S. (1965) "A theory of the allocation of time," *Economic Journal*, 75, pp. 493 – 517.

Bontemps, C. and C. Nauges (2016) "The impact of perceptions in averting-decision models: An application of the special regressor method to drinking water choices," *American Journal of Agricultural Economics*, 98 (1), pp. 297–313.

Carson, R., N. Flores, K. Martin, and J. Wright (1996) "Contingent valuation and revealed preference methodologies: comparing estimates for quasi-public goods," *Land Economics*, 72(1), pp. 80 – 99.

Courant, P. and R. Porter (1981) "Averting expenditure and the cost of pollution," *Journal of Environmental Economics and Management*, 8 (4), pp. 321 – 329.

Dickie, M. (2003) "Defensive expenditures and damage cost methods," in P. Champ, K. Boyle, and T. Brown eds. *A Primer on Non-market Valuation*: Kluwer.

Dupont, D. and N. Jahan (2012) "Defensive spending on tap water substitutes: The value of reducing perceived health risks," *Journal of Water and Health*, 10(1), pp. 56 – 68.

DWI (2013) "Drinking water 2012; a report by the chief inspector of drinking water." Drinking Water Inspectorate, UK.

Grossman, M. (1972) "On the concept of health capital and the demand for health," *Journal of Political Economy*, 80 (2), pp. 223 – 255.

Jakus, P. M., W. Shaw, N. Nguyen, and M. Walker (2009) "Risk perceptions of arsenic in tap water and consumption of bottled water," *Water Resources Research*, 45 (5), p. W05405.

Lanz, B. (2015) "Using avertive expenditures to estimate the demand for public goods: Combining objective and perceived quality." CIES working paper.

Lanz, B. and A. Provins (2012) "Do status quo choices reflect preferences? evidence from a discrete choice experiment in thecontext of water utilities' investment planning." Centre for Energy Policy and Economics Working Paper 87.

Larson, B. and E. Gnedenko (1999) "Avoiding health risks from drinking water in moscow: An empirical analysis," *Environment and Development Economics*, 4, pp. 565 – 581.

Lee, C. and S. Kwak (2007) "Valuing drinking water quality improvement using a bayesian analysis of the multinomial probit model," *Applied Economics Letters*, 14(4), pp. 255 – 259.

McConnell, K. and M. Rosado (2000) "Valuing discrete improvements in drinking water quality through revealed preferences," *Water Resources Research*, 36, pp. 1575 – 1582.

Ofwat (2013) "Average household bills fact sheet." see `http://www.ofwat.gov.uk/regulated-companies/comparing-companies/charges-regulating/` (accessed March 2016).

ONS (2012) "Living costs and food survey, 2012 edition." See `http://www.ons.gov.uk/ons/rel/family-spending/family-spending/family-spending-2012-edition/index.html` (accessed March 2016).

Orgill, J., A. Jeuland, J. Brown, and A. Shaheed (2013) "Water quality perceptions and willingness to pay for clean water in peri-urban cambodian communities," *Journal of Water and Health*, 11, pp. 489 – 506.

Rosado, M., M. Cunha-E-Sa, M. Ducla-Soares, and L. Nunes (2006) "Combining averting behavior and contingent valuation data: an application to drinking water treatment in brazil," *Environment and Development Economics*, 11 (6), pp. 729 – 746.

Smith, V. (1991) "Household production functions and environmental benefit estimation," in J. Braden and C. Kolstad eds. *Measuring the Demand for Environmental Quality*, p. Chapter 3: North-Holland.

Smith, V. and W. Desvousges (1986) "Averting behavior: Does it exist?" *Economics Letters*, 20, pp. 291 – 296.

Um, M.-J., S.-J. Kwak, and T.-Y. Kim (2002) "Estimating willingness to pay for improved drinking water quality using averting behavior method with perception measure," *Environmental and Resource Economics*, 21, pp. 287 – 302.

Whitehead, J. . (2006) "Improving willingness to pay estimates for quality improvements through joint estimation with quality perceptions," *Southern Economic Journal*, 73 (1), pp. 100 – 111.

Whittington, D. and W. Hanemann (2006) "The economic costs and benefits of investments in municipal water and sanitation infrastructure: A global perspective." CUDARE working paper.

Willis, K., R. Scarpa, and M. Acutt (2005) "Assessing water company customer preferences and willingness to pay for service improvements: A stated choice analysis," *Water Resource Research*, 41, p. W02019.

Wu, P.-I. and C.-L. Huang (2001) "Actual averting expenditure versus stated willingness to pay," *Applied Economics*, 33 (2), pp. 277 – 283.

Yoo, S.-H. and C.-Y. Yang (2000) "Dealing with bottled water expenditures data with zero observations: a semiparametric specification," *Economics Letters*, 66, pp. 151 – 157.

Young, R. (2005) "Determining the economic value of water: Concepts and methods." Resources For the Future, Washington DC.

Zivin, J. G., M. Neidell, and W. Schlenker (2011) "Water quality violations and avoidance behavior: Evidence from bottled water consumption," *American Economic Review*, 101(3), pp. 448 – 453.