Determining the optimal investment plan for water utilities: the case of Veolia Water Central

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ABSTRACT

Water utilities face difficult choices in how most efficiently to plan for investments that best meet the needs of their customer base. An obvious interest of water utilities is thus to optimise their investment planning to obtain the maximum possible benefits for the costs accrued by the investments. The objective of this article is to demonstrate an approach for a water utility to determine the benefits of investments in different possible service areas. We used a stated preference choice experiment approach to estimate the willingness-to-pay of customers of a utility company in Southeast England for various water services that are both private and public in nature. Using state-of-the-art econometric methods, we demonstrate how customer preferences can be estimated at the individual level, as opposed to more standard modelling approaches that assume that tastes are homogeneous among the customer population. Willingness-to-pay results were mostly statistically significant for the various private and public services presented to customers, and results conformed to the expectations of economic theory. We demonstrate how individual-level customer preferences can be used to forecast the preferred alternatives of customers when faced with different possible investment programmes. Lastly, we outline how various benefits and costs, including those captured by willingness-to-pay, are used to optimise the water utility's investment planning.

Key words | choice experiments, investment optimisation, market simulations, stated preference, water services, willingness-to-pay

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INTRODUCTION

Water utilities face difficult choices in how to most efficiently plan for investments that best meet the needs of their customer base. An obvious interest of water utilities is thus to optimise their investment planning to obtain the maximum possible benefits for the costs accrued by the investments. In this paper, we present a framework for water utilities to optimise their investment planning by obtaining information on the benefits of investments in various possible service areas. The paper is based on work undertaken the company formerly known as Three Valleys Water (TVW), part of the Veolia Water group in the UK. TVW is a water utility in Southeast England serving 1.2 million households in the Home Counties North and West of London[1].

While utilities often have information on the costs of different possible investments, it is often much more difficult to obtain information on the ensuing benefits. The retail price customers pay for water services provide some

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measure of the benefits of these services, but this is not a measure that accurately reflects the value of these services. Information on the true value, in monetary terms, of water services to customers can thus help utilities in determining the possible benefits of various investment programmes. With this information, utilities can then be in a better position to know how much and where to invest in what customers want. Having information on the benefits of different investments can also provide strong justification for regulators to improve such services.

To determine the benefits of a given policy or investment programme, it is necessary to assess the total economic value of the ensuing benefits. "Stated preference" methods are commonly used to measure total economic value. These methods involve surveying customers about the value they would place on specified changes in the levels of goods and services, such as reducing the frequency of hosepipe bans or reducing CO_2 emissions. Economists often use a well-established method, called Choice Experiments (CE), to estimate the benefits of investment programmes. In particular, CE studies provide a measure of customer willingness-to-pay (WTP), which is equal to the well-being customers receive for being provided the good or service. Through the use of CE results, the benefits from any investment scenario, defined in terms of the levels of the attributes (e.g., reliability, low prices) included in the scenario, can be calculated.

OBJECTIVES

The objective of this paper is to demonstrate an approach for a water utility to determine the benefits of investments in different possible service areas. Through use of the CE methodology, we estimate customers' WTP for a variety of water services that are both private and public in nature. We then use state-of-the-art econometric analysis to demonstrate how WTP can be estimated at the level of the individual customer, providing much richer detail on customer preferences than standard modelling approaches. We demonstrate how individual-level preferences can be used to provide information that is important from a managerial perspective, such as which investment programme customers would prefer when given a choice of alternatives. Lastly, we outline how various benefits and costs, including those that are non-market in nature and captured by WTP measures, are used to inform TVW's investment planning.

METHODS

CEs are part of a wider set of stated preference methods known as attribute-based methods (ABMs). In the context of water services, ABMs present survey respondents with a number of attributes (e.g., supply interruptions, water quality) that can be provided at different possible service levels. In addition, the costs of various proposed changes are usually assigned using a price attribute which reflects the market price of the good, or the water bill in this context. Customers are asked to choose their most preferred alternative out of a series of different programme options, described by varying attribute levels. Repeated choices by customers from a set number of alternative scenarios reveals the trade-offs customers are willing to make between the attributes (Hanley *et al.* 2001). A choice of the *status quo* is also included to capture whether the respondent would not be willing to pay for any of the alternatives they are shown.

From the resulting choice data, the marginal utility of the various attributes of the good can be estimated. One particularly useful feature of ABMs is that they facilitate the calculation of the rate at which respondents would be willing to trade more of one attribute for less of another, i.e., the marginal rate of substitution (MRS) between different attributes (Hanley *et al.* 2001). Also, since a monetary variable is included in the set of attributes, the MRS between any attribute and the price can be computed. This enables marginal utilities of attributes to be converted into marginal values, thereby measuring the respondents' average WTP for a unit increase in the provision of a given attribute (Holmes & Adamowicz 2002).

Model and WTP estimation using the standard conditional logit model and its extensions

Attribute-based stated choice models are consistent with random utility theory and are conceived as random utility models (RUMs) (Adamowicz *et al.* 1998). Investigating taste heterogeneity in RUMs, however, is difficult. Recently, an approach that rigorously accounts for taste heterogeneity in RUMs has been developed, with the aim of relaxing many of the constraining assumptions imposed by the standard conditional logit (CL) specification, most notably the Independence of Irrelevant Alternatives (IIA) assumption. This is the mixed logit (MXL), or the random parameters logit (RPL), model, which assumes a continuity of preferences over some range of parameter values (McFadden & Train 2000; Train 2003). The use of MXL approaches is thus increasingly viewed as best practice in the estimation of stated preference data (Greene & Hensher 2003; Kamakura & Wedel 2004). Allowing parameters of the utility function to vary according to continuous parametric distributions enables the researcher to approximate virtually any preference structure. In this model, the conditional utility function becomes individual-specific. The vector of individual-specific preference parameters can then be decomposed into the population mean b, and the individual-specific deviation from this mean, η_n, itself most commonly assumed to be normally distributed with a mean equal to zero and standard deviation equal to σ. Therefore in addition to mean attribute parameters, standard deviations are also estimated in order to summarise the spread of preferences around the population mean for each service attribute.

The basic MXL model can be rearranged so as to estimate the additional variance (Σ) associated with a particular option or set of options that are usually more cognitively difficult to conceive. This gives rise to the error component (EC) model. The EC model is particularly useful in non-market valuation scenarios involving both status quo options, which customers of the utility is currently ‘experiencing,’ and generically designed options, which customers have to ‘imagine,’ and where the choice decisions associated with the latter are more prone to ‘noise’ as compared to the former.

Once the parameter vector has been estimated, the marginal WTP for a given attribute (which in effect is the MRS between income and the attribute in question) can be derived as follows:

$$\mathrm{WTP} = -\frac{\beta_{\mathrm{Attribute}}}{\beta_{\mathrm{Payment}}} \qquad (1)$$

where, β is a vector of estimated preference coefficients.

Survey design

A CE exercise was conducted through a representative survey of about 500 households served by TVW. The list of attributes to include in the CE was determined through research, consultation with TVW staff and other industry experts, and also through a series of focus groups with TVW customers. Through this research, we came up with a set of eight service areas, or attributes, which seemed to be of the highest priority to TVW customers. Comparing scenarios with eight attributes plus a bill change, however, would be too burdensome a task for many respondents. This could result in respondents adopting simplifying choice rules, such as always opting for status quo options, or ignoring a subset of the attributes (Coupey *et al.* 1998). Therefore, the eight attributes were grouped into two ‘blocks’ of four attributes, whereby respondents would have to answer choice cards constructed from attributes from only one of the blocks.

The attributes included in block A were as follows: The number of hosepipe bans lasting more than three months, the number of properties with unplanned interruptions to water supply lasting more than 6 h, the number of properties complaining about unpleasant taste, smell and/or appearance of tap water, and the number of properties complaining about hardness of tap water. Next, the attributes included in block B were as follows: River water levels, water saved through further water efficiency measures, annual greenhouse gas emissions, and the number of tests of water quality failing to meet standards.

After defining the attributes, it was necessary to define levels for each attribute. We sought advice from TVW for the definition of these levels. For each attribute except ‘river water levels,’ four levels were specified as follows: A *status quo* level (0) which defines the current level of service, one ‘deterioration’ level (-1) which would prevail should current levels of investment and bill levels be reduced, and two ‘improvement’ levels ($+1$ and $+2$) which would prevail should current levels of investment and bill levels be increased. The river water levels attribute included only two levels, a status quo level and one ‘improvement’ level based on enhanced service.

As to the associated changes in annual bills that would accompany improvements/deteriorations in attribute levels, 8 rather than 4 levels were defined: 2 decreases in annual bill (decrease by £15 or £5), no change in annual bill (i.e., status quo), and 5 increases in annual bill (increase by £5, £10, £15, £20 or £35). As to the bill change levels, their magnitudes were defined identically across the two blocks.

RESULTS

Tables 1 and 2 below present the MXL-EC parameter estimates for each company for the attributes in blocks A and B. Note that the underlying distributions of non-bill attributes were modelled as 'normal' in the MXL specifications. In contrast, the distributions of the BILL parameter were modelled as 'constrained triangular', i.e., forcing the distribution to be literally triangular in shape, with β as its mean and 0 and 2β as its respective lower and upper bounds. The reason why such a distribution is preferred to the normal is because it 'forces' the sign of the bill parameter distribution to be identical to the sign of the mean, ensuring that all respondents have a negative price coefficient and hence dread bill increases. More importantly, this distribution guarantees the derivation of more robust WTP population distributions. This is so because population WTP distributions, being simulated, are made up of a large number of attribute-to-bill parameter ratios, and the values that enter the calculation of each ratio are simultaneously drawn from the attribute and bill parameter distributions. A constrained triangular distribution will ensure that none of the randomly drawn WTPs will have a near-zero or zero bill denominator that would yield disproportionately large WTP values and hence would skew the distribution.

Table 1 | Block A model estimates

Variable	Coef.	Std. Dev.	Pr (Coef < 0)
PIPES	−0.012	0.035	63.0%
	− 2.69[*]	*5.26*	
INTER	−0.082	0.11	77.2%
	− 6.95	*7.33*	
TSA	−0.178	0.179	84.0%
	− 9.01	*7.18*	
HARDN	−0.023	0.021	86.6%
	− 7.45	*4.18*	
BILL	−0.034	0.034	100.0%
	− 11.71	*11.71*	
Σ	–	2.128	–
	–	14.38	
Log Likelihood		*− 2317.78*	
Pseudo R^2		*0.1989*	

[*] Z value.

Table 2 | Block B model estimates

Variable	Coef.	Std. Dev.	Pr (Coef < 0)
RIVER	0.124	0.652	42.5%
	1.44[*]	*5.22*	
SAVED	0.002	0.002	24.7%
	3.83	*2.95*	
EMISS	−0.009	0.012	77.0%
	− 7.18	*9.34*	
TESTS	−0.014	0.018	79.0%
	− 7.71	*8.55*	
BILL	−0.028	0.028	100.0%
	− 10.46	*10.46*	
Σ	–	1.995	–
	–	*12.86*	
Log Likelihood		*− 2094.98*	
Pseudo R^2		*0.1851*	

[*] Coefficient insignificant at the 5% confidence level.

The models are satisfactory in that all except one of the attribute parameters (RIVER in Block B) are significant, and conform to prior expectations in terms of the signs of the parameters. Attributes representing 'bads' (including bill increase) had negative signs, while attributes representing 'goods' had positive signs. The very highly significant standard deviation and error component estimates suggest that failure to account for either of these issues in the model would undermine the credibility of the model and WTP estimates.

Results generally conformed to economic theory, providing validity to the results. In block A, hosepipe bans (PIPES), supply interruptions (INTER), unpleasant taste, smell and/or appearance (TSA) and tap water hardness (HARDN) all had negative signs. This reflects the fact that increasing levels of these attributes will generate disutility to customers. In block B, river water levels (RIVER) and water savings through efficiency measures (SAVED) had positive levels, though RIVER was statistically insignificant (i.e., not different from a mean of zero). The positive values reflect the fact that increasing levels of these attributes are desirable to customers. Also in block B, greenhouse gas emissions (EMISS), water safety tests (TESTS) and bill increase (BILL) had negative signs. This again reflects the fact that increasing levels of these attributes will generate disutility to customers. In both blocks, bill increase (BILL) was significant and negative, meaning that increasing bills will generate disutility to customers.

In the last column of Tables 1 and 2, the probability that customers would have a negative preference parameter is estimated for each attribute using the MXL population standard deviation estimates. As expected, this probability is invariably larger than 50% for bads, and lower than 50% for goods. In most cases the proportion of customers with the expected parameter sign is in excess of 65%.

Willingness–to-pay estimates

As the main purpose behind model estimation is the derivation of marginal WTP (mWTP) estimates, the parameter estimates *per se* are of little interest, except to verify that the model is performing as expected. Rather, marginal WTPs for each attribute can be estimated by computing the negative of the ratio of the attribute to the bill parameter. This provides a measure of the monetary value that respondents are prepared to trade or give up for the marginal service change. Table 3 presents these mWTP estimates. Again, as with parameter estimates, mWTPs had negative signs when a *bad* is being valued and positive signs when a *good* is being valued.

Jointly with the parameter estimates, the results show that respondents are making genuine and significant trade-offs between the attributes and bill increases, as witnessed by the signs of the mean mWTP estimates. For example, TVW customers are willing to accept compensation of 34 pence for each additional hosepipe ban that would be experienced in 100 years (PIPES); £2.41 for every additional 100 out of 100,000 properties affected by unplanned water supply interruptions (INTER); £5.20 for every additional 100 out of 100,000 properties complaining about the taste, smell, or appearance of their tap water (TSA), and 68 pence for each additional property in 100,000 complaining about tap water hardness (HARDN). On the other hand, TVW customers were WTP £4.38 for river water levels to be at their enhanced, as opposed to their current, flow levels (RIVER), and 6 pence for increased water savings (SAVED) equivalent to the water consumed yearly by an additional 1,000 households. As for carbon emissions from TVW operations, customers are willing to accept compensation of 33 pence for each additional increment of carbon emissions equivalent to 1,000 cars travelling average yearly mileage. Lastly, TVW customers were willing to accept compensation of 50 pence for each additional sample in 1,000 samples that failed water safety standards.

Market simulations

The marginal utilities estimated in CE studies can also be used to simulate how respondents would choose among a set of competing alternatives. To obtain this information,

Table 3 | Marginal WTP estimates (£/household/yr/unit)

Variable	Current level	Unit of measurement	mWTP	Z	95% Conf. Int.	
PIPES	10	Nr. of hosepipe bans/100 yr	−£0.34	−2.67	−£0.58	−£0.09
INTER	6	100's in 100,000 households affected/yr	−£2.41	−6.54	−£3.13	−£1.68
TSA	3.6	100's in 100,000 households complaining/yr	−£5.20	−8.05	−£6.46	−£3.93
HARDN	20	Nr. in 100,000 households complaining/yr	−£0.68	−7.03	−£0.87	−£0.49
RIVER	0 (max = 1)	1 if enhanced, 0 if no change	£4.38	1.42	−£1.67	£10.43
SAVED	0 (max = 300)	1,000 s of additional households	£0.06	3.68	£0.03	£0.09
EMISS	65	1,000 s of additional cars	−£0.33	−6.72	−£0.42	−£0.23
TESTS	20	Nr. in 100,000 tests	−£0.50	−6.93	−£0.64	−£0.36

results from CE studies are commonly used in market simulation models (Green *et al.* 2001; Deal 2003). These simulations take the respondents' estimated marginal utilities and turn them into information more useful and understandable from a managerial perspective. Methods used to turn marginal utilities into predicted respondent choices are known as choice models (Murphy *et al.* 2004). With market simulations, the performance of competing alternatives, or in this case competing possible investment programmes, can be evaluated.

When individual-level preference data are available, the most common choice model, known as First Choice (FC), is consistent with a random utility maximization framework (Murphy *et al.* 2004). For each alternative under consideration, the FC model sums the marginal utilities of the attribute levels that comprise the various alternatives under consideration for each respondent, assuming that respondents would choose the alternative that would provide them with the highest utility.

To perform the market simulations, we used individual-level marginal utilities obtained from the MXL model. The model used for estimating marginal utilities differed from our preferred model for the main study results in that, instead of assuming the alternative specific constant was fixed across customers, we allowed it to vary. Thus, the respondent's utility from the status quo alternative was also modelled at the individual level. Following estimation of the new model, we then converted marginal utilities into discrete utility measures for the different levels of each attribute by multiplying the marginal utility of an attribute by the change in each attribute between status quo and other discrete levels ($-1, +1$, and $+2$) included in the CE study. This resulted in utility values for each respondent for the different possible attribute levels.

The next step was to set up the possible choice scenarios. For this, we calculated the market shares of the different possible investment programmes included in the study, or, having all attributes at their $-1, +1$, and $+2$ levels. Each of these investment programmes also included a resulting change in the annual household bill, which was either a decrease for the degradation scenario or an increase for the two improvement scenarios. We next calculated the utility of each respondent for each of the possible

Table 4 | Market shares for block A attributes

	Investment Programmes			
Attributes	**Degradation (all attributes at −1 levels)**	**Status quo (all attributes at current levels)**	**Low improvement (all attributes at +1 levels)**	**High improvement (all attributes at +2 levels)**
Hosepipe bans	1 in 4 years	1 in 10 years	1 in 25 years	Never
Unplanned interruptions	1,200 in 100,000 (14,000/yr in total)	600 in 100,000 (7,000/yr in total)	300 in 100,000 (3,500/yr in total)	150 in 100,000 (1,750/yr in total)
Taste/smell/appearance	720 in 100,000 (9,000/yr in total)	360 in 100,000 (4,500/yr in total)	180 in 100,000 (2,250/yr in total)	90 in 100,000 (1,125/yr in total)
Water hardness	40 in 100,000 (520/yr in total)	20 in 100,000 (260/yr in total)	10 in 100,000 (130/yr in total)	5 in 100,000 (65/yr in total)
Change in annual bill	Decrease by £5	No change	Increase by £5	Increase by £20
Market share (95% Conf.)	1.1% (0.0%–2.3%)	30.3% (24.9%–35.7%)	35.7% (30.1%–41.4%)	32.9% (27.3%–38.4%)

investment programmes by summing their utilities for attribute levels in each scenario. Market shares for the block A attributes are shown below in Table 4.

Results of the market simulation for block A indicated that the low improvement scenario was most preferred by TVW customers, with 35.7% of customers choosing this scenario when faced with the choice set shown in the table. The high improvement scenario came in a close second (32.9%) with the status quo scenario coming in third (30.3%). It is interesting to note that almost none of the TVW customers (1.1%) preferred to have a degradation of services, even when it resulted in a decrease in their annual bill.

One particularly useful aspect of performing market simulations is that any possible combination of alternatives and choice scenarios could be modelled. Market simulation outputs could thus provide information on a wide variety of possible investment programmes and how customers might prefer these potential programmes as compared to their current situation.

Investment optimisation

Information on customer WTP for various service improvements can be used to optimise company investment planning. The Investment Optimisation (IO) approach developed by ICS Consulting for TVW enables the water company to develop and select a portfolio of investments that will maximise net benefits to customers. The estimated WTPs are used to value investment benefits, and the IO approach also allows any minimum service targets or business constraints to be incorporated into the solution. By applying such constraints the IO approach also ensures that the financial, regulatory and resource requirements of the business are not compromised. Four elements are needed to support this structured approach to investment portfolio optimisation:

1. *Priorities*: an understanding of the value delivered by changes in service levels and/or risks for each of the output performance measures adopted by the company. This value is made up of customer WTP, social/environmental damage functions, and private costs avoided;
2. *Targets*: the service targets required to be delivered by the investment portfolio, expressed in terms of the output performance measures;
3. *Valuation*: a method for the valuation of each potential investment solution that allows comparison on a consistent basis. The valuation is done for each investment solution in terms of its impact on the output performance measures; and
4. *Constraints*: a set of constraints that can be applied to the portfolio to ensure it meets real business requirements. These constraints include total capital cost, resource usage, geographic split, investment types and asset types.

Output performance measures

The optimisation method is founded on a set of output performance measures (OPMs). These are a set of measures that describe the performance of the asset base in business terms. They are the point where the performance of the asset base impacts on the success of the business. In the case of TVW, the configuration of the IO model uses 15 OPMs, as listed in Table 5.

Table 5 | Output performance measures

OPM reference	OPM description
1	Water quality (biological & chemical)
2	Water quality (aesthetic)
3	Water pressure
4	Supply interruptions
5	Security of supply resources
6	Leakage
7	Sludge disposal
8	Extra regulatory reporting
9	Prosecution
10	Personal injury
11	Customer contacts
12	Carbon equivalent emissions
13	Staff productivity
14	Transport disruption
15	Avoided costs to business

Solution valuation

Each investment solution is evaluated based upon the extent to which it impacts against one or more of the OPMs over a 40 year time period. The value of each OPM is also articulated in the IO model based upon an understanding of: (1) customer WTP for improvements in service[2]; (2) social and environmental damage costs associated with service failure (i.e., the value of damage suffered by society or the environment); and (3) private costs associated with service failure (i.e., those costs incurred by the business in response to and as a result of the service failure). By combining the extent to which service risk is mitigated together with the value of that risk to the customer, business and society, a financial benefit for the solution is derived.

Solution costing

The costs (and savings) associated with the solution are also calculated over a 40-yr time period. The types of cost included are: (1) the initial capital expenditures (capex); (2) the consequential repeat capex (based upon the spending of initial capex against assets with different life expectancies during the remainder of the 40-year period); (3) operating costs or savings (opex); and (4) income (from grants and contributions).

CBA valuation

In deriving the cost and benefit values for a solution, the IO model calculates the discounted whole life cost of implementing the solution (over 40 years) and the associated discounted whole life financial benefits delivered by that solution (over a 40-year period). The discounted costs and benefits are combined to produce a Net Whole Life Cost or Whole Life Benefit for the solution.

Selecting the optimal portfolio of investment

The IO model selects the optimal mix of investment solutions to deliver the required performance levels (typically to deliver base or current service), at minimum whole life cost, taking into account any constraints required by the business[3]. In addition, the IO model will also include in the portfolio other solutions where it is cost beneficial to do so. This occurs when the financial benefits of a solution are greater than the cost of implementation and the solution therefore has a net whole life benefit. To look at this another way, the IO model selects those investments required to meet base service and where base service is below the economic level of service additional solutions will be included to provide service up to but not beyond the economic level.

CONCLUSIONS

Estimating the benefits of investments in water services can provide utilities with valuable information for maximizing their return on different possible investment programmes. In this paper, we demonstrate how stated preference methods can be used to provide a measure of the value of various water services to customers. Estimates of customer WTP suggested that customers have a positive value for water services of both a public and private nature. Results of mixed logit models indicated that there are advantages to modelling customer preferences at the individual level. As further indication of the value of estimating individual-level preferences, the individual-level data was used to perform a market simulation of different possible investment programmes. Market simulation results showed that the majority of customers preferred a 'low improvement' scenario with a moderate associated increase in their annual bill. Virtually none of the respondents favoured a scenario where services were degraded in return for a small decrease in annual bills. Finally, the outline of the investment optimisation tool developed by ICS and implemented by TVW shows how CE customer surveys can be applied in the business setting and used to identify an optimal investment plan for water utilities.

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[2] The fact that OPMs were difficult to value as such by customers meant they had to be simplified to 'customer-friendly' attributes. The resulting mismatch meant that attribute WTPs derived from the stated preference study had to be 'transferred' to the OPMs. For example, WTP for SAFE (water safety tests) had to be apportioned to the various components of the water safety OPM (i.e., boil notices and 'do not use' notices). For that, the WTP, expressed per failure in every 100,000 safety tests conducted per year, was aggregated over all failures.

[3] In the regulatory context for water utilities in England & Wales, the maintenance of current or base service levels is usually interpreted as the minimum requirement as part of meeting regulatory requirements around asset stewardship.

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