Environ Resource Econ (2013) 54:495–523
DOI 10.1007/s10640-012-9603-1

A Socially Efficient Water Tariff Under the English Optional Metering Scheme

Tatsuki Ueda · Peter G. Moffatt

Accepted: 31 August 2012 / Published online: 18 September 2012

Abstract We design a socially-efficient water tariff in the institutional context of England, where water metering is largely optional and non-metered households are levied proportional to the rateable value (RV) of their property. Within this context, it is theoretically demonstrated that: the larger the RV, the more likely the household to opt for metering; and the larger the RV, the smaller the Demand Effect of Metering (DEM; the fall in water consumption resulting from metering). These two hypotheses are confirmed with econometric analyses using datasets provided by a water company operating in East Anglia, England. The results signify an adverse-selection problem: wealthier households are more likely to opt for metering, yet they are expected to exhibit a smaller DEM once a meter is installed. In order to overcome this, we propose a two-part tariff for metered households consisting of: a variable charge levied proportional to water consumption at a uniform price; and a progressive standing charge to place a heavier burden on wealthier households. The latter component has a potentially major role in attaining social efficiency of metering, by encouraging poorer households to install meters whilst discouraging wealthier ones. The optimal two-part tariff is determined empirically.

Keywords Econometrics · Social efficiency · Water consumption · Water metering · Water supply

T. Ueda (✉)
National Institute for Rural Engineering, National Agriculture and Food Research Organization, 2-1-6 Kannondai, Tsukuba, Ibaraki 305-8609, Japan
e-mail: tued@affrc.go.jp

P. G. Moffatt
School of Economics, University of East Anglia, Norwich NR4 7TJ, UK

1 Introduction

1.1 Background and Objective of Study

In England and Wales, water companies are abstracting about a half of total freshwater resources (Environment Agency 2008a), and this proportion is projected to increase in order to support growing populations. On the other hand, scope to increase water supply in the future is reducing as a consequence of environmental constraints including climate change. It is therefore essential for water regulators to encourage households to save water, in order to mitigate such environmental pressures. One obvious way to achieve this is to implement "economic incentive" schemes that encourage households to save water through price mechanisms. Hence, water companies in England have been promoting the take-up of water meters by their domestic customers, so that fees may be levied on the basis of actual water consumption. It is well-known that meter-charged households nearly always use less water than those who pay a fixed fee (Environment Agency 2008a). This study therefore has as its main aim to design a socially-efficient metered tariff scheme, with a focus on the East Anglian region of England, UK, where water stress is particularly acute due to its relatively dry climate and high population density.

Whereas the necessity of promoting water metering has acquired widespread consensus across developed countries, how best to design metering (and metered tariff) schemes remains subject to debate. The most fundamental question is whether metering should be made compulsory (universal) or stay optional. Whilst the majority of OECD countries have chosen compulsory metering schemes (OECD 2010), the UK and Ireland remain notable exceptions, with only around 30 % of households in England and Wales equipped with metering in 2008 (Environment Agency 2008a). In addition, some countries (e.g. Canada, Czech Republic and Sweden) simultaneously adopt both non-metered and metered tariff schemes, as water tariff structure is often at the discretion of local municipalities (OECD 2010).

OECD (2010) attributed such relative inertia of keeping optional metering to the complexity in designing an appropriate metered tariff structure. On the one hand, a water company needs to maintain financial stability upon changing the tariff scheme by levying, for instance, costs of meter installation and reading. On the other hand, it would be necessary to address affordability of a metered tariff for various kinds of households. Whilst these two issues—financial sustainability (or economic efficiency) and affordability for all (or distributional concerns)—have been the main themes of discussion in the relevant literature, this study will chiefly concentrate on the former. Furthermore, a major obstacle to universal metering in the UK has been a common fear that universal metering might result in adverse financial consequences for poorer households (Herrington 2007). Other popular arguments against metering were that there were cheaper ways of conserving water, such as promoting dual-flush toilets, and that increased demand could be met by increasing supply (Dresner and Ekins 2006).

Given the current UK situation where most households are offered the option to adopt a meter, designing a socially desirable tariff scheme could follow one of two approaches. The first is to admit plainly that metering should be promoted on a universal basis, and accordingly to focus on designing a possible universal metering tariff scheme. The second is to maintain the optional metering scheme and to seek ways to improve it in order to attain social efficiency and to bring about further promotion of metering.

With regard to the first approach, Dresner and Ekins (2006) employed a dataset from Anglian Water to investigate the possible financial gains/losses of households upon switching to metering under the current tariff or some hypothetical tariffs. They found no evidence that switching under any tariffs will, on average, make low-income households worse off.

Likewise, assuming universal metering, one could design a variety of tariff schemes, starting with the decision of how to weight a standing charge[1] and volumetric rates. Then these two components could be adjusted to form variable standing charges and/or increasing block tariff (IBT) schemes etc., in order to achieve such objectives as promotion of thrift water uses and income redistribution. For aiding selection of such schemes, a large literature has emerged on existing universal metering schemes, which evaluates the effects of scheme change or price change on water demands using price elasticity of demand and other factors (e.g. Arbués et al. 2003).

Turning to the second approach, Cowan (2010) takes the optional metering scheme as given, and then theoretically investigates tariff schemes that would bring about socially efficient outcomes, that is, outcomes with positive benefits both to the household and to society. He examines cases in which water companies may or may not have information on household type (i.e. their demand function for water). He argues that households with smaller sensitivity of demand (i.e. those who would bring less benefit to society through water saving) would be more likely to opt for metering. This implies an adverse selection problem: those who are more expensive to serve (in terms of the cost-benefit ratio) are more likely to choose to have the service. He nonetheless concludes that, when water companies know households' type, they could implement a tariff scheme that discourages "expensive" customers from installing meters. However, such a "separating equilibrium" only exists when companies know households' types.

The current study will not attempt to adjudicate over which of the two approaches is superior; rather, we will focus a priori on the second approach. Our main motivation is that, in the UK context, it is reasonable to assume that the optional metering scheme will persist for at least a number of years, given the popular resistance to universal metering. Besides, the unit cost of meter installations might be higher if they were implemented too rapidly, in consequence of over-use of resources in a short period of time (Environment Agency 2008b). Environment Agency (2008a) forecasted that it would take more than 30 years at current penetration rates for water companies to install meters at all properties where it was reasonably practical to do so (i.e. around 90 % of households).

Therefore, the main objective of this study is to investigate a socially-efficient metered tariff, taking the optional metering scheme as given. Hence we follow an approach similar to Cowan's, with the further objective of extending his framework to establish an empirical model. Accordingly, our foremost concern is with the household decision over the discrete tariff change from moving from non-metered to metered status, and with the demand effect associated with this change (These key concepts are respectively termed "metering decision" and "demand effect of metering (DEM)"). This may be seen as constituting a significant diversion from most of existing literature on water pricing, which tends to focus on incremental price changes and/or inter-block tariff changes, while taking universal metering as given (Arbués et al. 2003).

This study is structured as follows. Section 2.1 begins by discussing theoretical frameworks regarding the metering decision and the DEM As a variable to represent household type in the context of Cowan (2010) theory, we choose the rateable value (RV), which will act as a proxy for household wealth. It is chosen because water companies do have access to such information—an essential condition in Cowan's theory. We consequently propose two hypotheses: (1) the larger the RV, the more likely the household is to opt for metering; and (2) the larger the RV, the smaller the DEM (the fall in water consumption resulting

[1] This is termed "recurrent fixed charge" by OECD (2010). This study will reserve the term "fixed fee" to describe what OECD called "flat fee" payable by non-metered households.

from metering). Together, the two hypotheses imply an adverse-selection problem in that: wealthier households are more likely to opt for metering, yet they are expected to exhibit a smaller DEM once a meter is installed. Sect. 2.2 empirically challenges these hypotheses with econometric techniques, and quantitatively evaluates the DEM.

Section 3 builds an empirical tariff model that addresses the adverse-selection problem, and hence attains social efficiency. Section 3.1 begins by introducing a theoretical condition for a water tariff scheme to achieve social efficiency, in the spirit of Cowan (2010). Section 3.2 then builds an empirical model on the basis of both the theory of Sect. 3.1 and econometric findings of Sect. 2.2 Here we choose a tariff model comprising a variable standing charge (in terms of RV) and a uniform volumetric rate. Section 3.3 discusses a remaining issue regarding the empirical model in Sect. 3.2: a tension between attaining social efficiency (or financial neutrality for a water company) and increasing relative affordability of metering (or promoting water meters further to attain more water savings). Here we will propose to increase the fixed tariff for non-metered households, in light of possible environmental costs incurred by excessive water use.

Although this study is structured on the basis of Kyle (2009) and Ueda (2010), it makes significant enhancements in the following directions: (1) the theoretical model in Sect. 2.1 is re-formulated in a way that makes it simple and straightforward; (2) the empirical model in Sect. 3.2 is significantly improved to achieve a two-part tariff that is closer to the first-best solution than the progressive volumetric pricing scheme proposed in Ueda (2010); and (3) in Sect. 3.3, we further advance the analysis to address environmental concerns.

1.2 Brief description of the Study Area

The East Anglia region occupies the eastern part of England, with a population of 5.8 million in mid-2009 (Office of National Statistics 2011), which is increasing at a rate of about 0.8 % a year, which is above the UK average. Gross disposable household income of residents was at £15,900 per head in 2009 which was above the UK average. The topography is typically flat and low-lying, and the land use is dominated by farmlands. Meanwhile the region receives just around 600 mm of rainfall a year, making it one of the driest regions in UK. These conditions make the region particularly vulnerable to water stress (Environment Agency 2008a). The company whose data we use, being the monopoly supplier of water services covering most of the region, has therefore made an effort to extend water meters, and the meter penetration rate in the region was 57.2 % in 2006/2007—well above the national average of 30.3 % (Environment Agency 2008b). The company has a target to increase the meter penetration rate to 80 % of households by 2014/2015, and to all households (subject to the practicalities of installation) by 2,035 (Anglian Water 2009a).

The company has separate charging schemes for non-metered and metered households (for the current fees, see Sect. 3.2.1.) (Anglian Water 2011). For non-metered households, the charge is levied proportional to the RV of property (which is closely related to its market value[2] and assessed by a local government or a water company) plus a standing charge. For metered households, the charge is levied in proportion to the volume of water consumption at a uniform volumetric price, plus a standing charge. In both cases, sewerage services fees are added on top of the standing and variable charges mentioned above, if the household is connected to a sewer.

A switch from non-metered to metered status is at the discretion of households, and it is also not compulsory for newly-built properties to install a meter. Any household is

[2] It is however gradually outdated. See footnote 4.

eligible to apply for meter installation, which is easy and offered free. Moreover, households are permitted to revert to non-metered status within 2 years of installation. (This study however abstracts from this "switch-back" option, since negligibly few households have actually taken it.) These conditions would establish that metering decision is essentially a free choice of households.[3] We will further discuss this matter in Sect. 2.2.

Meanwhile, the tariff levels of water companies in England and Wales are tightly regulated by an independent agency OFWAT, which aims to make water prices fair to customers. To this aim, OFWAT exercises its power in, for instance: setting every 5 years an upper limit in water charges that water companies can levy; demanding water companies to reveal information to ensure water prices accurately reflect actual costs; closely monitoring operations of water companies to make sure necessary investment is undertaken at a suitable time; and redressing water companies when their operations fall short of regulations or targets (OFWAT 2010).

2 Demand Effects of Water Metering

2.1 Theoretical Framework

We begin by appealing to neoclassical consumer theory in order to establish a microeconomic model that accurately represents the situation in East Anglia described in Sect. 1.2. This section will abstract from the standing charge described in Sect. 1.2, as it does not affect the conclusions.

2.1.1 Optimal Water Consumption

We first describe a household's decision problem as facing a two-good economy comprising water (x_1) and numeraire ("all other goods", x_2) (Fig. 1). This is a more formal and generalized representation of the theoretical framework developed, for a particular parametric specification, by Kyle (2009). In the discussion that follows, we let:

x_1 be quantity of water consumed,
x_2 be quantity of numeraire consumed (with price normalized to one),
p be the unit price of water for metered households,
f be the fixed fee for water for non-metered households,
m be household income,
c be the satiation point of water consumption (described below),
$X_m : (x_1^m,\ x_2^m)$ be the optimal consumption bundle under metering,
$X_f : (x_1^f,\ x_2^f)$ be the optimal consumption bundle with a fixed fee,
$U_m(.)$ be the indirect utility obtainable under metering,
$U_f(.)$ be the indirect utility obtainable with a fixed fee.

We assume that the consumer's preferences are strictly convex until x_1 reaches the satiation point c, beyond which additional water consumption adds no utility. Note that this is an important departure from standard theory. According to standard theory, MRS_{21} (that is, the marginal rate of substitution of good 2 with respect to good 1) diminishes with x_1, but is

[3] Strictly speaking, other than being a customer of the water company, a household may also have a choice of drilling their own well to supply residential water by themselves. Nevertheless, this option is largely irrelevant to those living in densely populated city and town areas, and assumes very minor role in residential water supply in England and Wales (Environment Agency 2010). Thus, we will abstract from this option as well.

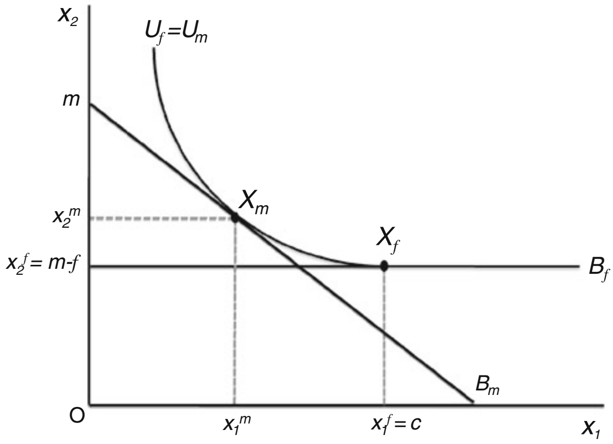


Fig. 1 Optimal bundles for a household facing the two-good economy

always positive; here, we assume that the MRS_{21} decreases all the way to zero, and remains at zero for all $x_1 \geq c$. In Fig. 1, this feature of preferences is represented by the fact that the indifference curve is horizontal to the right of c. The importance of this assumption is that it is necessary to account for a household observed consuming a finite quantity of water when their marginal cost of water consumption is zero.

A household faces different budget constraints depending on the water charging schemes (Fig. 1), as follows:

$$\begin{aligned} &(\text{For the metered}: \boldsymbol{B_m}) \qquad px_1 + x_2 \leq m \\ &(\text{For the non-metered}: \boldsymbol{B_f}) \qquad f + x_2 \leq m \end{aligned} \tag{1}$$

Under these constraints, a household would maximize their utility by choosing a bundle $\boldsymbol{X_m}$ under a metered fee or $\boldsymbol{X_f}$ under a fixed fee, where the indifference curve is tangent to the budget constraint (Fig. 1). (We impose a restriction that households would choose to consume c rather than $x_1 > c$ under a fixed fee, as environmental concerns would, we suppose, prevent blatant wastage of water). Figure 1 shows a case where the indirect utility obtainable under the constraint B_m (i.e. U_m) is exactly equal to that under B_f (i.e. U_f), and therefore the household is indifferent between the metered and non-metered options. Accordingly, a household would choose to opt for metering if $U_m > U_f$, and opt out if $U_m < U_f$.

2.1.2 Rateable Value and the Metering Decision

We next discuss the effect of the RV of household on the metering decision, that is, on the decision of whether to switch from non-metered to metered status. We now assign the RV a role as a proximate indicator for household income, because the dataset discussed later lacks information on household income. This means we assume a priori that there is a broadly proportional relationship between RV and household income. In this connection, we shall make a more specific assumption about the relationship between RV and income: $0 < df/dm < 1$. This implies that when the income of a non-metered household rises, it is spent in part, but not completely, on a rise in the fixed charge for water (this rise stemming from an upgrade of the household's real estate).[4]

Furthermore, we assume that the satiation point of water consumption, c, does not change in response to a *ceteris paribus* income change, so that $\partial c/\partial m=0$. Put differently, we assume that c does not change in response to a change in m, once we control for the occupancy and the number/size of water-using appliances etc. in the household's possession.[5]

When the household is under a fixed fee, it is apparent from Fig. 1 that the optimal consumption bundle is: X_f: $(c, m{-}f)$. Hence, the marginal increase in utility resulting from a marginal rise in income is:

$$\frac{\partial U_f}{\partial m} = \frac{\partial U_f}{\partial x_1^f}\frac{\partial x_1^f}{\partial m} + \frac{\partial U_f}{\partial x_2^f}\frac{\partial x_2^f}{\partial m} = \frac{\partial U_f}{\partial x_2^f}\left(1 - \frac{df}{dm}\right) \tag{2}$$

This is the extra net income (after paying a higher fixed fee) times the marginal utility of the numeraire (on which all additional net income is spent). On the other hand, when the household is under a metered fee, the utility rises by the marginal utility of income, which is:

$$\frac{\partial U_m}{\partial m} = \frac{\partial U_m}{\partial x_1^m}\frac{\partial x_1^m}{\partial m} + \frac{\partial U_m}{\partial x_2^m}\frac{\partial x_2^m}{\partial m} \tag{3}$$

Hence the difference between Eqs. (3) and (2) constitutes a rise in the propensity to switch to metering in response to a marginal rise in income:

$$\begin{aligned}\frac{\partial d^*}{\partial m} &= \left[\frac{\partial U_m}{\partial x_1^m}\frac{\partial x_1^m}{\partial m} + \frac{\partial U_m}{\partial x_2^m}\frac{\partial x_2^m}{\partial m}\right] - \left[\frac{\partial U_f}{\partial x_2^f}\left(1 - \frac{df}{dm}\right)\right] \\ &= \frac{\partial U_m}{\partial x_1^m}\frac{\partial x_1^m}{\partial m} + \frac{\partial U_m}{\partial x_2^m}\frac{\partial x_2^m}{\partial m} - \frac{\partial U_f}{\partial x_2^f} + \frac{\partial U_f}{\partial x_2^f}\frac{df}{dm}\end{aligned} \tag{4}$$

where d^* is (as in Sect. 2.2.1) the propensity to switch to metering.

As long as the right-hand side of Eq. (4) is positive, and given the a priori relationship between income and RV, the following holds:

Hypothesis 1 The larger the reteable value of a household, the more likely they are to opt for water metering, *ceteris paribus*. In other words, there is a positive relationship between the RV and the propensity to switch to metering.

Hypothesis 1 holds, for example, with the assumption of quasi-linear utility function of the form:

$$U = x_2 + u(x_1) \tag{5}$$

subject to the budget constraints (1)
where $u(.)$ is utility derived from water consumption.

[4] This presumes that the RV of real estates is revised periodically. However, it should be noted that, since the RV was last assessed in 1973, it is losing relevance to present estate values (Dresner and Ekins 2006; Herrington 2007).

[5] This is a rather strong assumption, and therefore tested empirically in the Appendix. Note that the assumption does not exclude a possibility that a non-metered household would *indirectly* increase water consumption in response to income increase, through acquiring more water-consuming appliances (like water hoses for irrigating gardens) (Herrington 2007).

This obviously implies $\partial U/\partial x_2$=1. Furthermore, by solving the unconstrained maximization problem, it can be shown that the metered demand for water x_1^m depends only on water price but not on income, so $\partial x_1^m/\partial m = 0$ and $\partial x_2^m/\partial m = 1$. Consequently, we see the first term of the right-hand side of Eq. (4) is zero; the second and third terms cancel out; and the fourth term is always positive. Hence the right-hand side of (4) is definitely positive. It should be noted that the above form of preference is a sufficient, but not necessary, condition for holding Hypothesis 1.

2.1.3 Rateable Value and the Demand Effect of Metering

The fall in water consumption induced by installation of a water meter is termed the DEM. We define DEM in absolute-value terms throughout the paper. We hypothesize that there is an inverse relationship between RV (hence f) and DEM, given the household does switch to metering. We assume here that the wealthier the household, the higher their marginal rates of substitution (MRS) for water would be, after Arbués et al. (2003) and Cowan (2010). That is, the wealthy are willing to pay more (in terms of the numeraire) for consuming additional amounts of water below the satiation point. This assumption implies there is an income effect in the demand for water under a metered fee, so that $\partial x_1^m/\partial m$ is positive.[6] Thus, since the DEM is defined as: $DEM = c - x_1^m$, we have:

$$\frac{\partial DEM}{\partial m} = \frac{\partial c}{\partial m} - \frac{\partial x_1^m}{\partial m} = -\frac{\partial x_1^m}{\partial m} < 0 \tag{6}$$

Hence we claim, by accepting the a priori relationship between income and RV, that:

Hypothesis 2 The larger the RV of a household, the smaller the demand effect of metering, *ceteris paribus*, given the household does switch to metering.

2.2 Econometric Analyses

We next challenge the above theory with econometric analyses, using datasets obtained from a water company operating in the East Anglian region of England. The data sets used, and some aspects of the econometric methodology, are broadly similar to those of Kyle (2009).

Between 1990 and 2001, the company conducted a survey of its domestic customers ("Survey of domestic water consumption", referred to as "SoDCon"), with the primary objective of investigating the determinants of household water consumption. Initially, the sample consisted of non-metered households, selected by a stratified sampling approach, and subject to their agreement to participate. Some of the non-metered households switched to metered status during the observation period, and such households are referred to as "optants". Because of the growing interest in metering, the sample was boosted with the addition of 1000 metered households in 1997.

Each sampled household, whether metered or non-metered (fix-charged), was fitted with a supplementary meter,[7] which was linked to the company's telemetry, enabling collection of consumption data into a database. Sampled households were also interviewed face-to-face in order to collect information on socio-economic characteristics. RV, which determines the fixed charge for non-metered households, was extracted from the company's charging database.

[6] We will empirically test this in the Appendix.

[7] Note that those meters installed at households paying fixed fees were for an experimental purpose only, and do not represent the normal metering policy of the water company.

Two data sets are used in this paper. In Sect. 2.2.1, a single cross section of 2,997 households is used in order to investigate the determinants of switching propensity. In Sect. 2.2.2, panel data on a sample of 595 households, whose consumption is observed each month for a 5-year period, are used in order to estimate the demand effect of metering. Further descriptions of datasets and justification for these choices of data types are provided in the following sub-sections. All econometric estimation is performed using the statistical software Stata 11 (StataCorp 2009).

2.2.1 Test of Hypothesis 1

We begin by challenging Hypothesis 1 that suggests a positive relationship between RV and propensity to switch to metering. As mentioned, for this purpose we use a single cross section of 2,997 households, observed in 1998,[8] consisting of 1873 non-metered and 903 metered households. With this data, we model the metering decision[9] as a binary variable. In doing so, we are treating the adoption of a water meter in a similar way to the standard treatment of the adoption of a consumer durable or a new technology (see for example, Kennickell and Kwast 1997). It must be acknowledged that the decision to adopt a meter is reversible within a 2-year period. However, this is the case for any sort of new product or technology, and in any case, decisions to revert to non-metered status are very rare, partly as a consequence of water bills typically being lower ex-post under metering.[10] We therefore consider it reasonable to treat the metering decision as a one-off decision, justifying our use of the binary probit model applied to a single cross section of households. Note that, in order to ensure a sharp distinction between non-metered and metered households, the sample intentionally excludes households that switched from non-metered to metered status during the 1-year period of observation.

A further econometric issue that needs to be addressed is that the cross section is a choice-based sample (Manski and Lerman 1977). We do not have a random sample of 2,997 households. Instead we have a random sample of 1,873 non-metered households, and another random sample of 903 metered households. This gives a sample frequency of 30 % metered, while the proportion of households in the region under study who were metered in 1998 was only around 20 %. This sampling bias is corrected by weighting observations.[11]

Let the binary dependent variable be d (1 if meter chosen; 0 otherwise). Since we are using a simple probit model, we are assuming that the underlying (latent) model is:

$$d_i^* = \alpha' z_i + v_i \qquad i = 1, \ldots, n \tag{7}$$
$$v_i \sim N(0, 1)$$

[8] This year is chosen because the 1998 cross section is the only dataset available that contains data on both metered and non-metered households observed at the same time.

[9] Strictly speaking, this model would be better called a model of metering "status" rather than "decision", because the decisions to opt for metering were actually made before taking a snapshot of the cross section in 1998. However, we will continue to use the word "decision" here to maintain consistency with our theoretical models. This means we implicitly assume that household characteristics (such as occupancy) were static in the period between meter installation and the snapshot.

[10] See the OFWAT website: http://ofwat.gov.uk/regulating/charges/prs_web_charges2012-13.

[11] The [pweight] subcommand is used in STATA. Specifically, a variable p (representing the probability of selection) is generated, taking values of 1 for metered households, and 0.875 for non-metered. Then the probit model is estimated with the command: probit d x [pweight=1/p].

Table 1 Definitions of the variables

Variable	Definitions and descriptions
Water consumption	Household's annual water consumption in 1999–2000 (litres)
Meter	Water-metering dummy: 1 if household metered; 0 if not
Occupancy	1 if owned; 0 if not
Dummy variables concerning water-consuming appliances and activities	
Washing machine	Number of persons living in a household
Dishwasher	1 if owned; 0 if not
Dual-flush toilet	1 if owned; 0 if not (Dual-flush toilet is a device intended to reduce water consumption in flushing)
Power shower	1 if owned; 0 if not
Wash vehicle	1 if washes vehicle; 0 if not
Hose	1 if owned; 0 if not (*Hose* means summer hoses normally used for watering gardens)
Sprinkler	1 if owned; 0 if not
Water softener	1 if owned; 0 if not
Dummy variables indicating households' income status	
ACORN A	1 if top occupational class (wealthy achievers); 0 if not
ACORN B	1 if second occupational class (urban prosperity); 0 if not
ACORN C	1 if third occupational class (comfortably off); 0 if not
ACORN D	1 if fourth occupational class (moderate means); 0 if not
ACORN E	1 if fifth occupational class (hard-pressed); 0 if not
Rateable value (RV)	Rateable value of household when a house was built
Year-built	The year household was built (a.d.) minus 1900. 1900 is subtracted so that the variable has a sensible range

ACORN stands for "A Classification of Residential Neighbourhoods" (see text)

$$d_i = 1 \text{ (has opted for metering)} \qquad \text{if } d_i^* > 0;$$
$$d_i = 0 \text{ (has not opted for metering)} \qquad \text{if } d_i^* \leq 0$$

where d_i^* is a latent propensity to opt for water metering for household i; $\boldsymbol{z_i}$ is a vector of explanatory variables representing household characteristics; α is a vector of parameters, the first of which is an intercept; and d_i is binary variable representing meter choice by household i.

Definitions and descriptions of the variables are presented in Table 1, and their descriptive statistics in Table 2. The square of occupancy is included as an independent variable in order to allow flexibility with respect to the effect of occupancy. We also include various dummy variables representing the ownership of water-using appliances (such as *washing machine*). Dummy variables for *ACORN* category (standing for "A Classification of Residential Neighbourhoods", a geo-demographic classification system for small areas in the UK, due to CACI Ltd.) are included as they are expected to act as surrogate indicators of household income. *Year built* is included to reflect the fact that properties built in later years have higher probabilities of being metered, simply because meter installations to new properties have become quite common in recent years (Kyle 2009; Ueda 2010).

The results of estimation are reported in Table 3. It is estimated that the coefficient on *RV* is significantly positive. That is, the larger the RV, the more likely the household is to install a water meter, *ceteris paribus*. This endorses our Hypothesis 1. The average

Table 2 Descriptive statistics of the cross-sectional data

Variable	Whole sample					Metered households					Non-metered households				
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Min	Max
Water consumption															
Annual (L)	2,776	85,596	61,086	525	417,981	903	55,423	42,278	570	231,529	1,873	100,144	63,398	525	417,981
In natural log	2,776	11.02	0.962	6.263	12.94	903	10.56	0.973	6.346	12.35	1,873	11.24	0.874	6.263	12.94
*Per-day (L)**	2,776	234.5	167.4			903	151.8	115.8			1,873	274.4	173.7		
*Per-capita-day (L)***	2,776	90.29	125.5			903	78.00	114.2			1,873	94.26	128.1		
Meter	2,776	0.325	0.469	0	1										
Occupancy	2,776	2.597	1.334	1	9	903	1.947	1.014	1	6	1,873	2.911	1.356	1	9
Washing machine	2,776	0.949	0.220	0	1	903	0.908	0.289	0	1	1,873	0.968	0.175	0	1
Dishwasher	2,776	0.254	0.435	0	1	903	0.262	0.440	0	1	1,873	0.249	0.433	0	1
Dual-flush toilet	2,776	0.141	0.348	0	1	903	0.120	0.325	0	1	1,873	0.151	0.358	0	1
Power shower	2,776	0.220	0.414	0	1	903	0.255	0.436	0	1	1,873	0.203	0.402	0	1
Wash vehicle	2,776	0.173	0.378	0	1	903	0.116	0.321	0	1	1,873	0.200	0.400	0	1
Hose	2,776	0.564	0.496	0	1	903	0.503	0.500	0	1	1,873	0.593	0.491	0	1
Sprinkler	2,776	0.055	0.228	0	1	903	0.061	0.239	0	1	1,873	0.052	0.222	0	1
Water softener	2,776	0.017	0.130	0	1	903	0.022	0.147	0	1	1,873	0.015	0.121	0	1
ACORN A	2,776	0.216	0.411	0	1	903	0.268	0.443	0	1	1,873	0.191	0.393	0	1
ACORN B	2,776	0.189	0.392	0	1	903	0.161	0.367	0	1	1,873	0.203	0.403	0	1
ACORN C	2,776	0.139	0.346	0	1	903	0.121	0.326	0	1	1,873	0.148	0.355	0	1
ACORN D	2,776	0.327	0.469	0	1	903	0.340	0.474	0	1	1,873	0.321	0.467	0	1
ACORN E	2,776	0.128	0.334	0	1	903	0.111	0.314	0	1	1,873	0.137	0.344	0	1
Rateable value (RV)	2,776	17.0	90.25	46	980	903	249.5	105.4	68	662	1,873	201.3	77.23	46	980
Year-built (minus 1900)	2,776	59.14	21.48	5	95	903	62.83	18.48	5	95	1,873	57.36	22.58	5	95

Obs the number of observations, *SD* standard deviation. * Per-day water consumption = annual consumption/365. ** Per-capita-day consumption = per-day consumption / occupancy

Table 3 Estimated (choice-weighted) probit model for the metering decision

Variables	Coefficients	SE
Constant	−0.06994	0.1710
Rateable value (RV)	0.005107	0.0004954**
Year-built	0.005891	0.001465**
Occupancy	−0.8634	0.07366**
Occupancy-squared	0.07076	0.01089**
Washing machine	−0.2875	0.1212*
Dishwasher	0.008285	0.07223
Dual-flush toilet	−0.1108	0.07969
Power shower	0.1526	0.06601*
Wash vehicle	−0.3455	0.08594**
Hose (for gardening)	−0.1741	0.06262**
Sprinkler	0.03824	0.1330
Water softener	−0.007608	0.2309
ACORN A	0.04021	0.1024
ACORN B	−0.09402	0.1021
ACORN C	−0.06588	0.1038
ACORN D	0.1004	0.08735
ACORN E (base)	–	–
Sample size	2,776	
Log pseudolikelihood	−1,464.6241	
Pseudo R^2	0.2086	

Dependent variable: *Meter* (the water-metering dummy). * Significant ($p < 0.05$); ** Strongly significant ($p < 0.01$)

marginal effect of RV on the metering probability is 0.001388 (se = 0.0001241).[12] That is, the probability to switch to metering is expected, on average, to rise by 0.1388 percentage points when RV rises by 1 unit, *ceteris paribus*. Furthermore, the conditional marginal RV effects at 25 percentile, median and 75 percentile of RVs (which are RV=158, 198 and 253, respectively) are: 0.001224 (se = 0.0000961), 0.001375 (se = 0.000125) and 0.001544 (se = 0.0001544), respectively. These results imply that the marginal RV effect tends to be stronger as RV increases. That is, the rich would be more responsive to a rise in RV in installing a water meter. This would strengthen our Hypothesis 1 further still.

In the meantime, observations on the other variables in Table 3 suggest that households with higher water consumption would be less likely to opt for metering. This is because the coefficients on factors associated with higher water consumption tend to be negative. For instance, coefficients on *occupancy* and *occupancy-squared* imply an inverse and convex relationship[13] between occupancy and propensity to opt for metering. Also, some of the coefficients on water-consuming appliances and activities (i.e. *washing machine*, *wash*

[12] This is obtained using the STATA"margins" command, which uses the delta method to obtain the standard error.

[13] The "convex" relationship could be derived from a concave relationship between occupancy and water consumption observed in the OLS estimation (see discussions on Model A1 in the Appendix).

vehicle and *hose*) are negative and significant. These results could be expected because non-metered households consuming a lot of water would be more likely to expect tariff increases upon switching to metered status, and hence choose to opt out.

2.2.2 Test of Hypothesis 2

We next challenge Hypothesis 2 that suggests an inverse relationship between RV and demand effect of metering. As noted by Kyle (2009) and Ueda (2010), simple ordinary least squares (OLS) estimation using a cross-sectional dataset similar to that used in Sect. 2.2.1, with consumption as the dependent variable, would entail the problem of endogeneity of the meter dummy, resulting in biased estimation of DEM. Hence we will instead employ a panel dataset (unbalanced) extracted from the same survey for the years 1996–2001. The sample households comprised 595 households of the "optant", that is, households who switched from non-metered to metered status at some point during the 5-year period of observation.[14] For each household, monthly water consumption is observed for each month of the sample period. The use of this dataset is ideal for estimation of DEM, since the availability of repeated consumption data on each household, from both before and after their meter adoption, enables the effect of meter adoption to be identified while taking account of inter-household differences in consumption levels.

The fixed-effects model has been judged as preferred to both the pooled regression model and the random-effects model for analyzing the current data (Ueda 2010). The fixed-effects model gives a consistent estimator in the presence of heterogeneity across households, and is of the form:

$$y_{it} = x'_{it}\beta + \alpha_i + \varepsilon_{it} \tag{8}$$

where y_{it} is natural log of monthly water consumption; $\boldsymbol{x_{it}}$ is a $k \times 1$ vector of (observed) explanatory variables (not including a constant term); $\boldsymbol{\beta}$ is a vector of parameters; α_i is a constant term capturing the heterogeneity across households; ε_{it} is a disturbance term; and subscripts i $(i = 1, \ldots, n)$ and t $(t = 1, \ldots, T)$ indicate household and time, respectively.

In the above model, the natural log of water consumption is employed as the dependent variable, since a histogram of natural log of water consumption was found to be closer to symmetry than that of straight water consumption (Ueda 2010). In the list of explanatory variables, a *time trend* variable[15] (ranging from one for January 1996–1965 for May 2001), and a set of monthly dummies, were included, as a time series of the mean (across households) water consumption shows a clear downward trend in consumption over the 5 years of observation, but also contain a lot of seasonal variation and noises (Ueda 2010).

The results of estimation are reported in Model 4.1 of Table 4. In order to accommodate an inverse relationship between RV and DEM that was theorized earlier, the empirical model incorporates an interaction term: (*meter*)/(*RV*). Consequently, the DEM is effectively being estimated as:

$$DEM = -\left[\frac{\partial(\hat{\ln}(y))}{\partial(meter)}\right] \times 100\ (\%) = \left[-2.689 + \frac{2794}{RV}\right]\ (\%) \tag{9}$$

The relationship implied by (9) is graphed in Fig. 2. The inverse relationship is clearly illustrated, with DEM being very large for low RV households, and decreasing all the way to

[14] This implies we are going to estimate here what is referred to as an "average treatment effect on the treated" (ATT). That is, the estimate of the treatment effect reflects what happened to the treated households, and not necessarily what would happen if randomly drawn households were treated.

[15] The use of a time trend, in preference to a set of time fixed-effects, is justified in the current situation.

Table 4 Estimated fixed-effects models for water consumption

Variables[a]	Model 4.1		Model 4.2	
	Coefficients	SE	Coefficients	SE
Constant	8.127	0.05818**	8.114	0.05813**
Meter	0.02689	0.03520	−0.1317	0.01520**
Meter/RV	−27.94	5.887**	–	–
Occupancy	0.5015	0.04587**	0.5290	0.04585**
Occupancy-squared	−0.07722	0.008484**	−0.08232	0.008482**
Time trend	−0.003407	0.0003027**	−0.003430	0.0003028**
January (base)	–	–	–	–
February	−0.03028	0.01929	−0.03032	0.01925
March	0.08318	0.01920**	0.08409	0.01917**
April	0.04764	0.01933*	0.04841	0.01929*
May	0.07987	0.01946**	0.08049	0.01943**
June	0.05461	0.01942**	0.05523	0.01939**
July	0.1193	0.01959**	0.1188	0.01955**
August	0.08932	0.01966**	0.09119	0.01962**
September	−0.006670	0.01966	−0.006438	0.01962
October	−0.004515	0.02016	−0.009222	0.02012
November	−0.01888	0.02080	−0.01908	0.02077
December	0.01149	0.02049	0.01157	0.02046
σ_u	0.5895		0.6058	
σ_ε	0.6684		0.6700	
R^2 (within)	0.0303		0.0308	
R^2 (between)	0.4373		0.3853	
R^2 (overall)	0.2116		0.1846	
Sample size (*obs*)	27,013		27,242	
Sample size (n)	585		595	
Sample size (T; max)	65		65	
F test (p value)	22.89	(0.0000)	23.36	(0.0000)

Dependent variable: ln(*water consumption*)
[a] Time-invariant variables contained in the original dataset are omitted as they cannot be estimated by the fixed-effects model
* Significant ($p < 0.05$)
** Strongly significant ($p < 0.01$)

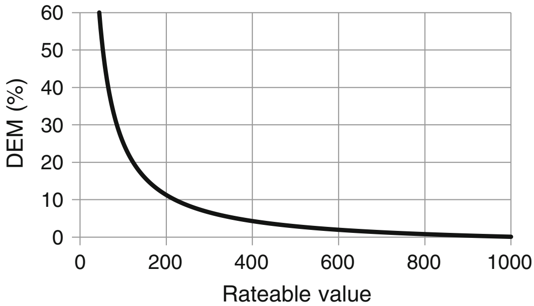


Fig. 2 Empirical relationship between the rateable value and the demand effect of metering

zero as RV increases. This might chiefly be attributed to different MRS for water across households, which suggests wealthier households would have less incentive to save water relative to poorer ones.

In comparison to Model 4.1 discussed above, Model 4.2 excludes the interaction term (*meter*)/(*RV*) (Table 4). In the latter, the coefficient *meter* is negative and strongly significant (Table 4). Hence we conclude that the sample households would have 13.2 % of DEM on average. Nevertheless, Model 4.2 has less explanatory power than Model 4.1, as indicated by the model R^2 (Table 4). In addition, Model 4.2 does not imply the inverse relationship depicted in Fig. 2. These observations suggest that Model 4.1 represents the preferred specification.

3 Socially-Efficient Water Tariff

We have found that wealthier households (with higher RV) are more likely to opt for metering, yet they would exhibit smaller DEM once a meter is installed. This suggests socially inefficient outcome, because social benefits in terms of water savings would be small relative to the cost of installing meters. The underlying cause of this "adverse selection" problem would be the current "flat" metered tariff scheme: households pay the same volumetric (per-volume) price and standing fee for water irrespective to their DEM or latent propensity to switch to metering. This implies that we might achieve socially more efficient outcome by, for instance, levying progressively heavier tariffs on wealthier households by differentiating the standing charge across households. Thus, we empirically seek a two-part tariff scheme following a theoretical work of Cowan (2010).

3.1 Theoretical Model

This section derives a condition to achieve socially efficient outcomes when a water company knows households' types regarding water consumption, in the spirit of Cowan (2010). To begin with, the objective of a water company, being a public body, is to maximize social welfare. Therefore, for every meter installed, they aim to attain larger social welfare relative to that before installation. Hence we should have:

$$u(x^m(t), t) - wx^m(t) - m \geq u(x^f(t), t) - wx^f(t) \tag{10}$$

where $x^m(t)$ and $x^f(t)$ are water consumptions of the metered and the non-metered, respectively, which depend on household's type t(that is attributable to the RV in our context); $u(.)$ is household's utility derived from water consumption, which depends on t; w is marginal cost of producing tap water; m is marginal cost of meter installation.

The left-hand side of inequality (10) expresses social welfare after meter installation, whilst the right-hand side that before installation. It could be modified as:

$$u(x^m(t), t) - u(x^f(t), t) + w\,[DEM(t)] \geq m \tag{11}$$

where $DEM(t)$ is the demand effect of metering (=$x^f(t) - x^m(t)$), which depends on t.

The left-hand side of inequality (11) expresses the social benefit of metering (with the third term indicating avoided production costs through water saving), whilst the right-hand side the social cost of metering.

On the other hand, the objective of a household is to maximize utility. Hence the condition for the household to choose to switch to metering is:

$$u(x^m(t), t) - T^m(x^m(t), t) \geq u(x^f(t), t) - T^f(t) \tag{12}$$

where $T^m(.)$ and $T^f(.)$ are annual water tariffs (i.e. a total (lump-sum) bill payable by a household over 1 year) levied on the metered and the non-metered, respectively, which depend on t.

The household's decision to switch to metering achieves social efficiency if both inequalities (11) and (12) hold together. A sufficient condition to achieve this is:

$$T^{m*}(x^m(t), t) - T^f(t) = m - w[DEM(t)]$$
$$or \quad T^{m*}(x^m(t), t) = T^f(t) + m - w[DEM(t)] \tag{13}$$

We call $\boldsymbol{T^{m*}}$ the "first-best" metered tariff. Equation (13) roughly implies that the larger the DEM of a household, or the smaller the non-metered tariff T^f, the lower the metered tariff for that household should be, since it incentivizes them to switch to metering, thereby attaining a socially more efficient outcome. The equation also implies that T^{m*} gives the water company a financially neutral position with respect to metering costs (m) and benefits ($w[DEM]$). In other words, T^{m*} should be higher than T^f if the metering costs exceeds the benefits (avoided production costs), so that the water company can recover any financial loss from meter installation.

3.2 Empirical Model

3.2.1 Modelling Framework

We now proceed to develop an empirical model for the above theory, to find a desirable metered tariff scheme. First, we assume that the household's type is represented by their RV. This assumption is deemed simplistic, because households' water consumption and metering decision could be influenced by a number of other factors. However, we should be mindful that we ought to select a household characteristic that is actually accessible to water companies in order to satisfy the "complete information" assumption of the theory. Hence RV is a suitable choice, since water companies indeed have such information when households are non-metered, and our main concern here is social welfare from the perspective of households' wealth.

Next, we empirically express Eq. (13) in terms of RV, using the results from the econometric analyses in Sect. 2. There are six stages to this. Firstly, we obtain a relationship between non-metered water consumption x^f and RV.[16] We propose a quadratic function[17]:

$$x^f = \beta_0 + \beta_1(RV) + \beta_2(RV)^2 \tag{14}$$

Using the same cross-sectional dataset as in Sect. 2.2.1, we conduct the OLS estimation on the non-metered households only, and obtain an estimate for Eq. (14) (in litres per household per annum):

$$\hat{x}^f = 49861 + 290.4\ RV - 0.1757\ RV^2 \tag{15}$$
$$se = (8065.32) \quad (66.56) \quad (0.1277) \quad R^2 = 0.0557$$

[16] It should be noted, however, this argument is somewhat inconsistent to our earlier discussion in Sect. 2.1.2, where we assumed that the water consumption of non-metered households, c, would be independent of RV or income level, once we control for household occupancy etc. By contrast, we now treat the RV rather loosely as a surrogate indicator representing household "type", that is, household wealth in general including income, occupancy and water-using appliances in possession, since we do not control here for any household characteristics. In other words, we prioritize the practicality of using the RV as discussed in the preceding paragraph, over the consistency of the argument.

[17] This is because we detected a concave relationship between the two parameters from the Lowess smoother, which provided locally weighted scatter-plot smoothing (Ueda 2010).

Second, we have earlier estimated a relationship between RV and DEM:

$$D\hat{E}M = -0.02689 + \frac{27.94}{RV} \qquad \text{[from Eq. (9)]} \tag{16}$$

The corresponding volumetric effect of metering is:

$$\begin{aligned} \Delta\hat{x} &= \hat{x}^f \times D\hat{E}M \\ &= 6772 - 12.72\ RV + 0.004726\ RV^2 + \frac{1{,}393{,}105}{RV} \end{aligned} \tag{17}$$

Metered water consumption x^m can then be predicted as:

$$\begin{aligned} \hat{x}^m &= \hat{x}^f - \Delta\hat{x} \\ &= 43089 + 303.1\ RV - 0.1804\ RV^2 - \frac{1{,}393{,}105}{RV} \end{aligned} \tag{18}$$

Third, current water tariffs levied by Anglian Water (as of July 2010) are (in pounds per household per annum):

$$\text{(Metered)} \qquad T^m = 67 + 0.0026943\ x^m \tag{19}$$

$$\text{(Non-metered)} \qquad T^f = 310.64 + 0.6998\ RV \tag{20}$$

where the constant terms indicate standing charges that are levied irrespective of water use or RV.

Fourth, we assume a constant returns-to-scale cost function for water:

$$TC = FC + wx \tag{21}$$

where *TC* and *FC* are total and fixed costs for producing water, respectively; and w (the marginal cost of producing water) is assumed to be constant.

In this case, average variable cost is equivalent to marginal cost. The total "operating cost" (assumed here to equal the total variable cost) of the water company in 2008–2009 was £591.8 million/year (Anglian Water 2009a) whilst supplying 438 billion L/year of water (Anglian Water 2009b). Hence, marginal cost of water production is roughly estimated as:

$$\begin{aligned} w &= 591.8(\text{million £/year})/438(\text{billion L/year}) \\ &= 0.001351 \quad (\text{£/L}) \end{aligned} \tag{22}$$

Fifth, the average incremental cost of installing and maintaining a water meter has been estimated at 0.001456 (£/L).[18] (Environment Agency 2008b). Hence we have:

$$m = 0.001456\ x^m \quad (\text{£ per household per annum}) \tag{23}$$

Finally, by combining Eqs. (17), (20), (22) and (23), we have an empirical model for the "first-best" metered tariff (Eq. 13):

$$\begin{aligned} \hat{T}^{m*} &= T^f + m - w\Delta\hat{x} \\ &= 376.0 + 1.158\ RV - 0.0002691\ RV^2 - \frac{3910}{RV} \end{aligned} \tag{24}$$

This in turn can be divided into "variable" and "standing" (lump-sum) parts to form a two-part tariff. For the variable part, we set a volumetric price of water equal to the marginal cost

[18] This includes: initial cost of a meter, survey cost, customer contact cost, billing cost, and meter reading cost (see Appendix 7 of Environment Agency (2008b)). Those costs appear to be amortized across the "asset life of a meter of 15 years or of a meter box of 30 years", at "a discount rate of 5.5 %".

of producing water and installing/maintaining a meter (i.e.0.001351 + 0.001456 = 0.002807 (£/L), due to Eqs. 22 and 23), in order to attain economic efficiency. [Note that this price is slightly higher than the current metered price at 0.002694 (£/L) (Eq. 19)]. Thus, the water company is expected, on average, to collect a variable part of the tariff, T^{mv*}, as:

$$\hat{T}^{mv*} = 0.002807\ \hat{x}^m$$
$$= 121.0 + 0.8508\ RV - 0.0005064\ RV^2 - \frac{3910}{RV} \tag{25}$$

It is therefore socially efficient to set the standing part of the tariff, T^{ms*}, equal to the difference between the first-best tariff (Eq. 24) and its variable part (Eq. 25). Hence we have:

$$\hat{T}^{ms*} = \hat{T}^{m*} - \hat{T}^{mv*}$$
$$= 255.0 + 0.3072\ RV + 0.0002373\ RV^2 \tag{26}$$

3.2.2 Estimated Results

Figure 3 shows predicted water consumption for the non-metered before and after switching to metering (due to Eqs. 15 and 18, respectively), against the RV. The gap between them indicates that the DEM is predicted to be larger for small-RV households than large-RV ones. Notice, however, that the dots indicating actual water consumption for the non-metered are understandably dispersed due to the noise associated with unexplained factors. In addition, the 95 % confidence interval for the regression on non-metered water consumption (Eq. 15) is particularly wide at the high-RV range, which is attributable to the fewer number of such households in our sample.

The first line of Fig. 4 shows the current non-metered tariff T^f that the households are actually paying (Eq. 20), and the second line the metered tariff T^m that they will have to pay

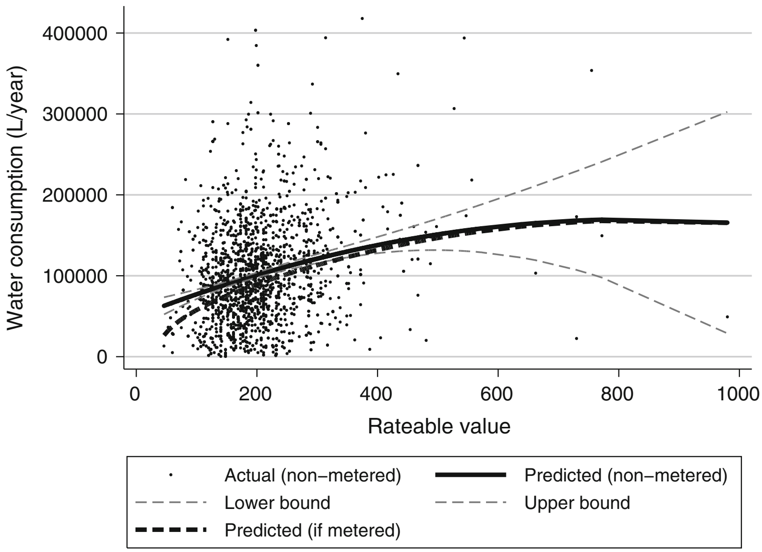


Fig. 3 Predicted and actual water consumption for non-metered households. Note: The *grey dashed lines* indicate lower and upper bounds of a 95 % confidence interval for the regression on non-metered water consumption (Eq. 15 in text)

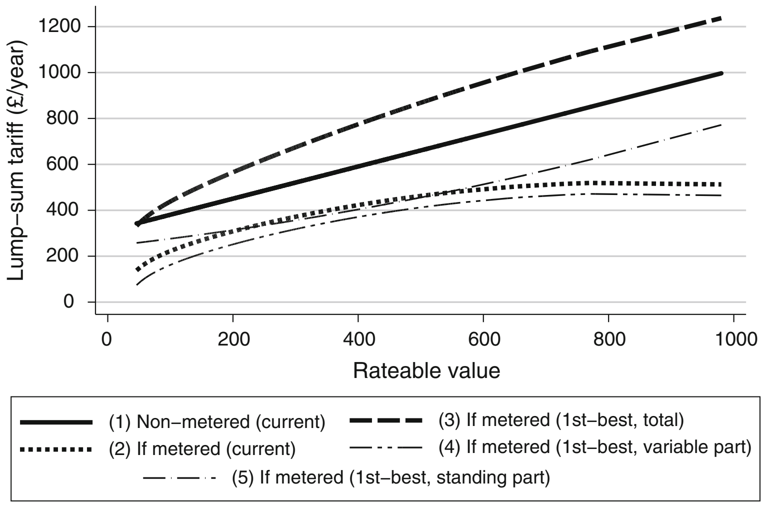


Fig. 4 Estimated water tariffs against the rateable value for "typical" households (based on predicted water demands)

(after switching) under the current metered charge (Eq. 19), if they would consume water according to the prediction $\hat{x}^m$ (Eq. 18). It is suggested that, under the current tariff scheme, "typical" households, which consume the predicted amounts of water, could enjoy tariff savings upon switching over the entire RV range. The third line then shows the "first-best" tariff T^{m*} (Eq. 24) that is expected to bring a socially efficient outcome. It shows that T^f and T^{m*} are virtually the same at the low end of RV, but the gap between them widens as the RV increases. This implies that the water company should impose higher tariff increases when high-RV households switch to metering, because they would not generate sufficient benefits (in terms of DEM) for the water company to fully offset metering costs.

The first-best tariff is then divided into the variable part (Eq. 25; the fourth line of Fig. 4) and the standing part (Eq. 26; the fifth line). The variable part is roughly parallel with the current metered tariff that includes the standing charge (line 2). Meanwhile the new, progressive standing charge (line 5) effectively fills the gap between the first-best tariff (line 3) and its variable part (line 4) by levying progressively higher fees on high-RV households. Since line 5 is close to linearity, the proposed standing charge (Eq. 26) may well be approximated with a linear equation to enhance practicality.

3.3 Aggregate Effects of the Socially-Efficient Water Tariff

We have so far concentrated on constructing the socially-efficient (first-best) tariff model, on the basis of predicted water demands of "typical" households (Eq. 15). Now that the model is formulated, we turn back to the original water consumption data, and use them to simulate the effect of tariff-scheme change on household water demands, their revenues and metering decisions, as well as tariff revenues of the water company. Our objective is to evaluate social (aggregate) benefits and costs of water metering through simplified simulations. Throughout Sect. 3.3, we confine our analysis to water consumption data of non-metered households (1,873 in total) extracted from the cross-section dataset used in Sect. 2.2.1. This means we assume a hypothetical baseline condition where every household is not metered yet, and investigate estimated changes from the baseline when various optional metering schemes are introduced.

3.3.1 Analytical Framework

We begin by calculating estimated (if-metered) water consumption of each non-metered households ($\tilde{x}^m$), on the basis of actual water consumption of non-metered households (x^f):

$$\tilde{x}^m = x^f - \Delta\tilde{x} \tag{27}$$

where $\Delta\tilde{x} = x^f \times D\hat{E}M$

Note that this is a slight modification of Eqs. (17) and (18), where $\hat{x}^f$ predicted by a quadratic function (Eq. 15) was used instead. We then substitute Eq. (27) into Eqs. (19) and (25) to get metered tariffs (current, Eq. 28; the first-best, Eq. 29) that each household is likely to pay:

$$\tilde{T}^m = 67 + 0.0026943\ \tilde{x}^m \tag{28}$$

$$\tilde{T}^{m^*} = \tilde{T}^{mv^*} + \hat{T}^{ms^*} \tag{29}$$

where

$$\tilde{T}^{mv^*} = 0.002807\ \tilde{x}^m \tag{30}$$

$$\hat{T}^{ms^*} = 255.0 + 0.3072\ RV + 0.0002373\ RV^2 \tag{26}$$

We then make a simplified assumption that a household would opt for metering if they could expect a tariff saving upon switching to metering, that is:

$$\text{if} \quad T^f > \tilde{T}^m \qquad \text{in case of current tariff} \tag{31}$$

$$\text{if} \quad T^f > \tilde{T}^{m^*} \qquad \text{in case of the first-best tariff} \tag{32}$$

Next we aggregate the social benefit of metering (*BOM*) and the cost of meter installation and maintenance ($\tilde{m}$) only across households who opt for switching, according to the above criteria.

where:

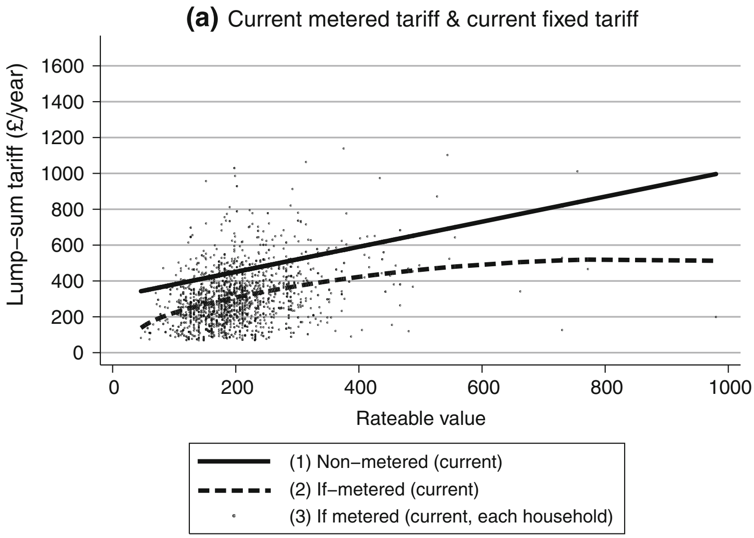
$$BOM = w\ \Delta\tilde{x} \tag{33}$$

$$\tilde{m} = 0.001456\ \tilde{x}^m \tag{34}$$

Finally we estimate a total tariff revenue expected by the water company under a new tariff scheme, by aggregating fixed tariffs (T^f) across all opt-out households, and metered (current $\tilde{T}^m$ or the first-best $\tilde{T}^{m^*}$) tariffs across all opt-in households, according to the switching criteria (Eqs. 31 and 32).

3.3.2 Estimated Results

In Fig. 5, the dots represent the estimated "if-metered" tariffs for each household (Eqs. 28 or 29), whilst aggregated figures are shown in Scenarios 1 and 2 of Table 5. In addition, Table 5 crudely divides the households into two groups, i.e. the poor and the rich, by the median value of RV of their property (at 190).



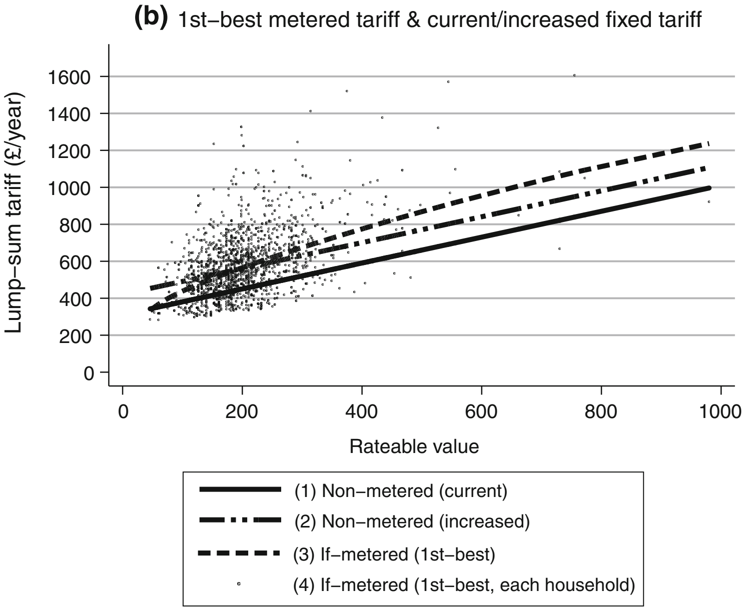


Fig. 5 Estimated water tariffs for "typical" and each household

Assuming the current metered tariff, the dots are mostly below the solid line 1 indicating the fixed tariff (Fig. 5a), which implies most (1612 out of 1873) households would get a tariff reduction upon switching to metering (Table 5), Lines 1 and 2, Scenario 1), who are thereby thought to opt for metering. By contrast, under the first-best tariff, the dots are generally shifted upwards and above the line 1 (Fig. 5b, and hence the number of households getting tariff reduction is reduced significantly to 419 households (Table 5, Scenario 2). This could be a problem in promoting metering further, which will be discussed in the next Sect. 3.3.3.

Table 5 Simulations on the effects of a tariff change on households and the water company

Scenarios (combination of tariffs)	1. T^f (fixed, current) & T^m (metered, current)			2. T^f (fixed, current) & T^{m*} (metered, 1st-best)			3. T^{fi} (fixed, increased) & T^{m*} (metered, 1st-best)		
Income (RV) status of households[a]	Total	Poor	Rich	Total	Poor	Rich	Total	Poor	Rich
Households' decisions									
1. Total no. of households	1,873	968	905	1,873	968	905	1,873	968	905
2. No. of households who switch[b]	1,612	855	757	419	239	180	974	565	409
3. % of households who switch	86.1	88.3	83.6	22.4	24.7	19.9	52.0	58.4	45.2
Benefits and costs of metering									
4. Social benefit of metering	22,638	14,653	7,986	2,080	1,443	637	9,376	6,588	2,788
5. Costs of meter installation & maintenance	168,237	76,932	91,304	14,273	7,012	7,261	65,566	34,781	30,785
6. Net benefit of metering (4–5)	−145,598	−62,280	−83,319	−12,193	−5,569	−6,624	−56,191	−28,193	−27,998
7. % of the net loss (6) attributed to		42.8	57.2		45.7	54.3		50.2	49.8
Tariff revenue for water company									
8. Revenue before tariff change[c]	845,654	401,894	443,760	845,654	401,894	443,760	845,654	401,894	443,760
9. Revenue after tariff change[d]	540,038	247,032	293,007	822,553	389,784	432,769	953,688	452,217	501,471
10. Net increase in tariff revenue (9–8)	−305,616	−154,862	−150,753	−23,101	−12,110	−10,991	108,034	50,323	57,711
Financial gain for water company									
11. Net financial gain for company (6 + 10)	−451,214	−217,142	−234,072	−35,294	−17,679	−17,615	51,843	22,130	29,713
12. % of the net loss/gain (11) attributed to		48.1	51.9		50.1	49.9		42.7	57.3

Unit: benefits and costs in pounds/year

Only households who are currently non-metered and paying fixed tariff are sampled and analysed

[a] Poor: households with RV $\leq$ 190 (median value); Rich: RV > 190

[b] Switching condition: Fixed tariff > Metered tariff

[c] Baseline tariff revenue where all households pay the current fixed tariff, T^f

[d] Tariff revenue where opt-in households pay metered tariff (current or 1st-best) whereas opt-out ones fixed tariff (current or increased)

We then calculate the net benefit of metering (Table 5, line 6), which is a difference between the social benefit of metering (Eq. 33) and the cost of meter installation and maintenance (Eq. 34). It is noticed that the aggregate net benefits are negative (that is, water metering is aggregately making a loss) in both Scenarios 1 and 2, which implies that metering costs are somehow subsidised by another budget, possibly by tariffs from non-metered households (Dresner and Ekins 2006). We will return to this issue later. Here we emphasise the fact that such a net loss is more heavily attributed to the rich than to the poor (Table 5, line 7). Nevertheless, the gap in percentage weights between the two groups is narrower in the first-best tariff scenario (54.3–45.7 = 8.6 %), than in the current tariff scenario (57.2–42.8 = 14.4 %). This might suggest that the first-best tariff is relatively successful in selectively discouraging the rich, or the "expensive" customers to switch, thereby mitigating a collective net loss incurred by the rich.

Meanwhile, introducing a new tariff scheme also affects tariff revenues for the water company (Table 5, line 10). By combining the net revenue changes with the net loss due to metering (line 6), we can estimate the net financial gain or loss for the water company (line 11), which represents the difference between the left- and right-hand sides of Eq. (13). As for the current tariff case (Scenario 1), the net loss is large, implying the water company is offering the metered tariff at discount rates. In the first-best tariff case (Scenario 2), the loss is smaller but still remains. This seems odd as the tariff was designed to be financially neutral for the water company (see end of Sect. 3.1). This could be because: whereas the first-best tariff model was constructed to be financially neutral *on average* across all non-metered households, in this simulation we allow each household to opt-out if they expect a tariff increase upon switching. Thus, the presence of such opt-out households would render the company's financial position slightly negative in Scenario 2.

3.3.3 Tension Between Social Efficiency and Metering Promotion

We have found that the first-best tariff could put the water company closer to the financially neutral position, but impose tariff increases on most households, rich and poor alike, thereby discouraging them to switch. This means there might be a tension between pursuing the social efficiency (i.e. financial neutrality for a water company) and promoting water metering further thereby attaining environmental goals (i.e. water savings).

Such negative consequences for households could be attributed to the design of the first-best tariff: the metered tariff would be increased automatically relative to the fixed tariff, if the net benefit of metering were negative (Eq. 13). One could then argue that the water metering project is not worthwhile to undertake in the first place, as we would only expect a negative outcome (Table 5, line 6) from the viewpoint of project appraisal (cost-benefit ratio) criteria. Nevertheless, we could make a counterargument in that: the social benefit of metering due to water saving (line 4) could be underestimated because we might fail to count external (environmental) costs of water abstraction (since the cost we used, w, is essentially a private cost of water production for the water company, see Eq. 22). Water abstraction is indeed approaching or possibly exceeds the environmental capacity in the East Anglia region (Environment Agency 2008a), which suggests an external cost of excessive water consumption through congestion effect. In addition, we might also fail to account external benefit of meter penetration, because area-wide penetration of water metering reportedly has an effect of enhancing better detections and management of supply pipe leakage (Environment Agency 2008b). Thus, if we counted such external costs and benefits, the net benefit of metering would possibly be positive.

The above arguments suggest that such external costs of expanding water abstraction or offering the non-metered option may well be borne by non-metered households, which are granted an unlimited access to water consumption at zero marginal cost. In this regard, a simple tariff design would be to increase a standing charge payable by non-metered households (i.e. shifting line 1 of Fig. 4 upwards). It will increase relative affordability of metered tariff, thereby motivating more households to switch. Nevertheless, we ought to remember that the prime objective of the first-best tariff is to encourage poorer households to switch whilst discourage richer ones, in order to address the adverse-selection issue.

Therefore, we choose to increase the standing charge of the fixed tariff so as to maintain revenue neutrality of a household with the median RV.[19] The median household, with the RV of 190,[20] is due to pay £443.60/year of the current fixed (non-metered) tariff (Eq. 20), or is expected to pay, on average, £554.01/year if switched to the first-best metered tariff (Eq. 24). Hence we design to increase the standing charge of fixed tariff by £110.41/year to maintain their revenue neutrality upon switching, on average.

The new "increased fixed tariff" (T^{fi}) is depicted in line 2 of Fig. 5. It crosses over the first-best tariff (line 3) at the median RV of 190. Furthermore aggregate consequences of the new tariff are shown in Scenario 3 of Table 5. As the first-best metered tariff is now made less expensive relative to the increased fixed tariff, more households (52 % of the total) would now opt for metering in comparison to Scenario 2 (Table 5, line 3). Although the new scheme would still result in a net social loss due to metering (line 6), the less portion of such loss would be attributed to the rich (49.8 %) relative to Scenarios 1 and 2 (line 7). This might again imply the effect of the first-best tariff in selectively discouraging the rich to adopt a meter.

Meanwhile, introducing the new fixed tariff (T^{fi}) naturally augments a tariff revenue base of the water company (Table 5, line 9) relative to the current fixed tariff (line 8), which results in a net increase in the revenue (line 10). As a result, the net financial position of the company now turns positive (line 11), which implies that the net loss of metering scheme is subsidised by tariff revenues from the non-metered households, particularly the rich group (line 12).

4 Conclusions

This study has empirically examined a socially-efficient ("first-best") metered tariff on the basis of: (1) econometric analysis of DEM, which suggests an inverse relationship between RV and DEM; and (2) a theory of welfare economics, which implies that a socially-efficient outcome can be achieved by making the tariff financially neutral with respect to metering costs and benefits. Then, we proposed to divide the first-best tariff to form a two-part tariff for metered households, which consists of: (1) a variable charge levied on households in proportion to their water consumption, at a uniform volumetric price equal to the marginal cost of water production and metering; and (2) a standing charge, designed in such a way as to place a progressively heavier burden on wealthier households with higher RV. The latter component has a potentially major role in the attainment of social efficiency of metering, by encouraging poorer households to install meters whilst discouraging wealthier ones. Since our conclusion is based on an empirical study on an optional metering scheme, it would be

[19] Although we admit such a tariff design is rather arbitrary, it will not affect the basic characteristics of the first-best metered tariff in mitigating the adverse-selection issue.

[20] Note that the dataset has several households with the RV of 190.

particularly relevant to water companies that offer water metering as an option and want to improve social efficiency of metering. Finally, we examine the implications of the first-best tariff on each household and the water company, and found that there could be a tension between pursuing social efficiency and further promotion of water metering. We therefore propose to increase the standing charge of fixed tariff just as much as encouraging the poorer households to switch, whilst discouraging the richer ones, and maintaining revenue neutrality of the median-RV household.

There remain, however, a number of issues that are not addressed by this study, and hence suggest directions of future studies. First, we did not explicitly deal with the "affordability of water tariffs for all", which is one of the important focal points in the relevant literature. Rather, we have concentrated in changing households' incentives to attain social efficiency, through modifying relative prices of metered and fixed tariffs. Thus, a question remains as to whether we should deal with the "affordability" issue through further modifications of tariff designs, or separately through some forms of income subsidies or tax credits.

Second, the proposed metered (first-best) tariff scheme (i.e. a combination of a uniform volumetric rate and progressive standing charges) may not be the only answer in mitigating the adverse-selection issue. We may as well propose an IBT scheme to discourage wasteful water consumption, for instance. But this scheme should carefully be designed so as not to harm households with a large number of inhabitants (Herrington 2007). Designing it properly will also necessitate assessing price (or inter-block) elasticity of water demands, which would be difficult at the moment as discussed below.

Third, we have not modelled the effect of price changes on DEM, since the available data does not allow this. The panel data set used in Sect. 2.2.2 covered a relatively short period of time, during which price changes would have been minimal, and insufficient to allow accurate estimation of a price elasticity. In any case, estimation of the DEM can be seen as a first stage towards an investigation of the price responsiveness of water consumption, and at the current stage of metering penetration, it is the aspect of price responsiveness that is of most interest in the water industry in the UK. Once metering penetration is complete, companies may well become more interested in the price elasticity. It should be added that there have been a large number of studies estimating the price elasticity of demand for water (see the survey by Dalhuisen et al. 2003). However, surprisingly, this is something that has never been done for the UK.

Fourth, designing the first-best tariff scheme solely on the basis of RV as a proxy for household wealth was rather unsatisfactory, because the situation was actually far from the ideal "complete information" condition in respect to water demands, as low R^2 of Eq. (15) suggested. Hence we should seek for better household indicators than the RV.

Finally, although we tried to mitigate a tension between pursuing social efficiency and promoting water metering, the final model of "increased fixed tariff" was rather arbitrary. This is partly because we failed to evaluate the external (environmental) costs of expanding water abstraction, and hence to estimate a true cost of additional water production. Thus, future studies will need to evaluate this by involving scientific and technological expertise as well.

Acknowledgments The authors are sincerely grateful to Christian Vossler, Simon Cowan, Ronald Griffin, and anonymous reviewers for their valuable and constructive comments, which have brought about significant improvements to the paper. We are also grateful to Willy Abu Judeh and Kevin Ling, who originally granted permission for the data used in the study to be used for the purposes of academic research.

Appendix: OLS analyses of water consumption

The objective of this Appendix is to challenge an assumption made in Sect. 2.1.2: the satiated water consumption of the non-metered households does not change in response to a *ceteris paribus* income change, i.e. $\partial c/\partial m$=0. We also test another assumption in Sect. 2.1.3, that is, water consumption of metered households, x_1^m, would be increasing in income, *ceteris paribus*: i.e. there is a positive income effect ($\partial x_1^m/\partial m$).

We employ the same single cross-section dataset as used in Sect. 2.2.1. Here we divide it into two subsets by the metering status of households (non-metered or metered). We then build a simple OLS model with (natural log of) annual water consumption as the dependent variable, and other variables described in Table 1 as explanatory variables. However, we exclude *RV* and *year-built*, because there would be no inherent reasons to believe that these two variables, which represent characteristics of the properties but not household individuals or water appliances, have direct effects on water consumption. Thus, we alternatively use *ACORN* variables as a proximate indicator for income.[21]

Specifically, we assume a model:

$$y_i = \gamma d_i + \beta' x_i + u_i \qquad i = 1, \ldots, n \tag{A1}$$
$$u_i \sim N(0, \sigma^2)$$

where: y_i is the natural logarithm of annual water consumption by a household i; d_i is the metering dummy; $\boldsymbol{x}_i$ is a vector of other explanatory variables describing household characteristics; γ is a parameter representing a proportionate effect of metering on consumption; $\boldsymbol{\beta}$ is a vector of parameters, the first of which is an intercept.

The results of the OLS estimation are reported in Table 6.[22] Model A1 estimates on the whole dataset, whilst Models A2 and A3 on the subsets comprising the non-metered and the metered, respectively.

Coefficients of Model A1 could briefly be interpreted as follows.

- The coefficient on *meter* implies that metered households would consume 42.9 % less water than non-metered ones on average, *ceteris paribus*. Nonetheless, we should not interpret this as the DEM, as there is an endogeneity problem in estimating it using the cross-section model (Kyle 2009).
- The positive sign of the *occupancy* coefficient together with the negative sign of the *occupancy-squared* coefficient imply a concave relationship between occupancy and the dependent variable. This may make sense because, as the occupancy increases, the members of a household tend to share some water-consuming facilities such as dishwashers and washing machines. Such sharing may reduce per-capita water consumption as occupancy increases, and hence result in the concave relationship observed.
- Dummy variables on household equipments (excluding *dual-flush toilet* and *sprinkler*) are all positive and significant at the 1 % level. This implies that their uses have strong positive effects on water consumption. In particular, a strong effect of *washing machine* (48.9 %) should be noticed. This could be expected because, when a household does not

[21] This is a diversion from the main text, which rely on RV for a proximate indicator for income. Although we indeed observed the apparent effect of RV on water consumption in Sect. 3.2 (Eq. 15), we regard it as an indirect effect through income etc.

[22] On the basis of the Breusch-Pagan test statistic (Table 6), we reject H_0 at the 1 % level and hence conclude there is strong evidence of heteroscedasticity, whose presence implies that OLS standard errors are invalid. Therefore, we alternatively use heteroscedasticity-robust (White-corrected) standard errors, which have been reported in Table 6.

Table 6 Estimated log-linear OLS models for water consumption

Variables	Model A1		Model A2 (non-metered only)		Model A3 (metered only)	
	Coefficients	SE[a]	Coefficients	SE[a]	Coefficients	SE[a]
Constant	9.568	0.1108**	9.639	0.1416**	8.894	0.1795**
Meter	−0.4293	0.03805**	–	–	–	–
Occupancy	0.4516	0.04384**	0.4653	0.05044**	0.5673	0.1279**
Occupancy-squared	−0.03869	0.006079**	−0.03861	0.006620**	−0.06999	0.02500**
Washing machine	0.4893	0.09186**	0.4380	0.1182**	0.4994	0.1389**
Dishwasher	0.1148	0.03652**	0.1261	0.04268**	0.06876	0.07045
Dual-flush toilet	0.03055	0.04235	0.01961	0.04592	0.04058	0.09433
Power shower	0.1216	0.03656**	0.08355	0.04260*	0.2097	0.06768**
Wash vehicle	0.1104	0.04114**	0.09111	0.04592*	0.1901	0.08964*
Hose	0.1566	0.03598**	0.1619	0.04341**	0.1618	0.06156**
Sprinkler	0.07190	0.05589	0.01275	0.05907	0.1656	0.1098
Water softener	0.3019	0.09674**	0.3830	0.1170**	0.1755	0.1588
ACORN A	0.2255	0.05824**	0.1232	0.06797	0.4202	0.1131**
ACORN B	0.08259	0.05696	0.08229	0.06426	0.08099	0.1194
ACORN C	0.08008	0.06403	0.04760	0.07330	0.1652	0.1262
ACORN D	0.1059	0.05512	0.01652	0.06551	0.3183	0.1045**
ACORN E (base)	–	–	–	–	–	–
Sample size	2,776		1,873		903	
R^2	0.2789		0.1928		0.2065	
Breusch-Pagan test	101.52	($df = 15$; $p = 0.0000$)	101.77	($df = 14$; $p = 0.0000$)	46.13	($df = 14$; $p = 0.0000$)

Dependent variable: ln(*water consumption*)
[a] Heteroscadasticity-robust standard errors are shown
* Significant ($p < 0.05$)
** Strongly significant ($p < 0.01$)

possess a washing machine, they may tend to get laundry services outside home. On the other hand, a positive and insignificant coefficient on *dual-flush toilet* is disappointing, because it is intended to *save* water consumption in flushing toilet.

– The *ACORN* variables (excluding *ACORN A*) are individually insignificant. Nonetheless, the F test[23] implies that *ACORN* variables are jointly significant at the 5 % level. Hence we choose to maintain them in the independent variable.

Model A2 is designed to test the "$\partial c/\partial m$=0" hypothesis. Here we assume that: *ACORN* variables act as proxy indicators for household incomes; and water consumptions of non-metered households equal the satiation point. By accepting these, then, the hypothesis can be interpreted as: *ACORN* variables are jointly *in*significant in determining water consumptions of non-metered households, given occupancy and appliance dummies are included in the explanatory variables.

[23] We conduct a F test on Model A1 as the unrestricted model:
H_0: $\beta_{ACORN\ A} = \beta_{ACORN\ B} = \beta_{ACORN\ C} = \beta_{ACORN\ D} = 0$
Number of restrictions = 4 Degree of freedom = 2,760 $R^2_R = 0.2741$ $R^2_U = 0.2789$.
Hence $F = 4.5930 > 2.37 = F_{0.05,4,\infty}$. Hence we reject H_0 at the 5 % level.

Thus, after picking only non-metered households from the whole sample, we conduct the F-test on the same model as equation A1 (but with *meter* excluded due to multicollinearity):

$$H_0\text{: } \beta_{ACORN\ A} = \beta_{ACORN\ B} = \beta_{ACORN\ C} = \beta_{ACORN\ D} = 0$$
$$\text{Number of restrictions} = 4 \quad \text{df} = 1858 \quad R_R^2 = 0.1904 \quad R_U^2 = 0.1928.$$
$$\text{F} = 1.3811 < 2.37 = \text{F}_{0.05,4,\infty}\text{. Hence we } \textit{fail to} \text{ reject } H_0 \text{ at the } 5\,\% \text{ level.}$$

Hence we conclude that *ACORN* variables are jointly *in*significant in determining water consumption of non-metered households. In addition, it is shown that all the *ACORN* variables are individually *in*significant at the 5 % level when only non-metered households are estimated (Model A2, Table 6). All these results would suggest that water consumptions of non-metered households (and hence their satiation points) would be independent of income levels, *ceteris paribus*.

Finally, Model A3, where only metered households are estimated, is designed to test the “positive income effect” hypothesis. Here the coefficients on *ACORN* dummies indicate the percentage-point difference in water consumption between *ACORN A* (or *B*, *C*, *D*) and *ACORN E* (base), which is the least well-off group. Therefore, if the above hypothesis is true, these coefficients should be significantly positive (because the well-offs should have higher water consumption relative to the worse-offs when meter-charged). Model A3 in Table 6 indicates that the coefficients on *ACORN A* and *D* are indeed significantly positive at the 1 % level, and the magnitudes of these coefficients are larger than those of Models A1 or A2. F-test[24] also gives evidence that the *ACORN* variables are jointly significant at the 5 % level in determining water consumption of metered households.

In summary, these results on Models A2 and A3 together suggest that the assumptions we made in Sect. 2.1 (i.e. constant $x_1^f(c)$ and increasing x_1^m with respect to income, *ceteris paribus*) would be plausible, although the evidence is not decisive (as the variables *ACORN B* and *C* remain insignificant in Model A3).

References

Anglian Water (2009a) Annual report and accounts 2009

Anglian Water (2009b) Community and environmental report 2009

Anglian Water (2011) Tariffs and charges. http://www.anglianwater.co.uk/household/your-account/tariffs/ Cited 1 May 2011

Arbués F, García-Valiña MA, Martínez-Espiñeira R (2003) Estimation of residential water demand: a state-of-the-art review. J Soc Econ 32: 81–102. doi:10.1016/S1053-5357(03)00005-2

Cowan S (2010) The welfare economics of optional water metering. Econ J 120: 800–815. doi:10.1111/j.1468-0297.2009.02307.x

Dalhuisen JM, Florax R, Groot Hde , Nijkamp P (2003) Price and income elasticities of residential water demand: a meta-analysis. Land Econ 79: 292–308. doi:10.3368/le.79.2.292

Dresner S, Ekins P (2006) Design of environmentally and socially conscious water metering tariffs for the UK. J Environ Plan Manag 49(6): 909–928. doi:10.1080/09640560600947048

Environment Agency (2008a) Water resources in England and Wales—current state and future pressures. Environment Agency, Bristol, UK. http://publications.environment-agency.gov.uk/PDF/GEHO1208BPAS-E-E.pdf. Cited 1 Aug 2012

[24] We conduct the *F* test for metered households only:
$\text{H}_0\text{: } \beta_{ACORN\ A} = \beta_{ACORN\ B} = \beta_{ACORN\ C} = \beta_{ACORN\ D} = 0$
Number of restrictions = 4 df = 888 $\text{R}_R^2 = 0.1843$ $\text{R}_U^2 = 0.2065$.
Hence $\text{F} = 6.2110 > 2.37 = \text{F}_{0.05,4,\infty}$. Hence we reject H_0 at the 5 % level.

Environment Agency (2008b) The costs and benefits of moving to full water metering. Science Report SC070016/SR1 (WP2). Environment Agency, Bristol, UK. http://www.swanforum.com/uploads/5/7/4/3/5743901/_env_agency.pdf. Cited 1 Aug 2012
Environment Agency (2010) Underground, under threat—the state of groundwater in England and Wales. Environment Agency, Bristol, UK. http://publications.environment-agency.gov.uk/PDF/GEHO0906BLDB-E-E.pdf. Cited 1 Aug 2012
Herrington P (2007) Waste not, want not? Water tariffs for sustainability. A report to WWF-UK, centre for sustainable energy. The CREATE Centre, UK
Kennickell A, Kwast M (1997) Who uses electronic banking? Results from the 1995 survey of consumer finances. Board of governors of the federal reserve system, finance and economics discussion paper series: 1997/35
Kyle J (2009) Economic and econometric analysis of the demand effect of water metering. Unpublished MPhil thesis, University of East Anglia
Manski CF, Lerman SR (1977) The estimation of choice probabilities from choice-based samples. Econometrica 45: 1977–1988
OECD (2010) Pricing water resources and water and sanitation services. OECD studies on water, OECD Publishing, Paris. doi:10.1787/9789264083608-en
Office of National Statistics (2011) Regional profile: east of England. http://www.statistics.gov.uk. Cited 1 September 2011
OFWAT (2010) Delivering sustainable water—of what's strategy. http://www.ofwat.gov.uk/aboutofwat/reports/. Cited 1 September 2011
StataCorp (2009) Stata statistical software: release 11. StataCorp LP, College Station
Ueda T (2010) Demand effects and social welfare of water metering in East Anglia. Unpublished MSc thesis, University of East Anglia