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The effects of the universal metering programme on water consumption, welfare and equity

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Abstract

There is consensus that meters are necessary for the promotion of efficient water usage. However, available evidence on the benefits and costs of metering is scant, and often based on small samples. We use data from the first large-scale compulsory metering programme in England to study its impact on consumption, social efficiency and distributional outcomes. We find a decrease in consumption of 22% following meter installation, a considerably higher value than assumed as a policy target. This result implies that, overall, the benefits of metering outweigh its costs. We also document a large heterogeneity in reaction, with many households showing low sensitivity to the new tariff. This novel finding suggests that selective metering, where only more price-sensitive households receive meters, would deliver even higher social welfare. Looking at distributional effects, we find similar reduction in consumption across income groups, although only high-income households gain financially from the new tariff.

JEL classifications: Q25, D12, H42.

1. Introduction

There is widespread consensus regarding the necessity of promoting efficient use of water, but how water utilities should be regulated, and how water metering and tariffs should be designed to achieve this end, remain subject to debate. For example, in 2013 Irish Water, the national water utility in Ireland, began an ambitious programme to install around 1.4 million meters over the following 4 years but, following strong opposition by residents in the affected areas, the programme was dropped in early 2016 when around 900 thousand meters had already been installed. (Expert Commission on Domestic Public Water, 2016; Joint Committee on the Future Funding of Domestic Water Services, 2017). Water charges were also scrapped and the Irish Parliament passed a law to fund water services through general taxation in November 2017. This example attests to the tension between having tariff schemes that, on the one hand, encourage households to save water, and give the necessary resources to companies to ameliorate infrastructure and water quality, and, on the other hand, ensuring that water remains affordable for all households.

Indeed, the fear that metering could result in adverse financial consequences for poor households has been the main obstacle to the introduction of universal metering in the UK, where only around 30% of households had a meter in 2008, according to figures published by the Environment Agency (2008). However, this concern has been mitigated by the increasing awareness that managing water demand through some form of price mechanism is unavoidable, given that environmental constraints, including climate change, limit the scope for increasing the water supply in the future. For this reason, several water utilities have started to implement a universal metering programme in their supply regions. In 2010, the first steps were taken by Southern Water, who began the installation of more than 400,000 meters in the south-east of England—an area classified by the government as under water stress. At the time of completion of this programme in March 2015, 87% of household properties in the region were metered, compared to about 40% at the beginning of the programme. A similar programme was initiated in 2014 by Thames Water, the largest water utility in England, serving more than 15 million people, with the aim of having all households metered in the firm's supply region by 2030.

Whereas metering and marginal cost pricing can eliminate the deadweight cost of overconsumption, installing and operating a meter is costly. Accordingly, as noted by Cowan (2010), 'metering is socially valuable if and only if the benefit from reducing overconsumption exceeds the cost of metering'. Results on the reduction in water usage that metering brings about are mixed. For instance, the National Metering Trials that took place at 11 different sites in England between the late 1980s and early 1990s found a reduction in demand of around 12%, a percentage considerably lower than the 21% reduction that was estimated using data from the complete metering of the Isle of Wight around the same period (National Metering Trial Working Group, 1993; Herrington, 2007). However, all existing studies have been based on rather small samples of households, and there is no evidence on large-scale universal metering programmes, as the UMP programme by Southern Water is the first of this type. Moreover, none of these studies has produced a detailed analysis of the efficiency and distributional effects of universal metering.

Using data for more than 150,000 customers under Southern Water's Universal Metering Programme (UMP), this paper produces a number of new results on the effects of metering on consumption, social welfare and equity. First, we find that, on average, metering reduces water usage by 22%; this figure is substantially higher than the 12.5% that has often been used as a target reduction for metering (Herrington, 2007). Thus, the evidence we provide—the first based on a large programme—shows that a fundamental parameter for the cost-benefit analysis of metering is substantially different from that generally assumed so far.

Second, we find substantial heterogeneity in the impact of metering on water consumption across households. In particular, we document that small households gain financially from metering, yet these households exhibit a lower reduction in the deadweight loss due to overconsumption once a meter is installed. By showing that households that have financial incentives to have a meter are not those whom it is socially efficient to meter, our analysis provides strong support for the arguments made by Cowan (2010) and Ueda and Moffatt (2013): that the optional metering programme of England and Wales is affected by a severe adverse selection problem.

Third, we assess the efficiency effects of the UMP by comparing the costs of installing and operating a meter to the benefits of reducing overconsumption. We find that, overall, the UMP has contributed to an increase in social welfare; however, our analysis shows that a large proportion of households should have not received a meter from a social welfare point of view, and that a selective metering programme, where only households more sensitive to prices are required to have a meter installed, would lead to higher social welfare.

Finally, we look at the distributional effect of the UMP by investigating whether there are significant differences in how metering affects the water consumption and bills of families with different levels of incomes. In contrast to the findings of Agthe and Billings (1987) and Wichman *et al.* (2016), we find that reduction in consumption is shared across income levels, rather than being concentrated in low-income households. As for the change in water bills, we find that high-income households gain financially on switching to metering, while low-income households are, on average, between £20 and £23 worse off on a yearly basis, which is equivalent to about 5% of their average yearly bill.

Most of the existing literature on water pricing focuses on the demand effects associated with incremental price changes and/or inter-block tariff change, while taking universal metering as a given.[1] The number of studies that have investigated the welfare effect of water metering is limited. In the case of optional water metering, the theoretical model by Cowan (2010) shows that a socially efficient outcome can be achieved when water companies know households' demand functions or, if households' type is not known, when small households are more sensitive to price. Conversely, optional metering is not socially efficient in the more plausible case where households' type are not known and only large households have a meter. The optional metering policies in the UK may be encouraging exactly the wrong households (i.e. those with low responsiveness to price) to opt for a meter. Empirical evidence on the existence of an adverse selection problem in the optional water metering is provided by Ueda and Moffatt (2013). Using data from a small water company operating in East Anglia, the authors find that wealthier households are more likely to opt for a meter, yet their demand shows a low responsiveness to the change in price.

Evidence on the distributional effects of water metering is equally scant. Economic analysis suggests that meters allow the introduction of tariff schemes (such as the Increasing Block Tariff, which offers the provision of a low-price block of water to cover essential usage) that can be effective in reducing overconsumption while addressing the problem of affordability (Herrington, 2007). However, the general public perception is that metering can only exacerbate the problem of water affordability for less affluent households. As noted by Zetland (2016), 'People are more interested in discussing how 18% of metered customers spent more than 3% of their income on water bills than the fact that 26% of unmetered customers face that problem'.[2]

1 For instance, Olmstead *et al.* (2007) find a price elasticity of demand of −0.33 in a sample of 1,082 households in the United States and Canada. Nataraj and Hanemann (2011) study the effects of the introduction of a third price block in California, and find that doubling the marginal price leads to a 12% decrease in consumption among high-usage households. Worthington and Hoffman (2008) provide an extended survey of empirical residential water demand analyses, while Dalhuisen *et al.* (2003) conduct a meta-analysis to investigate the relevant factors explaining variation in estimated price and income elasticities of residential water demand.

2 Arguments against water metering have been put forward on grounds other than equity—in particular, the fact that non-price instruments, such as voluntary or compulsory restrictions, or water-saving devices (e.g. low-flush toilets) can be equally effective in reducing consumption while being less costly than metering (Worthington and Hoffman, 2008).

This paper contributes to the filling in of existing gaps in the literature by providing a comprehensive analysis of the impact of the first large-scale metering programme in England on water consumption, social efficiency and distributional outcomes.

Besides England, metering is a major issue in the policy debate of several other areas. Cities such as Sacramento, California, have, for example, an ongoing metering programme due to end by 2020. As observed by the OECD (2010) in its survey of pricing structures across members' states, there is a decreasing number of countries using flat fees for water, albeit this system is still present in Canada, the Czech Republic and Sweden. Metering at the single household level for multi-family establishments (flats and apartments) is also an important issue in urban environments (Mayer *et al.* 2004), while the availability of increasingly smart meters in the water sector gives additional flexibility to water management. From a global perspective, understanding the impact of metering on water usage is particularly important, given that metering infrastructure is far from universal in low- and middle-income countries. In its overview of utility subsidies, the World Bank (2005), for instance, finds that '[o]f 50 water utilities reviewed for this study for which information on metering was available, about a quarter had meter coverage below 50%'.

The remainder of this paper is organized as follows. In Section 2, we present the theoretical framework used to interpret our empirical analysis. Section 3 explains the UMP and presents the data. In Section 4, we show the impact of metering on water consumption and we document its heterogeneous effects across households. In Section 5, we analyse the efficiency and distributional effect of the UMP. Section 6 concludes.

2. Theoretical framework

In this section, we study the decision problem faced by households in a two-good economy comprising water and a numeraire that corresponds to the disposable income after paying the water bill. We assume that households have additively separable utility in water consumption and income. Consumers' preferences are strictly convex until water consumption reaches the satiation level; beyond that level additional water consumption adds no utility. Following Cowan (2010), we indicate water demand as $Q(p, t)$, where p is the price of one litre of water and t is the household's type (i.e. a set of characteristics of the household such as number of family members, income and size of the property). Before the installation of a meter, the water tariff consists of a fixed amount F^U, based on the rateable value of the house, while the marginal price equals zero. Accordingly, households consume the satiation quantity $Q(0, t)$ and have a disposable income of (I-F^U), where I is the total income of the household. After meter installation, all households pay the same price p^M per unit of water and the same fixed amount F^M (which corresponds to the standing charge for water supply and sewage). Accordingly, they have a disposable income equal to $(I - p^M Q(p^M, t) - F^M)$. If the price of water was set equal to the marginal cost of production c, households would demand the socially efficient quantity $Q(c, t)$.

Figure 1, adapted from Ueda and Moffatt (2013), shows the choice of a household under the two regimes. The budget line under the unmetered tariff is B^U and under the metered tariff is B^M. The intercepts of B^U and B^M represent the disposable household income after deducting the fixed part of the unmetered tariff F^U and metered tariff F^M. The intercept of B^U is lower because $F^U > F^M$. Points X^U and X^M represent the bundles chosen by a household in the absence of a meter or with a meter, respectively. The utility under a meter tariff (i.e. U^M) is exactly equal to that in the absence of meter (i.e. U^U), and therefore

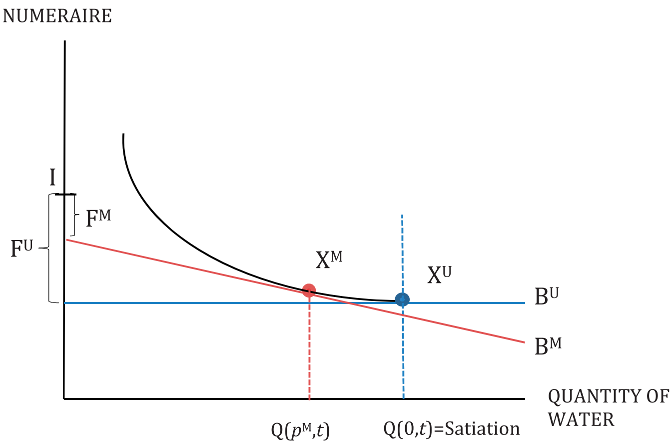

Fig. 1. Household choice

Notes: The vertical axis shows the amount that can be spent on goods other than water. 'I' is the initial total income.

this particular household is indifferent to the metered and unmetered options. The change in tariff entails a reduction (increase) in utility if a household moves on a lower (higher) indifference curve.

All households with a budget line B^M that crosses the budget line B^U to the right of X^U are certainly better off under the new tariff regime, since bundle X^U is within the budget set. On the other hand, if the budget line B^M crosses the budget line B^U to the left of X^U (as in Fig. 1), then a household can be better off at the new optimal level X^M only if its disposable income after paying the water bill is higher with a meter than without. This means that a small family is expected to be better off under the new tariff because, *ceteris paribus*, its point X^U is more likely to be on the left of the satiation point chosen by another household with more members, but similar in all other dimensions (and, in particular, resident in a property with the same rateable value). Similarly, households living in properties with a high rateable value are more likely to be better off than households that live in properties with a low rateable value (but otherwise similar) as the former experiences a higher shift in the intercept.

The existence of considerable heterogeneity in households' responses has an important welfare implication, given that the installation of a meter is socially desirable only when the gross benefits from water reduction are higher than the costs of metering. In particular, as shown in Equation (1), following the framework in Cowan (2010), we have:

$$\underbrace{\mathrm{U}\left(\mathrm{Q}\left(p^{\mathrm{M}},t\right)\right)-\mathrm{U}(\mathrm{Q}(0,t))}_{(a)}+\underbrace{\mathrm{c}\left[\mathrm{Q}(0,\,t)-\mathrm{Q}\left(p^{\mathrm{M}},t\right)\right]}_{(b)}\geq m \tag{1}$$

where m is the annualized cost of installing and operating a meter. The lefthand-side of Equation (1) shows the benefit of eliminating the deadweight loss from excess consumption. Specifically, the term (a) captures the decrease in consumer surplus when moving from the satiation level $\mathrm{Q}(0,t)$ to $\mathrm{Q}(p^{\mathrm{M}},t)$, while (b) refers to the related savings in costs. Figure 2 illustrates the benefit of metering in the case of a linear demand with water priced at marginal cost. Term (a) corresponds to the area below the black line between $\mathrm{Q}(p^{\mathrm{M}},\,t)$

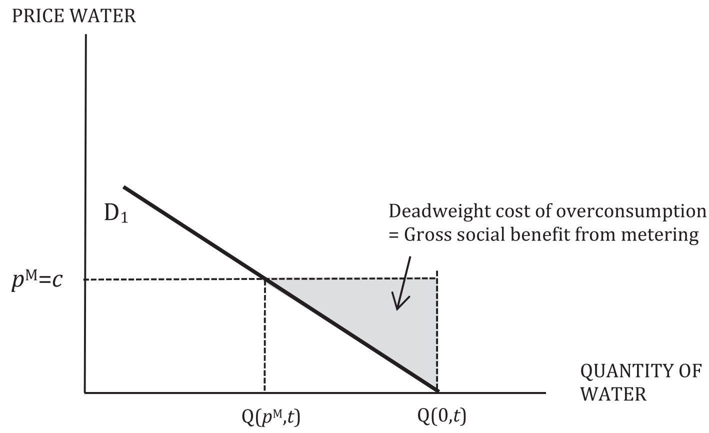

Fig. 2. Household demand.

and $Q(0, t)$, while (b) corresponds to the rectangle with base $Q(0, t)$ to $Q(p^M, t)$ and height c. The sum of the two terms corresponds to the shaded triangle.

Although the deadweight cost of overconsumption is easy to interpret theoretically, it is difficult to quantify empirically, as this would require knowing the marginal cost c of supplying the different households—a value that is not observed. In the welfare analysis of Section 5, we tackle this problem by using the observed market price as a proxy for c. We choose this approach as it provides an upper bound of the true benefits of metering and, therefore, a conservative evaluation of the number of households for which metering is not efficient from the social point of view. For instance, Fig. 3 shows that if water is priced above c, estimating the deadweight cost at the observed price p^M and quantity $Q(p^M, t)$ would lead to overestimation of the social benefit of metering by an amount equal to the shaded trapezoid.

Why is it reasonable to assume that the market price is an upper bound of the marginal cost? To answer this question, we start by noting that English and Welsh water tariffs are regulated through a price-cap regime implemented by the Water Service Regulation Authority (Ofwat) over a five-year regulatory period. The volume tariff corresponds to the (expected) *average costs* for water service that will be incurred by regional utilities to supply and treat water, and to maintain and improve the water supply and drainage system (e.g. replacement of pipes to reduce leakage and spillages from sewage into rivers) over the next regulatory period.[3] In 2017, the volume rate charged by Southern Water for water supply and sewage treatment was 3.322 £/m^3, or 0.003322 £/Litres.[4] As the average cost is typically above the marginal cost for public water supply and, more generally, for natural

3 Note that the price set by Ofwat also takes environmental aspects into consideration. The regulator evaluates different aspects of the water companies' business plans to calculate an efficient total expenditure allowance and, in turn, the price that the companies can charge to customers. One of the aspects assessed by the regulator is focused on making ecological improvements at abstraction.

4 In 2017, Southern Water charges for water and sewerage were, respectively, 1.248 £/m^3 and 2.242 £/m^3. Since volume charge for wastewater amounts to 92.5% of the water supplied, the price of water including sewerage is 3.322 £/m3 (=1.248 + 0.925*2.242).

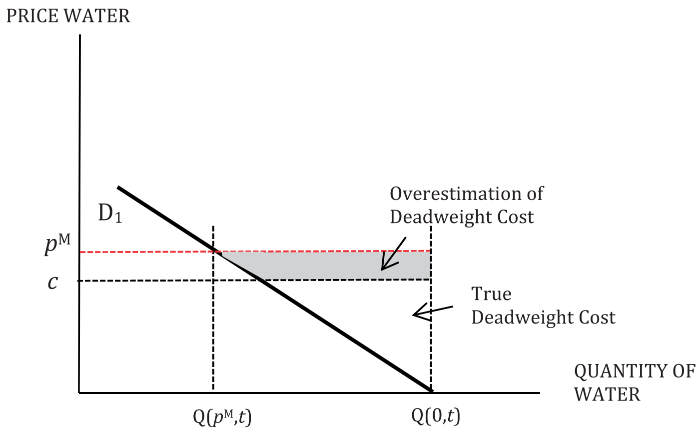

Fig. 3. Deadweight costs.

monopolies, this price is likely to represent an upper bound of the unobserved marginal costs. This view is also supported by the fact that estimates of c provided in the literature are generally well below 3.322 £/m^3, thus leaving room for some potentially unaccounted for environmental externalities.[5]

We conclude by noting that whereas marginal costs may be higher than average costs during peak demand, this is not true for most days of the year. Moreover, in the specific context of the UMP, results in Section 4 show that households with a lower reduction in consumption after meter installation are, unsurprisingly, also households with a low level of absolute consumption. This means that the households for whom metering may not be efficient from a social perspective (due to the small reduction in consumption) are unlikely to be responsible for peaks in demand (because their absolute consumption is also small).

3. Empirical framework

3.1 Institutional setting

The compulsory installation of water meters in all districts of south-east England served by Southern Water took place according to the timing shown in Fig. 4. The map shows that the UMP did not follow a clear pattern in terms of geographical location or district size. For instance, the metering started in late 2010 in Southampton (with a population of around 375,000),the largest urban area served by Southern Water, but installation in two other major urbanizations (Brighton: population 225,000; and Winchester: population 120,000), took place three years later, towards the end of the programme.

Around 40% of the households in south-east England had already had a meter installed when the UMP began. These households (henceforth defined as 'non-UMP') fell in the same geographical areas where the UMP was implemented and consisted of 'Households living in new dwellings' (given that all new properties built since 1990 have been fitted with water

5 According to the Tariff Review 2016 published by the Independent Competition and Regulatory Commission (2016) in Australia, 'all the marginal cost estimates calculated for the purposes of this paper, short- and long-run, are well below [. . .] current water price of $2.60 per kL', which corresponds to 1.4 £/m^3 using an exchange rate of 1.8 Australian $ per British £.

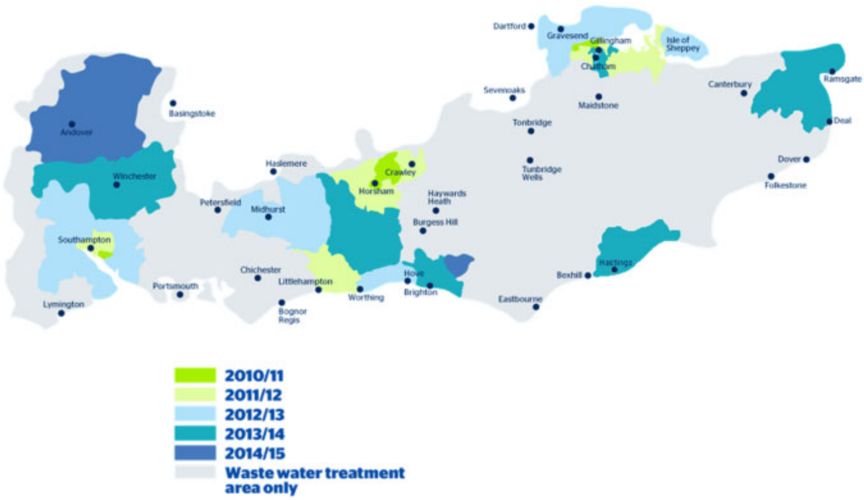

Fig. 4. Timing of installation.

meters) and 'Optants' (i.e. customers who chose to be metered before the compulsory installation—an option that was available at no cost).

The typical customer journey of UMP households starts with a meter installation, followed around three months after the installation by a switch of contract from the unmetered tariff to the metered tariff. In the period between meter installation and the switching of contract, water charges are still based on the previous contract and not on metered consumption. Three months after the switch of contract, customers receive a letter, known as the '3-months' (3 M) letter, showing the expected metered bill they will receive based on the observed consumption in the previous three months. This is the first information customers receive about their water usage since the switch of contract. Six months after the switch of contract (and three months after the 3 M letter), UMP customers receive their first bill. Subsequent bills are sent every six months (i.e. two bills per year). The top part of Fig. 5 shows the typical customer journey as has been described.

Both metered and unmetered tariffs comprise two parts. For the metered tariff, there is an annual standing charge, which covers the cost of maintaining the water services account, and a volume charge based on the amount of water consumed. The unmetered tariff does not depend on water usage and consists of a standing charge, fixed for all properties, and a rateable value (RV) charge, based on the rateable value of the house. Notice that the rateable value was an indicator of the rental value of the house as of 31 March 1990 and, as such, not necessarily in line with house prices in the period under consideration. As explained in Section 2, tariffs are regulated by Ofwat through a price cap regime that is reviewed every five years. Tariffs are set at a level that allows the companies to cover the costs of running the service, and to maintain and improve the water system. Table 1 shows the tariff charged by Southern Water to metered and unmetered customers from the period 2009/2010 to 2016/2017,[6] which corresponds to three different regulatory periods (2005–2010, 2010–2015 and 2015–2020). The different components of the tariff change at a rather similar rate over the time window of this study.

6 Tariffs go from 1 April to 31 of March of the following year.

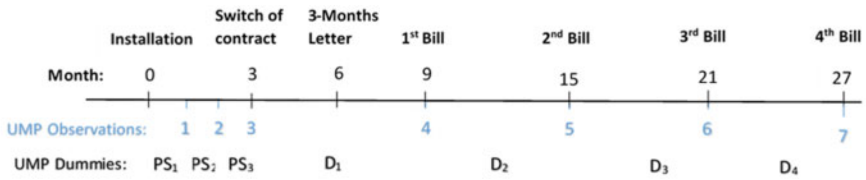

Fig. 5. Customer journey.

Table 1. Water tariff for metered and unmetered customers

Year	Unmetered				Metered			
	Water		Sewerage		Water		Sewerage	
	Annual standing charge	RV charge	Annual standing charge	RV charge	Annual standing charge	Volume charge (per m^3)	Annual standing charge	Volume charge (per m^3)
2009/10	29.54	0.533	56.28	1.117	26.37	0.923	47.17	1.698
2010/11	29.54	0.553	57.28	1.051	26.37	0.949	48.17	1.764
2011/12	31.95	0.598	60.82	1.116	26.37	1.040	49.17	1.877
2012/13	34.42	0.644	66.46	1.219	26.37	1.134	50.17	2.080
2013/14	35.97	0.673	70.88	1.300	26.44	1.169	54.70	2.198
2014/15	36.99	0.692	73.35	1.345	27.17	1.201	56.57	2.273
2015/16	21.00	0.710	56.00	1.343	25.26	1.233	60.20	2.270
2016/17	20.53	0.745	56.09	1.326	24.79	1.248	60.35	2.242

Source: 'Water and Sewerage Charges – A Guide for Household Customers'. Annual reports published by Southern Water over different years and available on the website of the company. The RV is applied per £ of rateable value. All the figures are in £.

The annual increase is typically below inflation, so that water bills decrease in real terms, keeping constant the amount of water consumed.

3.2 Data

The data used in the empirical analysis covers the period from January 2011 to October 2016 and refers to two groups of customer: UMP and non-UMP. We use the non-UMP data to control for the impact of weather and seasonality on consumption, and, more importantly, to test whether there is convergence in the water consumption of UMP and non-UMP customers after the former have a meter installed and, therefore, experience the same incentives.

The UMP sample consists of households that, in October 2016, had already received four bills and whose average daily consumption was below 2,000 litres per day.[7] Our dataset includes seven observations of average daily consumption for each household: three

7 Consumption above 2,000 litres per day is considerably in excess of what is reasonable for a household and suggests that these customers may not be private households but, rather, people that undertake business activities on their premises. The number of UMP households dropped because of this is very small, totalling 2,979 customers. We also note that our results are almost identical if we drop households with consumption above 1,500 litres per day.

observations for the pre-switch period, which typically spans over three months, and four observations after the switch of contract, corresponding to the first four metered bills. This means that each of the first three data points refers to the average daily consumption over one month, while the following four observations refer to the average daily consumption over the standard six-month billing cycle (see Fig. 5, for the correspondence between our observations and the customer journey). These seven observations come from two different sources. Average daily consumption for the post-switch period is retrieved from Southern Water billing data, while consumption during the pre-switch period, not relevant from a billing perspective, is obtained from Arad Group UK, which provides water meter services to Southern Water. Water consumption in the Arad dataset is observed with higher frequency, but raw data come in the form of a very unbalanced panel. Appendix A[8] gives further details on how we construct our balanced panel using the Arad readings and Southern Water billing data. The higher frequency for the pre-switch period provides us with a unique opportunity to investigate whether households had already changed their consumption behaviour in the period between meter installation and the switch of contract. Although customers were still subject to unmetered charges, they may have taken into account the fact that changing consumption patterns takes time and, therefore, they may have modified their consumption before the actual change in pricing.

Average daily water consumption for non-UMP customers is retrieved from Southern Water billing data only. Unlike the balanced UMP sample, the number of observations for the non-UMP sample varies across subjects. As mentioned, the non-UMP group consists of 'Households living in new dwellings' and 'Optants'. Optants are typically low-occupancy households, possibly living in properties with a high rateable value, who can save money by moving to metered charge. Accordingly, the level of consumption of the UMP group is likely to be higher than the consumption of the non-UMP group for two reasons: (i) differences in household characteristics (in particular, the number of occupants); and (ii) differences in behaviour (UMP customers do not pay a volume charge during the pre-switch period and they may need time to adjust to more efficient habits).

The existence of differences in household characteristics represents a challenge for our analysis as the reduction in water consumption due to metering in the UMP group may not be representative of the reduction in consumption for the whole customer base. Fortunately, Southern Water data include a variable ('periodic consumption') that provides an estimate of the expected consumption of household i at the beginning of a contract. This variable is an index generated by Southern Water using the information provided by the account holder on the number of household members, plus, potentially, certain property characteristics (e.g. the presence of a garden or swimming pool, or dishwasher usage).[9] Note that this variable is determined before observing the actual consumption of the households, and is not subsequently changed. In Section 4, we will show that, once we control for this variable, there is convergence in consumption between UMP and non-UMP households. Moreover, the coefficients measuring the decrease in consumption in Equation (2), which

8 All appendices are available on the Oxford University Press website, or on the authors' webpages.

9 For instance, around 15% and 16% of observations of periodic consumption take the value of, respectively, 50 and 100. Discussion with Southern Water representatives revealed that these are households with, respectively, 1 or 2 members, for whom Southern Water has no other relevant information about their characteristics.

Table 2. Descriptive statistics

	UMP	Non-UMP
Number of households	167,976	532,981
Number of observations	1,175,832	4,065,656
	Consumption: daily litres	
Mean	340	248
Median	305	216
Min	0	0
Max	2,000	2,000
Obs	1,175,832	4,065,656
	Periodic consumption	
Mean	127	92
Median	115	100
Min	0	0
Max	380	500
Obs	1,083,383	2,163,282

makes use of periodic consumption, are very similar to the coefficients in Equation (3), which makes use of household fixed effects. This confirms that the variable is effective in controlling for different unobserved *ex ante* household characteristics—in particular, the number of occupiers—and therefore allows us to identify the reduction in consumption due to metering, net of differences in household characteristics, despite the existence of households that chose to have a meter installed before the implementation of the UMP.

Table 2 shows descriptive statistics of daily water consumption and periodic consumption for UMP and non-UMP households. The number of UMP households for which we can construct a balanced panel over the seven data points is 167,976; this implies a total of more than one million observations. The number of non-UMP customers is 532,981; these imply a total of more than four million observations.[10] Table 2 confirms that both mean and median water consumptions are significantly higher for UMP households. As for periodic consumption, we note that the mean value is lower for UMP households than for non-UMP households, confirming that these two groups have different characteristics. The number of observations reported at the bottom of Table 2 shows that this variable is available for most UMP households but it is only available for half of the non-UMP households.

Finally, to analyse the distributional effects of metering, we classified households into three different income groups using two different sources. The first source is the income deprivation index published by the Office for National Statistics, which offers an aggregate measure at the level of the lower-layer super output area (LSOA), each including a minimum of 400 and a maximum of 1,200 households. The second source is the socio-economic segmentation of UK households from Mosaic, a dataset published by Experian, a consumer credit reporting agency. The advantage of the Mosaic classification is that it is at

10 The non-UMP data represents an unbalanced panel with a number of observations that varies across customers. For instance, we have 11 observations for 145,768 households (around 27% of the non-UMP group) and 3 observations for 58,483 households (around 11% of the non-UMP group). See online Appendix A, for further information.

the household level, rather than at the LSOA level. The drawback, however, is that we do not have access to this measure for non-UMP households. Detailed information on how the income groups have been constructed can be found in online Appendix B.

3.3 Specifications and identification strategy

The impact of metering on water consumption is assessed in accordance with Equation (2):

$$Q_{i,n,\tau} = \alpha + \gamma * I_{UMP} + \sum_{j=2}^{3} \beta_{PSj} * D_{PSj} + \sum_{j=1}^{4} \beta_j * D_j + \mathbf{\delta C} + \eta_t + \eta_p + \varepsilon_{i,\tau} \quad (2)$$

where $Q_{i,n,\tau}$ is the average daily litres of water used by household i living in postcode area n in period τ. I_{UMP} is a dummy variable taking the value of 1 for UMP customers, and zero otherwise. D_{PSj} and D_j are a set of dummies taking the value of 1 when the household is at phase j of the UMP programme,[11] where the subscript PS refers to the pre-switch observations. Accordingly, D_{PS2} and D_{PS3} indicate the second and third observations before the change of contract, while D_1–D_4 refer to the periods corresponding to the first, second, third, and fourth bills after switching the contract (see Fig. 5, for the correspondence between the different phases of the customer journey and these variables). Note that the coefficient γ indicates how the water usage of the UMP group differs from the consumption of the non-UMP group at the very beginning of the pre-switch period, while the coefficients β_{PSj} and β_j show how the consumption of the UMP group differs from that of the non-UMP group in the subsequent periods. All specifications also include a complete set of monthly dummies, η_t,[12] and (4-digit) postcode dummies, η_p. The monthly dummies capture seasonal changes in water consumption common across both UMP and non-UMP households, while the term η_p absorbs time-invariant unobservable characteristics that may influence water demand at the postcode level, such as landscape features and time-invariant differences in local socio-economic characteristics. Lastly, in some specifications we also include periodic consumption to control for different unobserved characteristics of the households—in particular, the number of occupiers. To capture non-linear effects, we divide the households into 10 different groups with increasing values of periodic consumption (e.g. group 1 comprises households where periodic consumption is less than 50 litres, and group 10 comprises households where periodic consumption is 200 litres or more), constructing a dummy for each group. The vector **C** in Equation (2) refers to these ten indicator variables.

As mentioned, in Equation (2) the coefficient γ measures the differences in levels of consumption between UMP and non-UMP households when we observe the water usage of UMP households for the first time (i.e. the first observation of the pre-switch period), while the βs coefficients provide an estimate of the reduction in litres of water consumed by UMP households in the subsequent six periods. Initial differences in water consumption, captured by γ, can occur for two different reasons. First, UMP households are likely to use more water than non-UMP households, as they still do not pay a volume charge during the pre-switch period. Second, we know that the characteristics of UMP households—in particular, the number of occupiers—is different from non-UMP households. As already mentioned,

11 These dummies are always zero for non-UMP households, as they do not receive a meter.

12 The monthly dummies refer to calendar time (e.g. September 2013). They take a value of 1 if they refer to the period τ, and 0 otherwise. For instance, in the post-switch period, when τ refers to a billing period of 6 months, we will have six monthly dummies taking a value of 1.

results in Section 4 show that the use of periodic consumption is effective in controlling for structural differences between the two groups, thus allowing the identification of initial overuse of water driven by differences in the pricing structure.

Equation 3 estimates a further specification that includes household fixed effects (FE) η_i:

$$Q_{i,\tau} = \alpha + \sum_{j=2}^{3} \beta_{PSj} * D_{PSj} + \sum_{j=1}^{4} \beta_j * D_j + \eta_t + \eta_i + \varepsilon_{i,\tau} \quad (3)$$

The term η_i controls for unobserved differences across households that affect their water consumption, such as the number of members in a household, preferences for the environment, and usage of water-intensive durable goods. Unlike in Equation (2), where we control for differences across households using periodic consumption as a control variable, household fixed effects provide a more general way to control for unobserved heterogeneity in our data. However, results reported in Section 4 suggest that there are no major differences between the estimates of βs using the two specifications (columns (2) and (3) of Table 3). This indicates that periodic consumption provides a credible control for unobserved characteristics that are invariant over the time frame under consideration (e.g. for most cases, family size). Note that the time invariant regressors I_{UMP} η_p and C cannot be included in Equation (3) as they are perfectly collinear with η_i. This means that the household fixed effects specification shown in Equation (3) has the disadvantage of not allowing the identification of initial differences in the level of consumption of UMP and non-UMP customers and, accordingly, whether there is the expected convergence of the two groups.

Table 3. Metering and water consumption

Variable		OLS	OLS	FE	Q25	Q50	Q75
Description	Name	(1)	(2)	(3)	(4)	(5)	(6)
Non-UMP	α	248.4	248.4	248.4	124	216	329
UMP:							
Pre-switch (1st)	I_{UMP}	154.930*	90.461*		105*	129*	171*
		(0.71)	(0.59)		(0.44)	(0.45)	(0.78)
Pre-switch (2nd)	D_{PS2}	−54.564*	−58.311*	−55.688*	−3.0*	−22.0*	−53.0*
		(0.82)	(0.57)	(0.48)	(0.60)	(0.63)	(1.08)
Pre-switch (3rd)	D_{PS3}	−61.665*	−66.723*	−64.362*	−17.0*	−37.0*	−69.0*
		(0.82)	(0.57)	(0.51)	(0.60)	(0.63)	(1.08)
1st bill	D_1	−62.437*	−69.149*	−67.476*	−16.0*	−39.0*	−78.0*
		(0.84)	(0.66)	(0.54)	(0.60)	(0.63)	(1.08)
2nd bill	D_2	−79.835*	−83.684*	−82.266*	−24.0*	−49.0*	−95.0*
		(0.82)	(0.65)	(0.56)	(0.60)	(0.63)	(1.08)
3rd bill	D_3	−86.278*	−86.902*	−86.201*	−29.0*	−54.0*	−101.0*
		(0.82)	(0.66)	(0.58)	(0.60)	(0.63)	(1.08)
4th bill	D_4	−91.370*	−89.211*	−89.336*	−31.0*	−56.0*	−102.0*
		(0.82)	(0.66)	(0.58)	(0.60)	(0.63)	(1.08)
Periodic cons. dummies	C		Incl.				
Number of Observations		5,241,488	3,246,210	5,241,488	5,241,488	5,241,488	5,241,488
N × (mean of) T - *UMP*		167,976 × 7	154,769 × 7	167,976 × 7	167,976 × 7	167,976 × 7	167,976 × 7
N×(mean of) T − *non-UMP*		532,981 × 7.6	387,006 × 5.5	532,981 × 7.6	532,981 × 7.6	532,981 × 7.6	532,981 × 7.6

Notes: Water consumption is measured in litres per day; robust standard error in parentheses; *p < 0.001.

The fact that the distribution of meter installations is scattered across both geographical areas and time allows us to avoid confounding factors—a major threat to identification in the evaluation of those public programmes where subjects are all treated at the same time (see Wichman, 2017). In fact, it is very unlikely that unobserved changes in household behaviours or characteristics take place systematically contemporaneously with meter installation across the hundreds of thousands of UMP customers. At the same time, in each geographic area we observe both UMP and non-UMP customers. These households are exposed to common weather, annual tariff increases, and other exogenous shocks and, if the effect of these factors is common across the two groups, we can use non-UMP customers to control for their impact on UMP customers. Moreover, given that the treatment (i.e. meter installation) takes place at different points in time, we can use other UMP customers whose meter was installed in a different time period to identify seasonal changes in consumption that are unrelated to metering.

4. Results

In this section, we analyse the average effect of metering on water consumption for all UMP customers, and then explore whether there is substantial heterogeneity in the way these customers respond to metering. In particular, we explore whether the reaction of households that experience a large increase in their bill is substantially different from those receiving a lower bill. The rationale for this exercise is that customers that gain financially from having a meter installed are typically smaller and more affluent households than those that are financially worse off under the new tariff. Given that family size and income are two fundamental determinants of household water consumption, if only minor differences were found in the responsiveness of households, we would conclude that we should adopt a corner solution (universal metering, or no metering), while major differences would call for more selective metering.

Table 3 shows the change in consumption for UMP households from meter installation until the fourth metered bill. Columns (1) and (2) show the estimated coefficients of Equation (2), with and without periodic consumption, while column (3) refers to Equation (3) with household fixed effects. The first row of Table 3 shows that the average daily water consumption for non-UMP households, corresponding to the intercept of our empirical specifications, is 248.4 litres.[13] As we have three different data points for the pre-switch period, we can observe whether there is any adjustment in the period between installation and switch of contract. We find that there is, indeed, a drastic reduction in consumption during the pre-switch period. For instance, column (1) shows that UMP customers consume 155 litres more than non-UMP customers at the very beginning of the pre-switch period,[14] but only 93 (= 155 - 62) litres more at the end of the pre-switch period. Looking at the

13 Discussion with managers at Southern Water confirmed that 250 litres per day is a reasonable measure of average consumption of 'already' metered customers. Note that this number has been manually computed as the simple average for all available observations of non-UMP customers. The constant showed by Stata®, the software used for our analysis, is not informative because it corresponds to the average consumption of non-UMP for the month and post-code dummies that are automatically dropped because of multicollinearity (dummy variable trap).

14 We assume that consumption observed at the very beginning of the pre-switch period is a good approximation of water usage when households were unmetered.

overall change two years after meter installation, we observe an average reduction in water usage of 22%, from 403 (= 248 + 155) to 312 (= 403 - 91) litres per day. This result is in line with the Isle of Wight metering, but is significantly higher than the 12% reduction observed in the national metering trials that took place in England in late 1980–early 1990 (Herrington, 2007).

The 22% reduction represents an assessment of the impact of metering on UMP customers, but is not necessarily the reduction that we would observe if none of the customers served by Southern Water had a meter before the beginning of the programme, because UMP and non-UMP households have different characteristics—in particular, regarding the number of occupants. In order to identify the effect of metering in the presence of differences in household characteristics, in column (2) of Table 3 we estimate a specification that includes periodic consumption. The lower number of observations is due to the fact that periodic consumption is not available for some households in our dataset. We obtain similar results (not reported) to those in column (1) when using the same sample of households with non-missing periodic consumption, as in column (2). This suggests that that there are no problems of sample selection due to the fact that periodic consumption is not observed for all households. Two interesting results emerge. First, the average UMP customer is now found to consume around 90 litres of water more in the pre-switch period. This means that around 65 litres of the 155 litres difference reported in column (1) can be attributed to differences in the characteristics of UMP and non-UMP households. Second, the reduction at the fourth bill of -89 litres suggests that there is almost perfect convergence in water usage between the two groups two years after installation. This is a remarkable result and gives strong support to the assumption that periodic consumption can effectively capture structural differences between households. Convergence shows that similar households, when facing the same incentives for a sufficient period of time, consume similar amounts of water, irrespective of being part of the UMP or not. The results in column (3) of Table 3 show that the reduction estimated using OLS is confirmed when using the household fixed effects estimator, which controls for unobserved time invariant heterogeneity across customers. Given the relatively short time period considered, this would, in most cases, also include the number of occupants. This gives further support to our identification strategy.

The results in columns (2) and (3) of Table 3 confirm that the reduction in consumption, once we control for differences in household characteristics, amounts to 89 litres per day. A similar reduction could be expected if universal metering were extended, as is currently the case, to other areas of England and Wales where households have similar characteristics, as they face the same institutional environment as south-east England. However, this figure is higher than we would have observed if none of the Southern Water customers had already had a meter installed. This is due to the 40% of non-UMP households with a meter already installed, and particularly optants, being likely, on average, to have fewer occupants and, therefore, less leeway to adjust their consumption, as has been discussed.[15]

As a first exercise to explore the heterogeneous effects of metering across households with different levels of consumption, we estimate quantile regressions at percentile 25, 50, and 75 of the distribution of water usage. The last three columns of Table 3 show that the reduction two years after meter installation for these three quantiles is respectively, 13.5%,

15 Online Appendix C shows that our analytical framework and empirical findings are substantially unaffected by the fact that metering allows the detection of leaks in the internal pipes of dwellings.

16%, and 20.5%. These results show clearly that there is a large heterogeneity in the effects of metering: absolute reduction in water usage at percentile 75 is more than three times the reduction observed for quantile 25. The results of the quantile regression will be used in Section 5.1 to evaluate the proportion of customers that it may not be cost-effective to meter due to the reduction in their water consumption being lower than the minimum reduction required to cover the cost of metering.

The theoretical analysis in Section 2 shows that small families living in high-value houses are more likely to be better off with a meter. This insight is confirmed by empirical evidence in Sim *et al.* (2007: 18) who find that single and two-person households are more likely to take the metering option. There is then a concern that the wrong types of household are choosing a meter under the Optional Metering Scheme because, as argued by Cowan (2010), 'if smaller households have a low responsiveness to the price increase caused by being metered then the social benefits of metering may be lower than the costs. Meanwhile larger households rationally choose to remain without meters, though it would be socially efficient for them to have meters.' The last part of this section is devoted to the assessment of whether there are substantial differences in the reduction of consumption between UMP households that are better off and those that are worse off under the new metered tariff. Note that whereas, in theory, there should be no UMP households that, given their consumption under the unmetered tariff, are better off under the metered tariff (because they would have already taken the metering option), we do observe a large number of such households in our data. This can be for many reasons. One possibility is a lack of information about their own consumption in the absence of a meter and, thus, the inability to assess whether metering represents a saving opportunity or not. Inertia is another plausible factor.

As explained in Section 2, a household is surely better off if, keeping consumption fixed at satiation level, its water bill is lower under the new metered tariff. To identify households that are better off or worse off, we then estimate the difference between the (observed) unmetered bill and the (theoretical) metered bill that UMP households would have received for the consumption level observed at the beginning of the pre-switch period, as this can be reasonably considered a good approximation of the satiation level. Using the single observation at the beginning of the pre-switch period to assess the change in consumption may, however, suffer from the problem of reversion to the mean.[16] To avoid this problem, we regress the difference between the metered bill and the unmetered bill on periodic consumption and rateable value, in order to estimate the difference in bills that is explained by exogenous characteristics highly correlated with the metered bill (periodic consumption) and the unmetered bill (rateable value). Indeed, these two variables can explain around 90% of the variation in the dependent variable. Finally, the predicted differences between metered bills and unmetered bills are used to classify UMP households in the following three groups:

i. *winners*, if the predicted metered bill is more than 10% higher than the unmetered bill;
ii. *losers*, if the predicted metered bill is more than 10% lower than the unmetered bill;

16 For instance, there may be cases where the first observed consumption is unusually high (or low) because, say, relatives visit the household (the household goes on holidays). We would then classify these customers as losers (winners), observe a large reduction (increase) in consumption and wrongly attribute it to the change in bills, rather than to the fact that relatives have left (or the household is back from holidays).

Table 4. Water consumption and billing

Variable		Billing		
Description	Name	Winner (1)	On par (2)	Loser (3)
Non-UMP	α	248.4	248.4	248.4
UMP:				
Pre-switch (1st)	I_{UMP}	4.703*	140.09*	356.685*
		(0.66)	(1.13)	(1.30)
Pre-switch (2nd)	D_{PS2}	−23.644*	−48.559*	−106.147*
		(0.76)	(1.33)	(1.55)
Pre-switch (3rd)	D_{PS3}	−26.166*	−53.736*	−118.621*
		(0.76)	(1.31)	(1.53)
1st bill	D_1	−13.837*	−50.894*	−138.104*
		(0.81)	(1.33)	(1.51)
2nd bill	D_2	−18.844*	−61.470*	−173.723*
		(0.81)	(1.34)	(1.49)
3rd bill	D_3	−20.979*	−66.397*	−186.976*
		(0.81)	(1.35)	(1.49)
4th bill	D_4	−24.118*	−70.645*	−193.580*
		(0.82)	(1.36)	(1.50)
Number of observations		4,564,203	4,267,431	4,442,032
N × (mean of) T – *UMP*		71,221 × 7	28,825 × 7	53,768 × 7
N × (mean of) T – *non-UMP*		532,981 × 7.6	532,981 × 7.6	532,981 × 7.6

Notes: Water consumption is measured in litres per day; robust standard error in parentheses; *$p < 0.001$.

iii. *on par*, if the predicted metered bill is within 10% of the unmetered bill.[17]

This approach addresses possible concerns that the classification of customers based on their bills may be endogenous to the level of consumption, as the predicted satiation levels do not depend on the new tariff structure.[18]

Using the classification above, the percentages of *winners*, *losers*, and *on par* households are, respectively, 46%, 35%, and 19%. Table 4 shows the results obtained for these three groups of UMP households. Note that each specification includes all non-UMP customers. The coefficients reported in columns (1)–(3) of Table 4 show how water savings are dramatically different between these groups: winners use 24 litres of water less by the fourth bill, while losers decrease consumption by 194 litres.[19] The large difference in the volume of water saved is mainly due to the fact that losers are large households.

17 A cut-off of 10% gives a reasonably high number of households in all three groups. Similar results are obtained with a cut-off of 15%.

18 Indeed, classifying households as winners by looking at the difference between the last unmetered bill and the first metered bill would include behavioural responses to metering; as we have shown, UMP customers react very swiftly to metering.

19 To compute the percentage reduction, we need to know the level of consumption of UMP customers soon after the installation (i.e. the coefficient on I_{UMP}). Using an OLS estimator as in column (1) of Table 3, we find that the reduction for winners and losers is, respectively, 9% and 32%.

Assuming that people opting for metering are similar to our 'winners', these findings confirm that the optional metering scheme is affected by a severe adverse selection problem. The fact that the largest reduction in consumption is observed in the group of customers that are worse off under the new tariff scheme means that, from society's point of view, customers that should receive a meter do not have a financial incentive to opt for a meter. Interestingly, the fact that a large proportion of households would be better off under the new metering tariff even at saturation consumption level (i.e. before any adjustment to the new pricing scheme) suggests that several customers are not aware or cannot predict the financial advantages of installing a meter. While this softens the aforementioned problem of adverse selection, it also calls into question the relevance of designing an optimal tariff under optional metering, unless informational and behavioural constraints are taken into account.

5. Efficiency and distributional effects of metering

5.1 Efficiency

The findings in Section 4 show that there are substantial differences in households' response to metering. This suggests that there may be a subset of households for whom the benefits associated with the reduction in overconsumption exceeds the cost of metering. But what is the proportion of households for which, from the societal point of view, it is optimal to have a meter? This section is devoted to answering this important question.

In Section 2, we explained that, for a linear demand, the gross benefit from reducing overconsumption corresponds to the area of the shaded triangle in Fig. 2. Accordingly, Equation (1) can be rewritten as:

$$365 * \frac{c\left[\mathrm{Q}(0,\, t) - \mathrm{Q}\left(p^{\mathrm{M}}, t\right)\right]}{2} \geq m$$

or, rearranging:

$$\left[\mathrm{Q}(0,\, t) - \mathrm{Q}\left(p^{\mathrm{M}}, t\right)\right] \geq \frac{2m}{365c} \quad (4)$$

where the gross benefits associated with the daily reduction in water consumption from $\mathrm{Q}(0,\, t)$ to $\mathrm{Q}\left(p^{\mathrm{M}}, t\right)$ are multiplied by 365, given that m is the *annualized* cost of meter installation.

The marginal cost is assumed to be equal to $c = 0.003322$ (£/L). As already observed, this is likely an upper bound of the true but unobserved marginal cost for most households and, in particular, for small households that are not the main culprit for peaks in demand, when marginal costs of water extraction and supply may admittedly be higher. Accordingly, our analysis provides a conservative measure of the proportion of houses for which metering is not efficient from the societal point of view.[20] As for the cost of metering m, figures published by the Environment Agency (2008) suggest that the additional annual costs per metered household for reading, billing, and customer services amount to £15.5 per year,[21] whereas the one-off cost of installation may vary from £206 for a simple internal

20 The marginal cost may be considerably higher during peaks in demand if heavy water abstraction has a negative impact on the aquatic ecosystem and the nearby environment.

21 The figures reported in Environment Agency (2008: 84) are £9.15 for customer contact, £1.95 for billing costs and £2.21 for reading costs, giving a total of £13.31. We then multiply this figure by 1.17 to account for inflation over the period 2008–2016.

Table 5. Cost of meter installation

Type of installation	Percentage[a] (1)	Cost Installation[b] (2)	Annualized cost Installation[c] (3)	Minimum water reduction to cover costs[d] (4)
	%	£	£	Litres
Simple external	60.0	225	20.64	59.62
Difficult external	20.0	450	41.29	93.67
Complex external	5.0	1,126	103.32	195.98
Simple internal	2.5	206	18.90	56.74
Difficult internal	7.5	412	37.80	87.92
Complex internal	5.0	1,030	94.51	181.45
Replacement		70	6.42	36.16

Source: Environment Agency (2008).
Notes:
[a]Percentage of installations that are simple, difficult or complex, taken from last column of table 3.4 in Environmental Agency (2008).
[b]Figures for total cost taken from Environmental Agency (2008: 83) have been multiplied by 1.17 to adjust for inflation.
[c]The annualized cost is computed using an interest rate of 5% and the assumption that the lifetime of a meter is 15 years (Environmental Agency, 2008: 4).
[d]Right-hand side of Equation (4) with $m =$ (column (3) + £15, 5) and $c = 0.003322$.

installation to £1126 for a complex external installation. Table 5 shows the different values that the righthand side of Equation (4) can take, depending on the complexity of the installation. To understand the figures in Table 5 consider the first row, simple external installations, which account for 60% of all installations undertaken in dwellings in England and Wales. Given that the cost of the installation needs to be divided over the 15 years of a meter's life, we first compute the annual cost of the installation in column (3), to which we add the £15.5 of annual operating costs to obtain m; we then calculate the right-hand side of Equation (4) dividing this total by $365{*}c$. The results in column (4) show that metering is socially efficient only for those households that reduce consumption by at least 59.6 litres.

A number of interesting facts emerge from the figures in Table 5. First, given the average water reduction of 89 litres, the decision to install meters in all households served by Southern Water has, overall, been beneficial from society's point of view. So, extending universal metering to other areas of England and Wales would improve welfare compared with the optional metering scheme currently used. However, considering that, for the median households, the reduction in water consumption is around 56 litres (see column (5) of Table 3) more than half of the UMP households should not receive a meter, even if the most optimistic estimate of the cost of installation (simple internal) is applied. The analysis in Section 4 also shows that small households (those with a lower absolute value of water consumption) are also those with a smaller reduction in the volume of water consumption after meter installation. These households are unlikely to generate peaks in demand where marginal costs may be significantly higher than average costs, thus supporting the idea that the benefits of metering them are small. Second, the last row of Table 5 considers the costs of replacing a meter in an existing boundary box, which is the reference point used when assessing the efficiency of metering after all structural works have been undertaken. In this case, the percentage of households for whom it is not cost-effective to have a meter installed would be more than 25%.[22] Finally, complex installations (which account for around 10% of installations) should never be undertaken, as they are very unlikely to generate a reduction in consumption that can compensate for the costs of the intervention. This seems compatible with the fact that the target of the UMP was to increase the number of metered customers to 90%, as Southern Water anticipated technical problems for around 10% of properties.

The fact that, under reasonable assumptions about marginal costs and the shape of demand, we find that there is a large share of households for whom it may not be socially efficient to have a meter suggests that a selective metering programme (where large households are required to have a meter installed, while small households need to pay for the cost of installing the meter should they want one) would be a more efficient way to address the problem of excess consumption, as advocated by Cowan (2010).

5.2 Distributional effects

This section investigates whether there are significant differences in how metering affects the water consumption and water bills of more affluent households in relation to the less well off. Given that an unmetered bill is based on the rateable value of the house, switching to a metered tariff is likely to be very costly for large families living in small properties and beneficial to single occupants living in expensive houses. Metering may also exacerbate existing disparities in water consumption between more and less affluent households, since previous studies have found that high-income families not only use more water, but their demand seems also to be less sensitive to changes in the price (see, for instance, Agthe and Billings, 1987). Most of these studies, however, focus on water consumption response to price changes within the existing metering system, often using surveys of households. The analysis in this section differs from existing works in several dimensions. First, we can observe changes in both water consumption and water bills. Second, the change in pricing is a particular and interesting change, as it consists. Third, our sample is made of hundreds of thousands of households. Last, but not least, we can use both aggregate and individual measures of income.

The first three columns of Table 6 show the impact of metering for three different income groups created using the income deprivation index, described in Section 3.2. As expected, average water consumption for non-UMP households is higher in richer areas. The Table 6 shows that the difference in consumption between non-UMP and UMP households at the first observation of the pre-switch period is also greater in more affluent areas. The wealthiest areas are found to have a greater reduction in the absolute number of litres of water used but, interestingly, the percentage reduction in consumption is almost identical among the three groups: 23% (= -87.5/(238.5 + 147.2)), for UMP households in low-income areas; 22% and 23%, for UMP households living, respectively, in medium- and high-income areas. The last two columns in Table 6 use the Mosaic classification. Estimates confirm that the reduction in consumption is greater for high-income households, while we find a larger percentage drop in consumption for low-income families (24.5%) compared to high-income families (21.5%).

22 The required reduction in water usage in the case of the replacement of a meter (last row of Table 5) is 36 litres, which is more than the 31 litres reduction at percentile 25 reported in Table 4.

Table 6. Water consumption and income

Variable		Area income			Mosaic income	
Description	Name	Low (1)	Medium (2)	High (3)	Low (4)	High (5)
Non-UMP	α	238.50	248.90	269.70	248.40	248.40
UMP:						
Pre-switch (1st)	I_{UMP}	147.21*	156.95*	165.56*	133.288*	226.725*
		(1.16)	(1.02)	(2.04)	(1.49)	(1.71)
Pre-switch (2nd)	D_{PS2}	−53.222*	−52.841*	−65.008*	−55.357*	−68.608*
		(1.32)	(1.18)	(2.36)	(1.81)	(2.09)
Pre-switch (3rd)	D_{PS3}	−58.432*	−60.615*	−72.143*	−62.131*	−74.961*
		(1.32)	(1.17)	(2.37)	(1.78)	(2.06)
1st bill	D_1	−56.341*	−60.842*	−71.172*	−62.637*	−75.324*
		(1.37)	(1.20)	(2.40)	(1.76)	(2.02)
2nd bill	D_2	−75.308*	−77.982*	−87.276*	−81.243*	−91.678*
		(1.34)	(1.18)	(2.35)	(1.73)	(1.99)
3rd bill	D_3	−81.661*	−84.941*	−92.806*	−87.595*	−98.479*
		(1.34)	(1.18)	(2.35)	(1.73)	(1.99)
4th bill	D_4	−87.492*	−89.386*	−99.051*	−93.730*	−102.479*
		(1.33)	(1.18)	(2.35)	(1.72)	(1.99)
Number of observations		1,873,868	2,408,201	736,345	4,302,490	4,259,988
N× (mean of) T – *UMP*		66,525 × 7	79,545 × 7	20,571 × 7	33,832 × 7	27,761 × 7
N× (mean of) T – *non-UMP*		192,297 × 7.3	237,019 × 7.8	71,201 × 8.3	531,966 × 7.6	531,966 × 7.6

Notes: Water consumption is measured in litres per day; robust standard error in parentheses; *$p < 0.001$; mosaic classification is available only for UMP, so all non-UMP data are used in the specifications of columns (4) and (5).

Despite some differences between the two sets of results, the message across the two measures is that a substantial reduction in consumption is shared across income levels, rather than being concentrated in low-income households, as other studies have documented. However, this analysis does not consider the decrease in consumer surplus to be associated with the reduction in consumption. Assuming that all households have a linear demand, the numbers above suggest that low-income families have a steeper demand around the satiation point compared to high-income families and, therefore, experience a larger welfare loss. Whereas the percentage reduction in consumption may be similar between low-income and high-income families, the former are likely to stop using water for activities that provide them with higher utility.

To investigate the impact of metering on water bills, we compute the difference between metered and unmetered bills at pre-switch consumption (before major adjustments in consumption take place) and two years after installation (when consumption has fully adjusted). These two variables take positive values when the metered bill is higher than the unmetered bill, thus implying that a household is financially worse off. Results in Table 7 show the mean and median changes in bills for different income groups.

Households living in low-income areas (column 1), or that are less affluent according to Mosaic classification (column 4), experience an average increase in water bills between £10.1 and £11.5 at the fourth bill. Given that there are two water bills per year, this means

Table 7. Water bills and income

Bill difference	Statistics	Area income			Mosaic income	
		Low (1)	Medium (2)	High (3)	Low (4)	High (5)
Metered–unmetered	*Mean*	27.17	0.92	−25.99	23.01	−27.35
At pre-switch	*Median*	8.20	−11.75	−34.96	4.35	−34.63
Metered–unmetered	*Mean*	11.50	−10.97	−38.04	10.18	−36.64
At bill 4	*Median*	−2.94	−17.43	−41.52	−3.74	−37.68

that less affluent households are around £20–£23 worse off on a yearly basis, equivalent to 5% of their average yearly bill. As expected, this difference would be much higher (between £23 and £27) if these households were to have kept their consumption at the pre-switch level. The results in columns (3) and (5) show that more affluent families gain, on average, around £36–£38 under the metered tariff. Looking at the median changes at the fourth bill, we observe that most of the families are not worse off under the new tariff. These results are in line with the work by Dresner and Ekins (2006), which finds that switching to the current metered tariff (or other hypothetical tariffs) does not, on average, make low-income households worse off.

6. Conclusions and policy implication

This paper investigated the impact of the Universal Metering Programme insouth-east England on water consumption, and the related efficiency and distributional effects. We find that, on average, UMP households decrease consumption by 22%, a percentage substantially higher than assumed in the literature. Given the relevance of this figure for any *ex ante* cost-benefit analysis, this finding represents an important input into policy making. In particular, such a large reduction in average consumption suggests that it would be advisable to extend compulsory metering to other areas of the country where households have similar characteristics.

Our analysis shows that there is considerable heterogeneity in the way households react to metering. In particular, we observed low responsiveness in the group of households that are better off under the metered tariff—typically, small households living in expensive dwellings. These results suggest that optional metering in England is inducing the wrong types of household to choose a meter. Furthermore, our study offers the first large-scale evidence that the percentage reduction in water consumption is very similar across income groups. Analysing the difference between metered and unmetered bills, we found that high-income households gain financially on switching to metering, while less affluent households are, on average, around £10 worse off. However, looking at the median of the distribution, we find that more than half of low-income households end up paying a lower bill after adjusting their consumption.

An important contribution of our study is that we have investigated when metering a household has social value. Whereas the answer to this issue critically depends on the correct identification of the (unobservable) marginal cost of water, our analysis shows that the proportion of households for which the cost of metering outweighs the benefits is likely very large, well in excess of 25% in some scenarios. These results suggest that a selective metering programme, where only 'large' households receive a meter, would most likely be the solution delivering the highest social welfare.

Certainly, selective metering at household level may be problematic to implement for both technical and political reasons. The technical barriers are due to the lack of relevant information on the size and consumption habits of individual households; for instance, water utilities may not know the number of occupants. In a dynamic setting, we need also to consider that the number of members of households may change over time, or households may change their location. Moreover, selective metering at household level is likely to increase unitary costs of installation, since there are economies of scale in metering all dwellings in an area. On a political ground, the decision to have compulsory free metering for some households and optional metering for other customers (who need to pay) may find strong opposition from residents' and customers' associations, particularly if this increases perceived inequalities in water consumption. All these considerations make the implementation of universal metering easier to manage and less risky than selective metering. An alternative approach—one that is easier to implement and, possibly, less controversial—would be to meter only districts where water consumption is above average. Studying the effects of selective metering at district level and those of universal metering would be an interesting topic for future research.

Supplementary material

Supplementary material is available on the OUP website. The supplementary material comprises the online Appendixes and Stata® files for the analysis of data. This paper uses proprietary data covered by a confidential agreement. Access to the data should be requested directly from Southern Water, using the following link: https://www.southernwater.co.uk/do-it-online

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