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 promoting an efficient use of water. However, available evidence on benefits and costs of metering is scant and often based on small samples. We use data of 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% after meter installation, a considerably higher value than assumed as 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 classification**: Q25, D12, H42.

1. **Introduction**

The necessity of promoting an efficient use of water receives widespread consensus, but how water utilities should be regulated and how water metering and tariffs should be designed to reach this end remains subject to debate. For example, in 2014, Irish Water, the national water utility in Ireland, started an ambitious programme to install over one million meters but, following strong opposition by residents, the programme was stopped in 2016, when more than 900 thousands meters had already been installed (Expert Commission, 2016). Water charges were also scrapped and the Irish Parliament passed a law to fund water services through general taxation in November 2017. This example testifies 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, ensure that water remains affordable for all households.

Indeed, the fear that metering might result in adverse financial consequences for poor households has been the main obstacle to the introduction of universal metering in the UK, where more than 30% of households did not have a meter a decade ago. However, this concern has been mitigated over the last few years 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 to increase water supply in the future. For this, several water utilities have started a universal metering programme in their supply regions. In 2010 Southern Water (SW) was the first water utility to start installing 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 the rate of 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 over-consumption, 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 in eleven different sites in England in the late ’80-early ’90 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 (Herrington, 2007). However, all existing studies have been based on a rather small sample of households and there is no evidence on large scale universal metering programmes as those that have been undertaken in UK in the last few years. 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 of 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 metering on average reduces water usage by 22%, a figure substantially higher than the 12.5% that has been often 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 what has been 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 they are those that exhibit a lower reduction in the deadweight loss due to over-consumption 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 to 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 over-consumption. We find that overall the UMP has contributed to an increase in social welfare but 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 metered installed, would lead to higher social welfare.

Finally, we look at the distributional effect of UMP by investigating whether there are significant differences in how metering affects water consumption and bills of families of different income. In contrast with findings by Aghte and Billings (1987) and by 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 upon switching to metering while low-income households are, on average, around £20-£23 worse-off on a yearly basis, equivalent to 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 given.[[1]](#footnote-1) Instead, 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. On the contrary, optional metering is not socially efficient in the more plausible case where households’ type is not known and only large households should 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 introducing tariff schemes (such as Increasing Block Tariff with the provision of a low price block of water to cover essential usage) that can be effective in reducing overconsumption whilst 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 percent of metered customers spent more than 3 percent of their income on water bills than the fact that 26 percent of unmetered customers face that problem”.[[2]](#footnote-2)

This paper contributes to fill in the 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 like Sacramento, in California, have, for example, an ongoing metering programs, due to end by 2020. As noticed 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, 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 also 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 being 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 percent."

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.

1. **Theoretical Framework**

In this section we study the household’s decision problem 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, that is 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 FU, 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-FU), 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 FM (that 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*)-FM). 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 unmetered tariff is BU (in blue) and under metered tariff is BM (in red). The intercepts of BU and BM represent the ‘disposable’ household income after deducting the fixed part of the unmetered tariff FU and meter tariff FM. The intercept of the blue line is lower because FU>FM. Points XU and XM represent the bundles chosen by the household in the absence of a meter or with a meter, respectively. The utility under a meter tariff (i.e. UM) is exactly equal to that in the absence of meter (i.e. UU), and therefore this particular household is indifferent between the metered and non-metered options. The change in tariff entails a reduction (respectively, increase) in utility if a household move on a lower (higher) indifference curve.

**Figure 1**. Household Choice

FM

FU

I

Q(0,*t*)=Satiation

QUANTITY OF WATER

NUMERAIRE

XU

XM

Q(*p*M,*t*)

BU

BM

*Notes*: The vertical axis show the amount that can be spent on goods other than water. ‘I’ is the initial total income.

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

The existence of a large heterogeneity in households’ responses has 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, following the framework in Cowan (2010), we have that:

 (1)

where *m* is the annualized cost of installing and operating a meter. The left-hand-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  *t*o 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 and while (*b*) corresponds to the rectangle with base - and height ‘*c’*. The sum of the two terms corresponds to the shaded triangle.

**Figure 2**. Household Demand

*p*M=*c*

D1

Q(0,*t*)

PRICE WATER

Q(*p*M,*t*)

QUANTITY OF WATER

Deadweight cost of overconsumption

= Gross social benefit from metering

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 because 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, Figure 3 shows that if water is priced above *c*, estimating the deadweight cost at the observed price *p*M and quantity would lead to overestimate the social benefit of metering by an amount equals to the shaded trapezoid.

**Figure 3**. Deadweight Costs

*p*M

*c*

D1

Q(0,*t*)

PRICE WATER

Q(*p*M,*t*)

QUANTITY OF WATER

Overestimation of Deadweight Cost

True Deadweight Cost

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 noticing that England and Wales 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* of 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]](#footnote-3) In year 2017, the volume rate charged by SW for water supply and sewage treatment is 3.322 £/m3, or 0.003322 £/Litres.[[4]](#footnote-4) As average cost is typically above marginal cost for public water supply and, more generally, for natural 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 £/m3, thus leaving room for some potentially unaccounted for environmental externalities.[[5]](#footnote-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, not surprisingly, households with low level of absolute consumption too. This means that the households for whom metering may not be efficient for the social point of view (because of the small reduction in consumption) are unlikely to be responsible for peaks in demand (because their absolute consumption is also small).

1. **Empirical Framework**

***3.1 Institutional Setting***

The compulsory installation of water meters in all districts of South-East England served by SW takes place according to the timing in Figure 4 below. The map shows that the UMP does not follow a clear pattern in terms of geographical location or district size. For instance, the metering starts in late 2010 from the biggest urbanization served by SW, Southampton (population of around 375,000), but installation in two other major urbanizations, Brighton (225,000) and Winchester (120,000), takes place 3 years after, towards the end of the programme.

**Figure 4**. Timing of Installation



Around 40% of the households in the South-East have already a meter installed when the UMP starts. These households (henceforth defined as *non*-UMP) live in the same geographical areas where the UMP is implemented and consist of ‘Households living in New Dwellings’, given that all new properties built since 1990 are fitted with water 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 unmetered to metered tariff. In the period between meter installation and switch 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* (3M) letter, showing the expected metered bill they will receive based on the observed consumption in the previous 3 months. This is the first information customers receive about their water usage since the switch of contract. Six months after switch of contract, (and three months after the 3M letter), UMP customers receive their first bill. Following bills are sent every six months - i.e. two bills per year. The top part of Figure 5 shows the typical customer journey as described above.

**Figure 5**. Customer Journey



Both metered and unmetered tariffs are made up of two parts. For 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 RV of the house. Notice that the rateable value was an indicator of the rental value of the house as of 31 March 1990, 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-year. 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 SW to metered and unmetered customers from the period 2009/2010 to 2016/2017,[[6]](#footnote-6) which correspond 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. The annual increase is typically below inflation, so that water bills decrease in real term keeping constant the amount of water consumed.

**Table 1**. Water Tariff for Metered and Unmetered Customers

|  |  |  |
| --- | --- | --- |
|   | Unmetered | Metered |
|   | Water | Sewerage | Water | Sewerage |
| Year | Stand. Charge | RV charge  | Stand. Charge | RV charge  | Stand. Charge | Vol charge (per m3) | Stand. Charge | Vol charge (per m3) |
| 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 | 1.04 | 49.17 | 1.877 |
| 2012/13 | 34.42 | 0.644 | 66.46 | 1.219 | 26.37 | 1.134 | 50.17 | 2.08 |
| 2013/14 | 35.97 | 0.673 | 70.88 | 1.3 | 26.44 | 1.169 | 54.7 | 2.198 |
| 2014/15 | 36.99 | 0.692 | 73.35 | 1.345 | 27.17 | 1.201 | 56.57 | 2.273 |
| 2015/16 | 21 | 0.71 | 56 | 1.343 | 25.26 | 1.233 | 60.2 | 2.27 |
| 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 SW over different years and available on the website of the company. The RV is applied ‘per £ of RV’.

***3.2 Data***

The data used in the empirical analysis covers the period from January 2011 to October 2016 and it refers to two groups of customers: 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 water consumption between UMP and non-UMP customers after the former have a meter installed and, therefore, face the same incentives.

The UMP sample consists of households that in October 2016 have already received four bills and whose average daily consumption is below 2,000 litres per day.[[7]](#footnote-7) Our dataset includes seven observations of average daily consumption for each household: three observations for the pre-switch period, which typically spans over three months, and four observations after switch of contract, corresponding to the first four metered bills. This means that each of the first three data points refer 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 Figure 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 SW 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 SW. 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]](#footnote-8) gives further details on how we construct our balanced panel using the Arad readings and SW billing data. The higher frequency for the pre-switch period provides us with a unique opportunity to investigate whether households change their consumption behaviour already in the period between meter installation and switch of contract. Although customers are still subject to unmetered charges, they may take into account that changing consumption patterns takes time and, therefore, they may modify their consumption before the actual change in pricing.

Average daily water consumption for non-UMP is retrieved from SW billing data only. Differently from the balanced UMP sample, the number of observations for non-UMP varies across subjects. As mentioned above, the non-UMP group consists of ‘Households living in New Dwellings’ and ‘Optants’. ‘Optants’ are typically low-occupancy households, possibly living in properties with high rateable value, who can save money by moving on to metered charge. Accordingly, the level of consumption of UMP group is likely to be higher than the consumption of non-UMP because of two reasons: (i) differences in households’ characteristics (in particular, number of occupants) and (ii) differences in behaviour, for 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 households’ characteristics represents a challenge for our analysis because 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, SW data include a variable, known as *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 SW using the information provided by the account holder on the number of household members, plus, potentially, some characteristics of the property (e.g. presence of a garden or swimming pool or dishwasher usage).[[9]](#footnote-9) Note that this variable is determined before observing the actual consumption of the households, and it is not changed afterwards. 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 the specification with periodic consumption are very similar to the coefficients in the specification with household fixed effects. This confirms that the variable is effective in controlling for different unobserved ex-ante characteristics of the households, in particular the number of occupiers, and therefore allows us to identify the reduction in consumption due to metering, net of differences in households’ characteristics, despite the existence of households that self-selected into metering before the implementation of 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, for a total of more than one million observations. The number of non-UMP customers are 532,981, for a total of more than four million observations.[[10]](#footnote-10) The table 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 than non-UMP, confirming that these two groups have different characteristics. The number of observations reported at the bottom of the table shows that this variable is available for most of UMP but it is only available for half of non-UMP.

**Table 2**. Descriptive Statistics

|  |
| --- |
| **Table 2**: Descriptive Statistics |
|  | **UMP** | **non-UMP** |
| # Household | 167,976 | 532,981 |
| # Observations | 1,175,832 | 4,065,656 |
|  | Consumption: Daily Litres |
| Mean | 340 | 248 |
| Median | 305 | 216 |
| Min | 0 | 0 |
| Max | 2000 | 2000 |
| 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 |

Finally, to analyse the distributional effects of metering, we classified households in three different income groups using two different sources. The first is the income deprivation index published by the Office for National Statistics, which offers an aggregate measure at the level of Lower-layer Super Output Area (LSOA), each including a minimum of 400 and a maximum of 1,200 households. The second 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 the household level, rather than at the LSOA level. The drawback is that we do not have access to this measure for non-UMP. Detailed information on how the income groups have been constructed can be found in Appendix B.

***3.3 Specifications and Identification Strategy***

To assess the impact of metering on water consumption we use the following specification:

where is the average daily litres of water used by household *i* living in the postcode area *n* in period , *IUMP* is a dummy variable taking value one for UMP customers and zero otherwise. *DPSj* and *Dj* are a set of dummies taking value one when the household is at phase *j* of the UMP programme,[[11]](#footnote-11) where the subscript PS refers to the pre-switch observations. Accordingly, DPS2 and DPS3 indicate the second and third observation before the change of contract while D1-D4 refer to the periods corresponding to the first, second, third and fourth bill after switch of contract (see Figure 5 for the correspondence between the different phases of the customer journey and these variables). Note that the coefficient indicates how water usage of the UMP group differs from the consumption of non-UMP at the very beginning of the pre-switch period while the coefficients and show how the consumption of UMP differs from that of non-UMP in the following periods. All specifications also include a complete set of monthly dummies, *ηt*,[[12]](#footnote-12) and (4-digit) postcode dummies, *ηp*. The monthly dummies capture seasonal changes in water consumption common across both UMP and non-UMP households, while the *ηp* term 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 in ten different groups with increasing values of periodic consumption (e.g. group 1 if per. cons. <50 and group 10 if per. cons. >=200) and we construct ten dummies, one for each group. The vector **C** in equation (2) refers then to these ten indicator variables.

As mentioned, in specification (2), the coefficient *γ* measures the differences in levels of consumption between UMP and non-UMP when we observe water usage of the former group for the first time (i.e the first observation of the pre-switch period) while the *β*s coefficients provide an estimate of the reduction in litres of water consumed by UMP customers in the following six periods. Initial differences in water consumption, captured by *γ*, can be due to 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 (in particular, the number of occupiers) is different from non-UMP. As already mentioned, results in Section 4 show that the use of *periodic consumption* is effective in controlling for structural differences between the two groups, thus allowing identifying the initial *overuse* of water driven by differences in the pricing structure.

We also estimate a second specification that includes household fixed effects (FE) :

The term control for unobserved differences across households that affect their water consumption, such as numbers of members, preferences for the environment and usage of water-intensive durable goods. Differently from specification (2), where we control for differences across households using *periodic consumption* as a control variable, household fixed effects FE 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 *β*s using the two specifications (cfr 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 window considered (e.g. for most cases, family size). Note that the time-invariant regressors *ηp* and *C* cannot be included in specification (3) as they are perfectly collinear with . This means that the FE specification has the disadvantage that it does not allow identifying initial differences in the level of consumption between UMP and non-UMP customers and, accordingly, whether there is the expected convergence between the two groups.

The fact that the distribution of meter installation 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 programs where subjects are all treated at the same time (see Wichman, 2017). In fact, it is very unlikely that unobserved changes in households’ behaviour or characteristics take place systematically at the same time of 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. 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 to control for their impact on UMP. Moreover, given that the treatment (i.e. meter installation) takes place at different points in time, we can use other UMP with a meter installed in a different time period to identify seasonal changes in consumption that are unrelated to metering.

**4. Results**

In this section, we first 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 households’ water consumption, if it were to find only minor differences 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 installation until the fourth metered bill. Columns (1) and (2) show the estimated coefficients of specification (2), with and without periodic consumption, while column (3) refers to specification (3) with households’ FE. 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]](#footnote-13) As we have three different data points for the pre-switch period, we can observe if 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 at the very beginning of the pre-switch period,[[14]](#footnote-14) but only 93 (=155-62) litres more at the end of the pre-switch period. Looking at the overall change two years after 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 it is significantly higher than the 12% reduction observed in the so-called National Metering Trials that took place in England in the late ’80-early ’90 (Herrington, 2007).

The 22% reduction represents an assessment of the impact of metering on UMP customers, but it is not necessarily the reduction that we would observe if none of the customers served by SW had a meter before the beginning of the programme, because UMP and non-UMP have different characteristics, in particular regarding the number of occupants. In order to identify the effect of metering in the presence of differences in households’ characteristics, in column (2) we estimate a specification which 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 out of 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 bill four of -89 litres suggests that there is almost perfect convergence in the water usage between the two groups two years after installation. This is a remarkable result which 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, indeed consume similar amounts of water, irrespective of being part of UMP or not. Results in column (3) show that the reduction estimated using OLS is confirmed when using FE estimator, which controls for unobserved time-invariant heterogeneity across customers. Given the relatively short time period considered, this would include in most cases also the number of occupants. This gives further support to our identification strategy.

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| **Table 3:** Metering and Water Consumption  |
| Variable |  |
| Description | Name | OLS(1) | OLS(2) | FE(3) | Q25(4) | Q50(5) | Q75(6) |
| *non-UMP* | *α* | 248.4 | 248.4 | 248.4 | 124 | 216 | 329 |
| *UMP:* |  |  |  |  |  |  |  |
| *Pre-Switch (1st)* | IUMP | 154.930\* | 90.461\* |  | 105\* | 129\* | 171\* |
|  |  | (0.71) | (0.59) |  | (0.44) | (0.45) | (0.78) |
| *Pre-Switch (2nd)* | DPS2 | -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)* | DPS3 | -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* | D1 | -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* | D2 | -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* | D3 | -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* | D4 | -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. |  |  |  |  |
| Nmb ObsN ×(mean of) T *- UMP*N×(mean of) T *– non-UMP* | 5,241,488167,976×7532,981×7.6 | 3,246,210154,769×7387,006×5.5 | 5,241,488167,976×7532,981×7.6 | 5,241,488167,976×7532,981×7.6 | 5,241,488167,976×7532,981×7.6 | 5,241,488167,976×7532,981×7.6 |
| *Note*: Water consumption is measured in Litres per Day. Robust Standard Error in Parenthesis. \*p<0.001 |

Results in columns (2) and (3) confirm that the reduction in consumption, once we control for differences in households’ characteristics, amounts to 89 litres per day. A similar reduction could be expected if universal metering was 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 the South-East. However, this figure is higher than what we would have observed if none of SW customers had a meter installed beforehand, because the 40% of non-UMP households with a meter already installed, and particularly optants, are likely to have on average a lower number of occupants and, therefore, a smaller leeway to adjust their consumption, as discussed above. [[15]](#footnote-15)

As a first exercise to explore the heterogeneous effects of metering across households with different level 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%, 16% and 20.5%. These results make clear that there is a large heterogeneity in the effects of metering: absolute reduction in water usage at percentile 75 is more than threefold 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 may not be cost-efficient to meter because their reduction in water consumption is 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 Sims et al. (2007, p.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 households 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 then devoted to assess 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 not be UMP households that, given their consumption with the unmetered tariff, are better-off under the metered tariff (because they should have already taken the metering option), we do observe a large number of such households in our data. This can be due to many reasons. One possibility is lack of information about own consumption in the absence of a meter and, thus, 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, for 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 a problem of reversion to the mean.[[16]](#footnote-16) To avoid this problem, we regress the difference between the metered bill and the unmetered bill on periodic consumption and rateable value (RV) 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 (RV). 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:

(a) *winners*, if predicted metered bill is more than 10% higher than unmetered bill;

(b) *losers*, if predicted metered bill is more than 10% lower than unmetered bill;

(c) *on-par* if predicted metered is within 10% of unmetered bill.[[17]](#footnote-17)

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

Using the classification above, the percentage of *winners,* *losers* and *on-par* 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 4th bill, while losers decrease consumption by 194 litres.[[19]](#footnote-19) The large difference in the litres of water saved is mainly due to the fact that losers are large households.

Assuming that people opting-in 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 customers that should receive a meter from the society’s point of view, 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 behavioral constraints are taken into account.

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| **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)* | IUMP | 4.703\* | 140.09\* | 356.685\* |
|  |  | (0.66) | (1.13) | (1.30) |
| *Pre-Switch (2nd)* | DPS2 | -23.644\* | -48.559\* | -106.147\* |
|  |  | (0.76) | (1.33) | (1.55) |
| *Pre-Switch (3rd)* | DPS3 | -26.166\* | -53.736\* | -118.621\* |
|  |  | (0.76) | (1.31) | (1.53) |
| *1st Bill* | D1 | -13.837\* | -50.894\* | -138.104\* |
|  |  | (0.81) | (1.33) | (1.51) |
| *2nd Bill* | D2 | -18.844\* | -61.470\* | -173.723\* |
|  |  | (0.81) | (1.34) | (1.49) |
| *3rd Bill* | D3 | -20.979\* | -66.397\* | -186.976\* |
|  |  | (0.81) | (1.35) | (1.49) |
| *4th Bill* | D4 | -24.118\* | -70.645\* | -193.580\* |
|  |  | (0.82) | (1.36) | (1.50) |
|  |  |  |  |  |
| Nmb ObsN ×(mean of) T *- UMP*N ×(mean of) T *– non-UMP* | 4,564,20371,221×7532,981×7.6 | 4,267,43128,825×7532,981×7.6 | 4,442,03253,768×7532,981×7.6 |
| *Note*: Water consumption is measured in Litres per Day. Robust Standard Error in Parenthesis. \*p<0.001 |

**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 over-consumption exceeds the cost of metering. But what is the proportion of households for which it is optimal from the societal point of view 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 Figure 2. Accordingly, equation (1) can be rewritten as:

or rearranging:

where the gross benefits associated with the daily reduction in water consumption from to 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 said, this is likely an upper bound of the true but unobserved marginal cost for most of the 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 be admittedly higher. Accordingly, our analysis provides a conservative measure of the proportion of houses for which metering is not efficient from the social point of view. [[20]](#footnote-20) As for the cost of metering *m,* figures published by the Environmental Agency (2008) suggest that the additional annual costs per metered households for reading, billing and customer services amount to £15.5 per year[[21]](#footnote-21) whereas the one-off cost of installation may vary from £206 for a simple internal installation to £1126 for a complex external installation. Table 5 shows the different values that the right-hand-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 done in dwellings in England and Wales. Given that the cost of the installation needs to be divided over the fifteen years of a meter 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* and then we calculate the RHS of equation (4) dividing by 365\**c*. The results in column (4) show that metering is socially efficient only for those households that reduce consumption of 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 to all households served by SW has been overall beneficial from the society’s point of view. So, extending universal metering to other areas of England and Wales would be welfare improving compared to 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 using the most optimistic estimate of the cost of installation (Simple Internal). The analysis in Section 4 also show that small households (those with lower absolute value of water consumption) are also those with a smaller reduction in the litres of water consumption after meter installation. These household 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 to assess the efficiency of metering after all structural works have been done. In this case, the percentage of households for whom it is not cost-efficient to have a meter installed would be more than 25%.[[22]](#footnote-22) Finally, complex installations (which account for around 10%) should never be performed, as they are very unlikely to generate a reduction in consumptions that can compensate for the costs of the intervention. This seems compatible with the fact that the target of the UMP programme was to increase the number of metered customers to 90% as SW anticipated technical problems for around 10% of properties.

The fact that under reasonable assumptions about marginal costs and shape of the 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 metered installed while small households need to pay for the cost of installing the meter if they want a meter) would be a more efficient way to address the problem of excess consumption, as advocated by Cowan (2010).

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| **Table 5**: Cost of Meter Installation |
| *Type of Installation* | *Percentage1* | *Cost Installation2* | *Annualized Cost Installation3* | *Min Water Reduction to cover costs4* |
|  | (1) | (2) | (3) | (4) |
|  | *%* | *£* | *£* | *Litres* |
| Simple External | 60 | 225 | 20.64 | 59.62 |
| Harder External | 20 | 450 | 41.29 | 93.67 |
| Complex External | 5 | 1126 | 103.32 | 195.98 |
| Simple Internal | 2.5 | 206 | 18.9 | 56.74 |
| Harder Internal | 7.5 | 412 | 37.8 | 87.92 |
| Complex Internal | 5 | 1030 | 94.51 | 181.45 |
|   |   |   |   |   |
| Replacement |   | 70 | 6.42 | 36.16 |
| *Source*: Environmental Agency (2008) - EA.  |
| *1* Percentage of installation that are simple, harder or complex, taken from last column of Table 3.4 in EA. |
| *2* Figures for total cost taken from page 83 in EA have been multiplied by 1.17 to adjust for inflation.  |
| *3* The annualized cost is computed using an interest rate of 5% and assuming that lifetime of a meter is 15 years (page 4 in EA).  |
| *4* Right-Hand-Side of Equation (4) with *m =* (column(3) + £15,5) and *c*=0.003322 |

***5.2 Distributional Effects***

This section investigates whether there are significant differences in how metering affects water consumption and water bills of more affluent vis-a-vis less affluent families. Given that the unmetered bill is based on the RV of the house, switching to a metered tariff is likely to be very costly for large families living in small properties and rather beneficial to singles 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 one as it consists in moving from unmetered (i.e. zero marginal cost) to metered tariff. 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 is higher in richer areas. The table shows that the difference in consumption between non-UMP and UMP at the first observation of the pre-switch period is also larger in richer areas. Wealthiest areas are found to have a larger reduction in the absolute number of litres of water but, rather interestingly, the percentage reduction in consumption is almost identical among the three groups: 23% (=-87.5/(238.5+147.2)) for UMP living in low income areas, 22% and 23% for UMP 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 larger 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%).

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 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 waters for activities that provided them with higher utility.

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| **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* | 238.5 | 248.9 | 269.7 | 248.4 | 248.4 |
| *UMP:* |  |  |  |  |  |  |
| *Pre-Switch (1st)* | *IUMP* | 147.21\* | 156.95\* | 165.56\* | 133.288\* | 226.725\* |
|  |  | (1.16) | (1.02) | (2.04) | (1.49) | (1.71) |
| *Pre-Switch (2nd)* | *DPS2* | -53.222\* | -52.841\* | -65.008\* | -55.357\* | -68.608\* |
|  |  | (1.32) | (1.18) | (2.36) | (1.81) | (2.09) |
| *Pre-Switch (3rd)* | *DPS3* | -58.432\* | -60.615\* | -72.143\* | -62.131\* | -74.961\* |
|  |  | (1.32) | (1.17) | (2.37) | (1.78) | (2.06) |
| *1st Bill* | *D1* | -56.341\* | -60.842\* | -71.172\* | -62.637\* | -75.324\* |
|  |  | (1.37) | (1.20) | (2.40) | (1.76) | (2.02) |
| *2nd Bill* | *D2* | -75.308\* | -77.982\* | -87.276\* | -81.243\* | -91.678\* |
|  |  | (1.34) | (1.18) | (2.35) | (1.73) | (1.99) |
| *3rd Bill* | *D3* | -81.661\* | -84.941\* | -92.806\* | -87.595\* | -98.479\* |
|  |  | (1.34) | (1.18) | (2.35) | (1.73) | (1.99) |
| *4th Bill* | *D4* | -87.492\* | -89.386\* | -99.051\* | -93.730\* | -102.479\* |
|  |   | (1.33) | (1.18) | (2.35) | (1.72) | (1.99) |
| Nmb ObsN×(mean of) T *- UMP*N×(mean of) T *– non-UMP* | 1,873,86866,525×7192,297×7.3 | 2,408,20179,545×7237,019×7.8 | 736,34520,571×771,201×8.3 | 4,302,49033,832×7531,966×7.6 | 4,259,98827,761×7531,966×7.6 |
| *Notes.* Water consumption is measured in Litres per Day. Robust Standard Error in Parenthesis. \*p<0.001. Mosaic classification is available only for UMP, so all non-UMP are used in the specifications of column (4) and (5). |

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 change in bill for different income groups.

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| **Table 7:** Water Bills and Income |
|  | AREA INCOME | MOSAIC INCOME |
| Bill Difference  | Statistics | 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 |
|  |  |  |  |  |  |  |

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 bill between £10.1 and £11.5 at bill 4. Given that there are two water bills per year, this means 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 would have kept their consumption at the pre-switch level. Results in column (3) and (5) show that more affluent families gain on average, around £36-£38 with the metered tariff. Looking at the median changes at bill 4 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 find that switching to current metered tariff (or other hypothetical tariffs) does not, on average, make low-income households worse off.

**6. Conclusions and Policy Implication**

This paper investigates the impact of the *Universal Metering Programme* of South-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 large heterogeneity in the way households react to metering. In particular, we observe 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 the optional metering in England is inducing the wrong types of households 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 find that high-income households gain financially upon 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 investigate when it is socially valuable for a household to be metered. 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 exceeding 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, a 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 size and consumption habits of individual households. Water utilities may not know, for instance, 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 move to different houses. Moreover, a 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’ association, in particular 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, 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 vs universal metering would be an interesting venue for future research.

**Supplementary material**

Supplementary material is available on the OUP website. The supplementary material comprises the Online Appendix 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>

**Funding**

This work was supported by the Economic and Social Research Council, UK [ES/K01210X/1]; and the University of Southampton Strategic Research Development Fund.

**Acknowledgements**

We would like to thank two anonymous reviewers as well as various conference and seminar participants for helpful comments. We also thank Carlos Pineda for excellent research assistance and Southern Water for providing the data.

**References**

Agthe, D. E. and Billings, R. B. (1987). Equity, Price Elasticity, and Household Income Under Increasing Block Rates for Water, *American Journal of Economics and Sociology*, **46**, 273-286.

Cowan, S. (2010). The Welfare Economics of Optional Water Metering, *The Economic Journal*, **120**, 800-815.

Dalhuisen, J.P., Florax R.J., de Groot H. and Nijkamp P. (2003). [Price and Income Elasticities of Residential Water Demand: A Meta-Analysis](https://ideas.repec.org/a/uwp/landec/v79y2003i2p292-308.html), [*Land Economics*](https://ideas.repec.org/s/uwp/landec.html), **79**, 292-308.

Dresner, S. and Ekins, P. (2004). Towards the Design of an Environmentally and Socially Conscious Water Metering Tariff, *PSI Research Discussion Paper*. <http://www.psi.org.uk/docs/rdp/rdp21-dresner-ekins-water.pdf> (last accessed 26/09/2019)

Environment Agency (2008). The costs and benefits of moving to full water metering. *Science Report SC070016/SR1 (WP2)*. Environment Agency, Bristol, UK. <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/290983/scho0508bobn-e-e.pdf> (last accessed 26/09/2019)

Expert Commission on Domestic Public Water (2016). Report on the Funding of Domestic Public Water Services in Ireland.

Herrington, P. (2007). Waste not, want not? Water tariffs for sustainability. A report to the WWF-UK, Centre for sustainable energy. *The CREATE Centre*, UK. <http://assets.wwf.org.uk/downloads/water_tariffs_report01.pdf> (last accessed 26/09/2019)

Independent Competition and Regulatory Commission (2016). Marginal cost pricing in the ACT, Tariff Review 2016. *Technical Paper 2*. Camberra, Australia

Joint Committee on the Future Funding of Domestic Water Services (2017). Report, <https://beta.oireachtas.ie/en/committees/32/future-funding-of-domestic-water-services/> (last accessed 26/09/2019)

Mayer, P. W., Towler E., DeOreo W. B., Caldwell E., Miller T., Osann E. R., Brown E., Bickel P. J., and Fisher S. B. (2004) National Multiple Family Submetering and Allocation Billing Program Study. Aquacraft, Inc. and the East Bay Municipal Utility District.

Nataraj, S. and Hanemann, W. (2011). Does marginal price matter? A regression discontinuity approach to estimating water demand, *Journal of Environmental Economics and Management*, **61**, 198-212.

National Metering Trials Working Group (1993). Water Metering Trials. Final report. London; WSA, WCA, Office of Water Services, WRc and Department of the Environment.

OECD (1999). Household water pricing in OECD countries. *Working Party on Economic and Environmental Policy Integration*, OECD, Paris.

OECD (2010). Pricing Water Resources and Water and Sanitation Services, OECD, Paris. <http://dx.doi.org/10.1787/9789264083608-en> (last accessed 26/09/2019)

Olmstead, S., Haneman M.W. and Stavins, R. (2007). Water demand under alternative price structures, *Journal of Environmental Economics and Management*, **54**, 181-198.

Ueda, T. and Moffatt P.G. (2013), A Socially Efficient Water Tariff Under the English Optional Metering Scheme, *Environmental and Resource Economics*, **54**, 495-523.

Wichman, C., Taylor, L. and von Haefen, R. (2016). Conservation Policies: Who Responds to Price and Who Responds to Prescription? *Journal of Environmental Economics and Management*, **79**, 114-134.

Wichman, C. J. (2017), Information provision and consumer behavior: A natural experiment in billing frequency. *Journal of Public Economics*, **152**, 13-33.

World Bank (2005). Water, Electricity, and the Poor. Who Benefits from Utility Subsidies?, Washington, DC. <https://openknowledge.worldbank.org/handle/10986/11745> (last accessed 26/09/2019)

Worthington, A. and Hoffman, M. (2008). An Empirical survey of residential water demand modelling. *Journal of Economic Surveys*, **22**, 842-871.

Zetland, D. (2016). The Struggles for Residential Water Metering in England and Wales”. *Water Alternatives* **9,** 120-138.

<http://www.water-alternatives.org/index.php/alldoc/articles/vol9/v9issue1/307-a9-1-6> (last accessed 26/09/2019)

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. [↑](#footnote-ref-1)
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 whilst being less costly than metering (Worthington and Hoffman, 2006). [↑](#footnote-ref-2)
3. Note that the price set by Ofwat takes also into consideration environmental aspects. The regulator evaluates different aspects of the water companies’ business plan 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. [↑](#footnote-ref-3)
4. In 2017 SW charges for water and sewerage were respectively 1.248 £/m3 and 2.242 £/m3. 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). [↑](#footnote-ref-4)
5. According to the Tariff Review 2016 published by the Independent Competition and Regulatory Commission 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 £/m3 using an exchange rate of 1.8 Australian $ per British £. [↑](#footnote-ref-5)
6. Tariffs go from the 1st April to the 31st of March of the following year. [↑](#footnote-ref-6)
7. A consumption above 2000 l/day is way above what is reasonable for a household and suggests that these customers may not be private households but people that, for instance, run some 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 1500 l/day. [↑](#footnote-ref-7)
8. All appendices are available on the website of the Oxford University Press or on the webpages of the authors. [↑](#footnote-ref-8)
9. For instance, around 15% and 16% of observations of periodic consumption take value of respectively, 50 and 100. Discussion with SW representatives revealed that these are households with respectively 1 and 2 members, for which SW does not have other relevant information about their characteristics. [↑](#footnote-ref-9)
10. The non-UMP data represent 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 non-UMP group). See Appendix A for further information.

 [↑](#footnote-ref-10)
11. These dummies are always zero for non-UMP households, as they do not receive a meter. [↑](#footnote-ref-11)
12. The monthly dummies refer to calendar time, e.g. September 2013. They take values 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 value of 1. [↑](#footnote-ref-12)
13. Discussion with managers at SW 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). [↑](#footnote-ref-13)
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. [↑](#footnote-ref-14)
15. Appendix C shows that our analytical framework and empirical findings are substantially unaffected by the fact that metering allows to detect leaks in the internal pipes of dwellings. [↑](#footnote-ref-15)
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). [↑](#footnote-ref-16)
17. A cut-off of 10% gives a reasonable high number of households in all the three groups. Similar results are obtained with a cut-off of 15%. [↑](#footnote-ref-17)
18. Indeed, classifying households as *winners* looking at the difference between the last unmetered bill and the first metered bill would include behavioural responses to metering because we have shown that UMP customers react very fast to metering. [↑](#footnote-ref-18)
19. To compute the percentage reduction, we need to know the level of consumption of UMP soon after the installation (i.e. the coefficient on IUMP). Using OLS estimator as in column (1) of Table 3, we find that the reduction for winners and losers is respectively, 9% and 32%. [↑](#footnote-ref-19)
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. [↑](#footnote-ref-20)
21. The figures reported at page 84 of Environmental Agency (2008) 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. [↑](#footnote-ref-21)
22. The required reduction in water usage in the case of “Replacement” (last row of Table 5) is 36 litres which is more than the 31 litres reduction at percentile 25 reported in Table 4. [↑](#footnote-ref-22)