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# The Effects of Universal Metering Programme on Water Consumption, Welfare and Equity

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# THE EFFECTS OF THE UNIVERSAL METERING PROGRAMME ON WATER CONSUMPTION, WELFARE AND EQUITY

BY CARMINE ORNAGHI AND MIRCO TONIN,[1]

*There is general consensus that water meters are necessary for promoting an efficient use of water through some form of pricing mechanism based on effective consumption. However, available evidence on benefits and costs of metering is scant and often based on a small sample of households. This paper uses data of the first large-scale universal metering programme in England to produce a comprehensive analysis of the impact of metering on consumption, social efficiency and distributional outcomes. We find that, on average, due to metering households decrease consumption between 18% and 22%, a higher value than assumed as a policy target. The percentage reduction in water consumption is very similar across different income groups but, whereas high-income households gain financially upon switching to metering, less affluent households are, on average, around £10 worse-off. Finally, our analysis shows that there is a large proportion of households for which the social cost of metering outweighs the benefits, thus calling into question whether universal metering should be extended to other areas of the country in its current format, as opposed to a selective metering programme where only "large" households receive a meter, which would be more efficient from the society's point of view.*

***Keywords**:* Water meters, social efficiency, equity.
***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 tariff should be designed to reach this end remains subject to debate. For example, in 2011 Italy held a referendum in which 95% of the voters decided to repeal two laws on water services introduced just a few years before, one that allowed privatization of local water companies and one that introduced new water tariffs that ensured a 7% return on invested capital. In 2014, Irish Water, the national water utility in Ireland, started an ambitious programme to install over one million meters but, following the strong opposition shown by residents, the programme was stopped in 2016 with around 900 thousands metered put underground (Expert Commission, 2016); water charges have also been scraped and the Irish Parliament is expected to pass a law to fund water services through general taxation (Joint Committee, 2017). These two examples testify the tension between having tariff schemes that, on the one hand, encourage households to save water and

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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, according to figures published by the Environmental Agency (2008), more than 30% of the 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 classed 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.[2]

Using data for around 250 thousands customers of Southern Water's *Universal Metering Programme* (UMP),[3] this paper produces a number of new results on the effects of metering on consumption, social welfare and equity. First, we find an average reduction in water usage of 18% (net of leaks), a number substantially higher than the 12.5% that has been often used as a target reduction for metering (Herrington, 2007). This call into question the conclusion of the National Metering Trials Working Group (1993) that the results of the Isle of Wight were abnormally high and that it would be unwise to generalize them to other times and places.

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[2] Zetland (2015) offers an interesting overview of efficiency and equity issues arising from meter installation in England and Wales.

[3] In the remaining of the paper the terms "households" and "customers" are used as synonymous.

Second, we find substantial differences in the impact of metering on water consumption across different households. In particular, we document that small and wealthier household gain financially from metering, yet they are those that exhibit a smaller reduction in the deadweight loss due to over-consumption once a meter is installed. By providing evidence that households that have financial incentives to have a meter are not those whom it is socially efficient to meter, our analysis gives strong support to the claims 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 universal metering programme by comparing the costs of installing and operating a meter to the benefits associated with reduction in over-consumption. In Section 2 we show that the proportion of UMP customers with a reduction in overconsumption that exceeds the cost of metering critically depends on the correct identification of the marginal cost of water. While the UMP has contributed to an increase in social welfare, our analysis confirms that a large proportion of households should have not received a meter from a social welfare point of view. An immediate implication of our results is that a selective metering programme where "large" households are required to have a metered installed, while "small" households need to pay if they want a meter, would be substantially more effective in increasing total welfare.

Finally, we look at the distributional effect of UMP by investigating whether there are significant differences in how metering affects water consumption and water bills of more affluent families vis-a-vis less affluent families. In contrast with the findings by Aghte and Billings (1987) and the recent study 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 less affluent households are, on average, around £10 worse-off.

Most of the existing literature on water pricing focuses on the demand effect associated with incremental price changes and/or inter-block tariff change, while taking universal metering as given.[4] 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

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[4] For instance, Olmstead et al. (2007) study consumers' sensitivity to water prices under alternative rate configurations. Using a structural model that accounts for non-linear prices, the authors find a price elasticity of water demand of -0.33 in a sample of 1,082 households in 11 urban areas of the United States and Canada. Nataraj and Hanemann (2011), on the contrary, study the effects of the introduction of a third price block in Santa Cruz, California, and find that doubling the marginal price leads to a 12% decrease in water use among the high-use households. Worthington and Hoffman (2008) provide an extended survey of empirical residential water demand analyses conducted since the early eighties.

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. To overcome this problem, the authors suggest using a two-part tariff with a constant marginal cost and a progressive standing charge that should encourage poorer households to install a meter whilst discouraging richer households.

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 low income households. As noted by Zetland (2015), "*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*".[5]

This paper tries to fill in the existing gaps in the literature by providing a comprehensive analysis of the impact of the first large-scale Universal Metering Programme in England on water consumption, social efficiency and distributional outcomes. Beside England, metering is a major issue in the policy debate in several countries. 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, 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 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."

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[5] 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, such as low-flush toilets, can be equally effective in reducing water consumption whilst being less costly than metering (Worthington and Hoffman, 2006). For instance, Wichman et al. (2016) find that voluntary and compulsory restrictions are effective demand management tools, reducing household consumption by approximately 8.5% and 13%, respectively. In a recent field experiment, Tiefenbeck et al. (2017) find that real-time feedback when showering reduced resource consumption for the target behaviour by 22%. However, evidence by Renwick and Green (2000) and Sim et al. (2007) suggest that price and non-price instruments should not be considered substitutes but should be rather used in combination to achieve large reductions in demand.

The remainder of this paper is organized as follows. In Section 2 we present the theoretical framework that is used to interpret the empirical analysis presented in the following sections. Section 3 explains some aspects of the metering programme and presents the data. In section 4 we show the results for the impact of metering on water consumption and we document also its heterogeneous effects across households. In Section 5 we analyse the efficiency and distributional effect of the universal metering programme. Section 6 concludes.

## 2. 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, which affect their demand. Before the installation of a meter, the water tariff consists of a fixed amount $F^U$, which is determined by the rateable value of the house,[6] 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 consumed and the same fixed amount $F^M$ (that corresponds to the standing charge for water supply and sewage) and, accordingly, they have a disposable income equals 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 unmetered tariff is $B^U$ (in blue) and under metered tariff is $B^M$ (in red). 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 meter tariff $F^M$. The intercept of the blue line is lower because $F^U > F^M$. Points $X^U$ and $X^M$ 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. $U^M$) is exactly equal to that in the absence of meter (i.e. $U^U$), 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.

All households with a budget line $B^M$ that crosses the budget line $B^U$ to the right of point $X^U$ are surely better off under the new tariff regime since the bundle $X^U$ is within the budget set. On the

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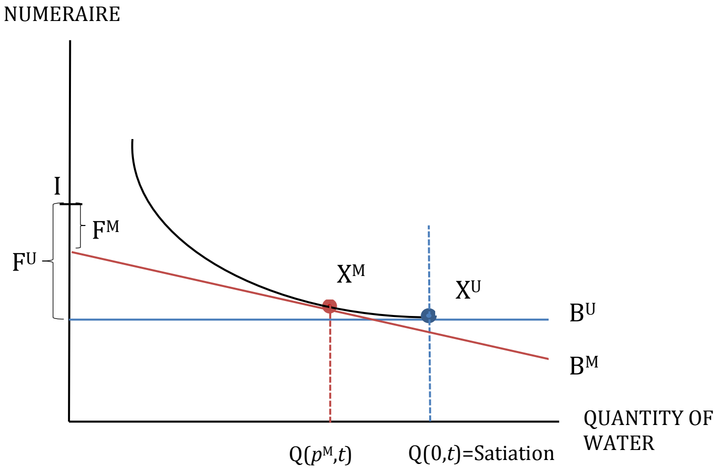
[6] See section 3 for more details.

other hand, if the budget line $B^M$ crosses the budget line $B^U$ to the left of point $X^U$ (as in Figure 1) then the households 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 one.[7] 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 a higher number of members, but similar in any other dimension (and in particular, with the same rateable value). Similarly, a household who lives in a property with high-rateable value is more likely to be better off than a household who lives in a less expensive house (but otherwise similar) because the former experiences a higher shift in the intercept.[8] In the following section we document the heterogeneity in reaction to metering across households that are better-off and worse-off under the new pricing scheme.

**Figure 1**. Household Choice



*Notes*: The vertical axis show the amount that can be spent on goods other than water. “I” is the initial income of the households before paying the water bill.

The installation of a meter is socially desirable if the gross benefits from metering are higher than the related costs. Following the framework in Cowan (2010), we have that:

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

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 a household’s loss of utility when moving from the satiation level $Q(0,t)$ *to* $Q(p^M,t)$ while $(b)$ refers to the related savings in costs. Figure 2 illustrates the

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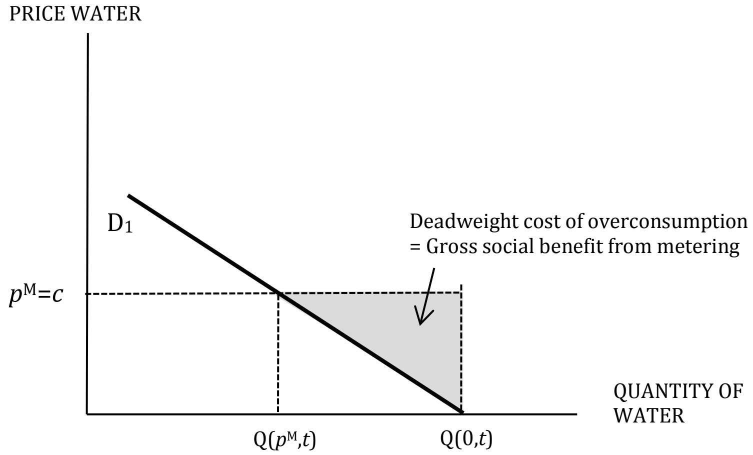
[7] A household is obviously worse off if $X^M$ is south-west of $X^U$ as it consumes less water and has a lower disposable income.

[8] While the two households pay the same $F^M$, the first household used to pay a higher $F^U$ and so it has a larger shift in the disposable income at $Q(p^M,t)=0$.

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

**Figure 2**. Household Demand



Although the deadweight cost of overconsumption is easy to interpret from a theoretical point of view, there are at least two different reasons why it is difficult to quantify empirically. First, the gross benefits of metering depend on the shape of households' demand, something that we cannot observe. To see this, note that in Figure 3 the deadweight loss is smaller in the case of the linear demand $D_1$ compared to the demand curve $D_2$. The rationale behind this alternative demand rests on the observation that part of the reduction in water usage following meter installation is due to leaks detection in home pipelines and, whereas leaks increase the quantity $Q(0, t)$ that we observe in our data, households do not receive any utility from this water (that is, their true consumption level is to the left of $Q(0, t)$). In Section 5 we first investigate the efficiency effects of metering under the assumption that the demand function is linear and we then discuss the sensitivity of our findings under the alternative assumption that households receive no utility from the last amount of water used (similar to the situation illustrated by the demand curve $D_2$).

Second, computing the deadweight loss requires knowing the marginal cost of production *c*, which is not observed either.[9] Figure 3 shows, for instance, that if water is priced below the marginal cost, the social benefit of metering would be underestimated by an amount equals to

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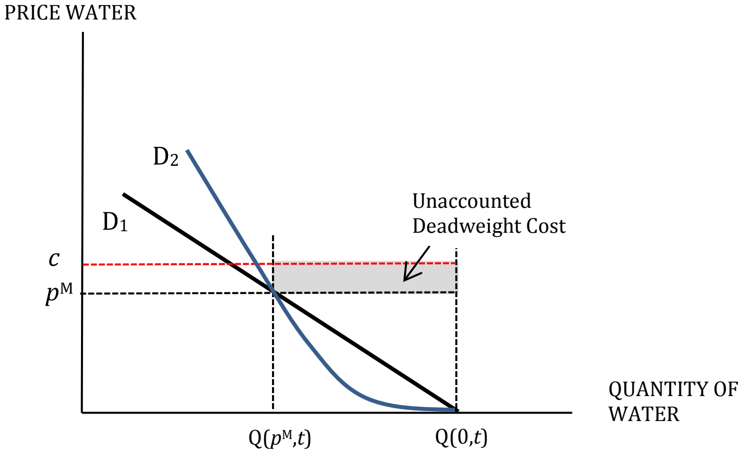
[9] Two main methods to estimate marginal costs have emerged from the literature: the "Turvey" approach and the "Average Incremental Cost" (AIC) approach. Detailed guidance on how to compute long-run marginal costs (LRMC) has been published and periodically reviewed by OFWAT since 2002 based on the AIC method. Nonetheless, the LRMC estimates have not been used to set the tariffs for end users, in part because of the large range of values that are obtained by the companies.

the shaded rectangle.[10] We note that the variable part of the bill paid by our UMP customers includes not only charges for water but also sewerage. For instance, for 2017 SW charges for water and sewerage were respectively 1.248 £/m$^3$ and 2.242 £/m$^3$. Since the volume charge for wastewater service is based on 92.5% of the volume of water supplied, the marginal cost of water including sewerage is 3.322 £/m$^3$ (=1.248+0.925*2.242). As this price falls in the upper side of the estimated long-run marginal costs reported in the literature,[11] the social benefits of metering shown in the empirical exercise of Section 5 can be considered an upper bound of the true benefits of metering.[12]

**Figure 3**. Household Demand



## 3. Data and Econometric Framework

The typical customer journey of UMP households starts with a meter installation, followed by a switch of contract from unmetered to metered tariff, around three months after the installation (see Figure 5). In the period between meter installation and switch of contract, water charges are still based on the previous contract - i.e. on the rateable value (RV) of the house[13] - and not on metered consumption. Three months after the switch of contract, customers receive a letter (known as 3-months letter) showing the expected metered bill they will receive based on the

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[10] This is because we would use $p^M$ instead of $c$ to compute the term (b) of equation 1.

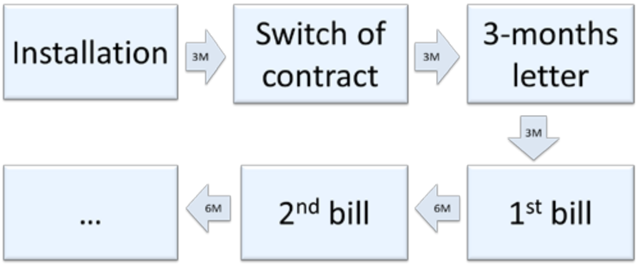
[11] According to the Tariff Review 2016 published by the Independent Competition and Regulatory Commission (ICRC) in Australia, "*all the marginal cost estimates calculated for the purposes of this paper, short- and long-run, are well below [..] current water price of $2.60 per kL*" which corresponds to 1.8 £/m$^3$ using an exchange rate of 1.8 Australian $ per British £. Similarly, Kim (1995) estimates a marginal cost of water of 0,016 cent per gallon for a cross-section of water utilities in the USA, which translates into a marginal cost of 2.81 £/m$^3$ using an exchange rate £ to $ of 1.5.

[12] If $p^M > c$, the actual benefit of metering is overestimated as consumption is moved to a point where the marginal utility is above the marginal cost.

[13] The rateable value was used as the basis for local authority taxation prior to 1990. Rateable values were set by the Valuation Office (part of HM Revenue and Customs) to reflect the rental value of the property. The rateable value is no longer used for taxation and no longer updated. The water company normally use the rateable value quoted in the Valuation List in force on 31 March 1990.

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, UMP customers receive their first bill. ollowing bills will be sent every six months i.e. two bills per year.

**Figure 5**. Customer Journey



Meter installation not only affects water consumption because of the new tariff, but it also allows easier detection of leaks in the house pipes. This means that part of the observed reduction in water usage may be due to repairs of leaks inside property.[14]

As the UMP is gradually implemented in Southern Water supply area, households go through the process outlined in Figure 5 at different points in time. Moreover, we also observe consumption for households who live in the areas where the UMP is being implemented, but are already metered and, thus, do not switch contract. Accordingly, we can trace consumption as households' progress through the different stages of UMP and compare it to the evolution of consumption in the same period by households who are not subject to the UMP but live in the same geographical area. This latter group of households allows us to capture variation in average consumption at the postcode level and also changes in consumption due to seasonality (e.g. temperature or precipitation) or to aggregate economic conditions (e.g. unemployment), thus making it possible to isolate the effect of the UMP.

The data used in the empirical analysis refer to the period from January 2011 to October 2016. The sample includes only customers that have already received four bills (i.e. meters were installed more than 2 years earlier) and whose daily consumption is below 2,000 litres per day.[15] We use two different datasets. The first reports consumptions at five points in time: at

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[14] Moreover, more than thirty thousands (high-usage) customers with water-affordability problems were offered free water-efficiency audits. Around 2/3 of these customers received a meter as UMP customers while the remaining 1/3 already had a meter installed. During these visits, households were given or installed water-saving devices, such as save-a-flush bags, together with general advices on how to save water and energy. These households represent a small percentage of Southern Water customers and results reported in this paper are substantially unchanged when we eliminate these households from the sample.

[15] Note also that it is standard in the water industry to perform various technical adjustments when calculating average consumption. For instance, a meter under-registration allowance should be added to the recorded consumption given that meters cannot record very low flow rates. These adjustments are not relevant for the purpose of the current analysis and, as such, are ignored.

switch of contract and then at bill 1, 2, 3 and 4 (that is, every six months over a period of 2 years). [16] The second will use 7 data points: three for the pre-switch period (typically one, two and three months after installation) and then at bill 1, 2, 3 and 4.[17] This second dataset is useful to investigate whether households start adjusting 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 water consumption patterns takes time and, therefore, they may modify their consumption before the actual change in pricing. We will refer to the first dataset as “Billing” data and to the second as “Arad” data.

**Table 1**: UMP Households

| | *Billing Data* | *Arad Data* |
|---|---|---|
| # Household | 246,665 | 167,976 |
| # Observations | 1,233,325 | 1,175,832 |
| Consumption: Daily Litres of Water | | |
| Mean | 325 | 340 |
| Median | 295 | 305 |
| Min | 0 | 0 |
| Max | 2,000 | 2,000 |
| Percentile 1 | 32 | 51 |
| Percentile 99 | 971 | 1,032 |

Table 1 shows descriptive statistics for UMP customers’ consumption in each of the two datasets. Throughout this entire document, water consumption is measured as litres per day. Using billing data, we observe 246,665 households at five points in time for a total of 1,233,325 observations. With Arad data the number of households for which we can construct a balanced panel over the seven data points is 167,976. The higher mean and median consumption for the Arad data is due to the fact that three readings refer to the pre-switch period, when consumption is generally higher.

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

$$\mathrm{Q}_{i,t} = \alpha_\mathrm{i} + \gamma * \mathrm{D}_{UMP} + \sum_{j=1}^{n} \beta_\mathrm{j} * \mathrm{D}_{j} + \gamma \mathrm{C}_{i} + \eta_{t} + \eta_{p} + \varepsilon_{i,t} \quad (2)$$

where $\mathrm{Q}_{i,t}$ is the average daily litres of water used by household *i* in period *t*, $D_{UMP}$ is a dummy variable taking value one for UMP customers and zero otherwise, $D_j$ is a set of dummies taking

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[16] Meters are set to 0 at the time of installation.

[17] The two datasets come from difference sources. The first has been provided to us by Southern Water and it is based on billing data. The second has been provided to us by Arad Group UK, which provides water meter service to Southern Water. Consumption in the Arad dataset is observed with higher frequency, but data need major work of cleaning. ARAD meter usually stores water consumption at the end of each calendar month. Consumption is also registered anytime a reading machine passes in the area, thus leading to a very unbalanced dataset. Whereas the ARAD data are more detailed, the number of observations in the clean dataset we construct is lower.

value one when the household is at phase *j* of the UMP (e.g. for the Billing data, *j=1,2,3,4* indicates that households have received the first, second, third and fourth bill, respectively). In some of the regression we include the variable "*periodic consumption*", C, as control variable. This variable is an estimate of the expected consumption at the beginning of a contract, with main inputs the information provided by the owner about the number of household members, plus, potentially, some characteristics of the property (e.g. presence of a garden or swimming pool or dishwasher usage). Note that this variable is determined before observing the actual consumption of the households, and it is not changed afterwards. Accordingly, this variable is useful to control for different unobserved ex-ante characteristics of the households, in particular the number of occupiers. Finally, all specifications also include a complete set of monthly dummies, $\eta_t$, and (4-digit) postcode dummies, $\eta_p$.

Equation (2) is estimated using pooled OLS (including time dummies and post-code dummies) and FE. We do not find major differences between the two sets of results.[18] This suggests that the behavioural response estimates reported in the Tables above are robust to unobserved characteristics that are invariant (or at least very persistent) over the time window considered (e.g. for most cases, family size).

## 4. Results

This section documents the average effect of metering using the "Billing" data (Section 4.1) and the "Arad" data (Section 4.2). The latter dataset is also used to investigate whether there is substantial heterogeneity in the way customers respond to metering. As mentioned above, meter installation generates water savings because of two different reasons: (i) behavioural change triggered by a variation in prices and (ii) more effective detection of leaks. In Section 4.1 we investigate the overall effects of metering including leaks while we delve deeper into the impact of leaks in Section 4.2.

### *4.1 Billing Data*

Table 2 shows the change in water consumption over the four bills for UMP customers. The average daily water consumption for metered households not involved in the UMP is 248.4 litres.[19] During the pre-switch period UMP households consume 122 litres more.[20] The coefficient for the dummy $D_1$ in Column (1) shows that there is a reduction in daily consumption

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[18] With Fixed Effects it is of course not possible to identify the difference in the level of consumption between customers subjects to UMP and customers already metered.

[19] This is the average consumption for all available observations of non-UMP customers. Discussion with managers at SW confirmed that 250 litres per day is a very reasonable measure of average consumption of the "already" metered customers.

[20] It should be noted that customers that were metered prior to UMP consist of 'Households living in New Dwellings' and 'Optants' (i.e. customers who chose to be metered). 'Optants' are typically low-occupancy households in properties with high rateable value who are likely to save money by moving on to metered charge. These customers are already conscious of their water consumption and their characteristics may differ from UMP households. As indicated above, the non-UMP group is primarily used to correct for the impacts of weather and seasonality on consumption. Note also that, as part of UMP, all customers who can be metered are being metered and, therefore, there is no selection bias in being part of UMP.

of around 38 litres of water during the six-month period that goes from switch of contract to the 1st bill. Similarly, the coefficients for the dummy $D_2$, $D_3$ and $D_4$ suggest that, compared to their pre-switch consumption level, UMP customers consume, respectively, 55 litres, 61 and 66 litres of water less in the periods leading to the 2nd, 3rd and 4th bill. The figures above suggest that two years after the installation of a meter (i.e. when the 4th bill arrives), we observe an average reduction in water usage of 17.8%, from 370 (=248+122) to 304 litres (=370-66).

**Table 2:** Meter and Water Consumption in Litres per Day

| Variable<br>Description | Name | OLS<br>(1) | OLS<br>(2) | FE<br>(3) | OLS-Arad<br>(4) |
|---|---|---|---|---|---|
| *non-UMP* | | 248.4 | 248.4 | 248.4 | 248.4 |
| *UMP:* | | | | | |
| *Pre-Switch* | $D_{PS}$ | 121.968* | 59.082* | | 111.255* |
| | | (0.53) | (0.46) | | (0.55) |
| *1st Bill* | $D_1$ | -38.054* | -42.543* | -41.446* | -19.168* |
| | | (0.66) | (0.53) | (0.36) | (0.71) |
| *2nd Bill* | $D_2$ | -54.600* | -56.309* | -55.670* | -36.581* |
| | | (0.64) | (0.52) | (0.38) | (0.69) |
| *3rd Bill* | $D_3$ | -61.261* | -59.262* | -60.048* | -43.237* |
| | | (0.64) | (0.53) | (0.40) | (0.69) |
| *4th Bill* | $D_4$ | -65.712* | -60.978* | -62.868* | -48.359* |
| | | (0.64) | (0.53) | (0.41) | (0.69) |
| *Periodic Consumption* | | | Incl. | | |
| *Nmb Obs* | | 5,298,961 | 3,294,522 | 5,298,961 | 4,905,471 |

*Note*: Water consumption measured in Litres per Day. Robust Standard Error in Parenthesis. *p<0.001

Customers' surveys show that the typical UMP household has a larger number of occupants than non-UMP customers.[21] This can explain part of the difference in average consumption between the two groups. Although we do not have a direct measure of the number of occupants, we can use "*periodic consumption*" to control for this and other unobserved characteristics of the household. Column (2) shows the results when adding this variable to the specification. The lower number of observations is due to the fact that *periodic consumption* is not available for some households in our dataset.[22] Two things are worth noting. First, the average UMP customer is now found to consume around 59 litres of water more in the pre-switch period. This means that half of the 122 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 -61 litres suggests that there is almost perfect convergence in the water usage between the two groups two years after installation. This result gives strong support to the assumption that *periodic consumption* can effectively capture structural differences between households,

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[21] This is also due to selection in choosing the metering option as explained in the footnote above

[22] Note that similar results to those in column (1) are obtained when using the sample of households with non-missing periodic consumption: the largest difference being for the coefficient on Bill 4 which is -62.6, i.e. three litres less than the corresponding coefficient reported in the column (1). This suggests that periodic consumption is missing at random and we do not have a problem of sample selection along this dimension.

since similar households, when facing the same incentives for a sufficient period of time, should indeed consume similar amounts of water, irrespective of being part of UMP or not. Similarly, results in Column (3) show that the reduction observed at Bill1-Bill4 using OLS is confirmed when using a Fixed-Effect (FE) estimator (which also controls for any unobserved time-invariant heterogeneity across customers, including in most cases number of occupants).

Finally, in Column (4) we run the same specification of Column (1) using only the (smaller) sample of households for which we have Arad data. We can see that this sub-sample of customers tend to consume 10 litres of water less in the pre-switch period (111 litres vs 121 litres). The estimated effect of metering is a reduction in consumption at 4th Bill of 48 litres, i.e. a 13.5% decrease with respect to the pre-switch period. The fact that the Arad sample shows a smaller decrease in consumption means that the results discussed in the next section may represent a lower bound of the actual impact of the UMP programme on water consumption.

### *4.2 Arad Data*

In this section, we use “Arad” data first to assess the effect of metering on average water consumption as well as the response of households at different points of the consumption distribution and then, to investigate whether the reaction of households that experience a large increase in their water bill is substantially different from those receiving a lower bill. The latter exercise allows us to understand whether customers that gain/lose financially from having a meter have a higher/lower responsiveness to metering (which in turn will ensure that metering is socially efficient).

“Arad” data contain three different observations for the pre-switch period. Therefore, we can observe if there is any adjustment in the period between installation and switch of contract. The first important result we obtain is that there is indeed a drastic reduction in consumption during the pre-switch period: Column (1) shows that UMP customers consume 155 litres more than non-UMP at the very beginning of the pre-switch period, but only 93 (=155-62) litres more at the end of the pre-switch period. This means that the 111 litres reported in Column (4) of Table 2 underestimate the baseline consumption of UMP customers.[23] Estimates in Column (1) suggest that the average water usage two years after installation is 22.6% lower, from 403 (=248+155) to 312 (=403-91) litres per day. Results in Columns (2) and (3) confirm the findings already discussed in Table 2, in particular the fact that we find almost perfect convergence between UMP and non-UMP once we use periodic consumption to control for structural differences between the two groups of customers. These numbers are in line with the Isle of Wight Metering that saw the installation of 50,000 meters in the period 1989-91 and resulted in a reduction in demand of 21%, but they are 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).

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[23] We assume that consumption observed at the very beginning of the pre-switch period is indeed a better approximation of baseline consumption, that is, water usage when households were unmetered.

As mentioned above, part of this reduction can be explained by the fact that meters allow to detect (and fix) leaks in the house pipes. According to internal estimates of SW, around 5% of UMP households had leaks in the house pipelines (i.e. the section of the pipelines after the meter) causing on average, a waste of 400 litres of water per day. This means that leak detection can account for up to 20 litres out of the 90 litres drop shown in column (1) of Table 3. Accordingly, we can place the percentage of water reduction due to behavioural changes, net of leaks, at 18%, from 383 litres (the revised baseline consumption, given that 20 of the 403 litres are wasted) to 312 litres, whereas leaks would instead account for 4%-5% of the observed average reduction in water consumption. This figure would be in line, for instance, with what has been estimated in the case of Christchurch in New Zealand, where installation of meters, although not used for charging purposes, allowed discovering domestic leakage, thus resulting in a 4% decline in water usage (OECD, 1999).

**Table 3:** Metering and Water Consumption

| Variable<br>Description | Name | OLS<br>(1) | OLS<br>(2) | FE<br>(3) | Q25<br>(4) | Q50<br>(5) | Q75<br>(6) |
|---|---|---|---|---|---|---|---|
| *non-UMP* | | 248.4 | 248.4 | 248.4 | 124 | 216 | 329 |
| *UMP:* | | | | | | | |
| *Pre-Switch (1st)* | $D_{PS1}$ | 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.* | | | Incl. | | | | |
| | | (0.82) | (0.66) | (0.58) | (0.60) | (0.63) | (1.08) |
| *Nmb Obs* | | 5241488 | 3246210 | 5241488 | 5241488 | 5241488 | 5241488 |

*Note*: Water consumption is measured in Litres per Day. Robust Standard Error in Parenthesis
*p<0.001

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 shows 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. Note that, differently from OLS regression, these estimates are substantially unaffected by high baseline water usage due to leaks because households with severe water leaks are likely to be concentrated above percentile 75 of the distribution.

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 in England and Wales 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 English 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 water 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 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 to the satiation level. Using the single observation at the beginning of the pre-switch period to assess the change in consumption may, however, suffers from a problem of reversion to the mean.[24] 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 unmetered bill (RV).[25] Finally, the predicted differences between metered bills and unmetered bills are used to classify UMP households in the following three groups:
(a) *winners*, if the difference is at least 10%,
(b) *losers*, if this difference is up to -10%, and

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[24] For instance, there may be cases in which consumption in the first part of the pre-switch period is unusually high (or low) because, say, of relatives or friends staying over for some days (or all the family going away on holidays). Then, we may wrongly 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 or friends have left (or the family is back from holidays) and the household goes back to the usual level of consumption.

[25] Indeed, these two variables can explain around 90% of the variability in the dependent variable.

(c) *on-par* if the difference is between -10% and +10%.[26]

**Table 4:** Water Consumption and Billing

| Variable | | | BILLING | |
|---|---|---|---|---|
| Description | Name | WINNER (1) | ON PAR (2) | LOSER (3) |
| *non-UMP* | | 248.4 | 248.4 | 248.4 |
| *UMP:* | | | | |
| *Pre-Switch (1st)* | $D_{PS1}$ | 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) |
| *Nmb Obs* | | 4564203 | 4267431 | 4442032 |

*Note*: Water consumption is measured in Litres per Day. Robust Standard Error in Parenthesis. *p<0.001

Around 55% of the households are found to be better off under the metered tariff, meaning that the difference as defined above is positive, with mean and median savings in their bills of respectively 6.5% and 6%. Using the classification above, we find that the percentage of *winners, losers* and *on-par* are respectively, 46%, 35% and 19%. The coefficients reported in columns (1)-(3) of Table 4 show how water savings are dramatically different between these three groups: winners use 24 litres of water less by the 4th bill, equivalent to a 9% reduction, while losers decrease consumption by 193.6 litres, equivalent to a 32% reduction compared to the pre-switch period. The large difference in the (absolute number of) litres of water saved is mainly due to the fact that losers are large households. However, it is interesting to note that the percentage change is also significantly higher, which is less intuitive given that consumption per-capita tends to decrease as the household size increases due to economies of scale.

Assuming that people opting-in for metering are close to our "winners", these findings confirm that the optional metering scheme currently used in England and Wales 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

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[26] Defining a winner on the basis of the difference between the last unmetered bill and the first metered bill would include behavioural responses to metering because we know that UMP customers react very fast to metering and therefore some households that are worse-off under the new tariff (given the pre-installation level of consumption) may reduce consumption enough to actually receive a lower bill.

that should receive a meter from the society's point of view, do not have a financial incentive to opt for a meter. At the root of this problem is the fact that metered households pay the same volumetric price and standing fee irrespective of their consumption. A socially more efficient outcome could be achieved if "small" household living in large dwellings would be discouraged to opt for a meter by, for instance, asking them to pay for the cost of installation (while keeping the free-meter policy for households with high occupancy) or introducing a standing charge that decreases with the number of occupants.

Interestingly, the fact that 55% of the households would be better off under the new metering tariff even at saturation consumption level (before any adjustment to the new pricing scheme) suggests that the majority of 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. Indeed, even if we could define a tariff scheme where only customers whom it is socially efficient to meter prefer to have meters, it is unlikely that these customers would suddenly become aware of the financial benefits of having a meter installed.

## 5. Efficiency and Distributional Effect of Metering

### *5.1 Efficiency*

The findings in Section 4 show that there are substantial differences in households' response to metering. This suggests that only for a subset of households, the benefits associated with the reduction in over-consumption exceed 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:

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

or rearranging:

$$[\mathrm{Q}(0,\mathrm{t}) - \mathrm{Q}(p^{\mathrm{M}},t)] \geq \frac{2m}{365c} \qquad (3)$$

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

As explained in Section 2, marginal cost is assumed to be equal to $c$=0.003322 (£/L). 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,[27] 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 (3) 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 life of a meter, 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 (3) 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.

**Table 5**: Cost of Meter Installation

| *Type of Installation* | *Percentage*[1] (1) | *Cost Installation*[2] (2) | *Annualized Cost Installation*[3] (3) | *Water Reduction*[4] (4) |
|---|---|---|---|---|
| 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 | 18.90 | 56.74 |
| Harder Internal | 7.5 | 412 | 37.80 | 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 (3) with $m$ = (column(3) + £15,5) and $c$=0.003322

A number of interesting facts emerge from the figures in Table 5. First, given that the median 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). 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 access 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%.[28] Finally, complex installations (which account for around 10% of the installations in

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[27] The figures reports at page 84 of Environmental Agency (2008) are £9.15 for customer contact, £1.95 for billing costs and £2.21 for meter reading costs, giving a total of £13,31. Given that the report has been published in 2008, we then multiply this figure by 1.17 to account for inflation over the period 2008 -2016 (based on the statistics published by the UK Office of National Statistics).

[28] In fact, 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 of percentile 25 reported in Table 4.

England and Wales) 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.

As mentioned in Section 2, the results above may represent a conservative estimate of the benefits of metering given that around 4%-5% percentage of the water reduction is due to leaks detection and, in the presence of leaks, the deadweight loss of overconsumption would correspond to the trapezoid above the demand curve $D_2$ in Picture 3, instead of the triangle above $D_1$. However, we note that under the plausible assumption that leaks affect the right tail of the distribution of water savings, the analysis above would be largely unaffected as this is based on median and lower quartile (percentile 25) rather than averages.

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 which 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 if they want a meter, would be a more efficient way to address the problem of excess consumption (as advocated by Cowan (2010), among others).

### *5.2 Distributional Effects*

This section investigates whether there are significant differences in how metering affects water consumption and water bills of more affluent families vis-a-vis less affluent families. The fear that metering might result in adverse financial consequences for poor households has been one of the main obstacle to the universal metering in the UK (Environmental Agency, 2008). Indeed, 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.

Indeed, our classification of households by income level is based on 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).[29] The second is the socio-economic classification of Mosaic, a dataset published by Experian.[30] The information in Mosaic does not allow a complete ordering of the sixteen groups in the database from low to high income, but we can nevertheless create two clusters of households: low-income households and high-income households.[31] The advantage of the Mosaic classification is that it is at the household level, rather than at the LSOA level. The drawbacks are that we do not have the measure for non-UMP households and the classification of households into the high and low income categories is not clear-cut.

The first three columns of Table 6 show the impact of metering for three different income groups created using the income deprivation index. 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 utility loss 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 family and therefore experience a larger welfare loss. In other words, 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 "essential" activities that provided them with higher utility.

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[29] There are 32,855 LSOA in England with a min/max number of households of 400/1,200. Our three income groups have been created using the income-score assigned to LSOA in South-East England: low, medium and high income groups correspond to areas that are respectively, in the lower quartile, between quartile 1 and 3, and in the upper quartile of the income-score distribution.

[30] Experian web page describes mosaic as a "powerful cross-channel consumer classification designed to help you understand the demographics, lifestyles, preferences and behaviours of the UK adult population in extraordinary detail."

[31] We classify as low-income the following groups in Mosaic: "Family Basic", "Model Tradition" and "Municipal Challenge". High-income households correspond to the following Mosaic group: "Prestige Position", "City Prosperity" and "Domestic Success". We find that there is a high correlation between these groups and the RV of the house. All other households are classified in a "third" group which Mosaic classifies using ambivalent or neutral definition, such as "Rental Hubs", "Rural Reality" or "Senior Stability". The numbers of households that we classify as low-income and high-income are respectively 33,831 and 27,762, representing around 20% and 16.5% of the UMP households in the "Arad" dataset (see Table 1).

**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* | | 238.5 | 248.9 | 269.7 | 248.4 | 248.4 |
| *UMP:* | | | | | | |
| *Pre-Switch (1st)* | $D_{PS1}$ | 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) |
| *Nmb Obs* | | 1873868 | 2408201 | 736345 | 4302490 | 4259988 |

Water consumption is measured in Litres per Day. Robust Standard Error in Parenthesis. *p<0.001

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.

**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 of £11.5 or £10 at bill 4. 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* (UMP) of South East England on water consumption and the related efficiency and distributional effects. We find that on average, UMP households decrease consumption between 18% and 22% depending on how much weight we may attribute to leakage. These figures are substantially higher than those assumed based on National Metering Trials, but in line with what experienced in the Isle of Wight Metering Trial (Herrington, 2007). Our analysis shows that it is important to observe the behaviour of consumers soon after the meter is installed as they tend to react rather quickly to meter installation, even in the absence of a change in the applicable tariff scheme.

Our analysis shows that there is large heterogeneity in the way households react to metering. In particular, we observe a significantly smaller reduction in consumption 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 scheme currently used in England and Wales 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 call into question whether universal metering should be extended to other areas of the country in its current format; a selective metering programme where only "large" households receive a meter would most likely be more beneficial from a social point of view.

We acknowledge that 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 do not know, for instance, the number of occupants and relevant information could only be obtained through extensive and expensive surveys. 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 (which are asked to pay for the installation) may find strong opposition from residents and customers' association, in particular if this increases perceived inequalities in water consumption. 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.

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