Price and Behavioural Signals to Encourage Water Conservation

A Report to Anglian Water*

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Executive summary

The global problem of water resource constraints is pertinent to the UK and particularly acute in the south and east of England. A greater emphasis is being placed on water demand management in the UK, with a need to find a balance among social, environmental, economic and political goals. Putting a price on water is conceptually straightforward but often challenging in implementation. As water bills are typically small relative to household income in the UK, expenditure-led incentives may be insufficient, and so it is important that attitude-led behavioural interventions are also considered for conservation purposes. There is increased penetration of water meters in the UK and there is evidence that metering in itself leads to greater awareness of water use. Development and introduction of conservation-oriented tariffs and behavioural interventions to manage demand have been modest compared to in some other locations. Also, there is a lack of evidence of how tariff signals and behavioural signals interact in the UK.

This report reviews international experience of price and non-price approaches to manage residential water demand, with a focus on drawing insights regarding the effectiveness of Increasing Block Tariffs and information-based behavioural interventions. It then offers some insights on the extent to which lessons from elsewhere may be transferable to the UK context.

Increasing Block Tariffs (IBTs)

- IBTs are theoretically attractive as they can target affordability and sustainability simultaneously.
- In practice, their complexities in design, implementation and consumer perception often make them a costly option for both utilities and households:
  - The design of IBTs involves multiple inter-related choices which requires good understanding of characteristics of local demand and local populations, as well as models of consumer behaviour. IBTs can be a risky option when relevant information is inadequate.
  - It can be costly for utilities to obtain such information when designing IBTs, and it can also be costly for them to adjust IBTs as relevant information becomes available.
  - While IBTs in general make price signals more complex for households to acquire, the possible psychological and financial losses appear to be more pronounced to low income households with above average size, raising some concerns over equity.
- Existing research suggests that the concurrent use of IBTs and some non-price conservation tools in response to severe weather events is likely to be successful in reducing water consumption. While there is little evidence on the effectiveness of conservation programmes in environments where water resources are not stressed, the absence of these schemes might suggest that few utilities and communities see the value of IBTs when water is relatively abundant.
- International experience of IBTs from the US, Spain and Australia suggests mixed evidence regarding the effectiveness of IBTs. In some cases IBTs effectively reduced residential

water consumption, while in other cases IBTs did not achieve noticeable demand reduction, increased overall consumption, or led to concerns about equity.

- The fact that designs of IBTs vary significantly across regions and communities reflects the insights above that they depend on local water situation, water demand and household profiles; thus caution is needed when evaluating and generalising from this evidence.
- Factors likely to improve the effectiveness of IBTs include:
  - Adoption as a response to severe weather conditions, such as a drought.
  - Sufficiently high unit prices for high blocks.
  - Continuous adjustments of rates and structures when needed.
  - Clear price information included on households' bills.
  - Adoption for a sufficiently long period.
  - Adoption alongside non-price conservation tools.
- True effects of IBTs are difficult to disentangle from the effect of local population characteristics and non-price conservation tools used in combination. This problem is exacerbated by technical issues associated with water demand estimation in the presence of IBTs.

Information-based behavioural interventions

- Household-level information interventions convey a behavioural signal that delivers desired conservation attitudes which allow for changes in consumption.
- Types of information that may be used alone or in combination in pro-environmental experiments to promote water saving initiatives and activities include:
  - Technical advice offering water-saving tips.
  - Norm-based information stating importance of water conservation and how individual households' effort matters for a community.
  - Devices or labels tailored to specific appliances such as showers and washing machines, used to monitor usage at actual point of consumption.
  - Feedback containing household water usage, comparison to average usage of neighbours and emoticon conveying social approval (or disapproval).
- A handful of studies have conducted information-based water conservation experiments, to evaluate the relative effectiveness of these information types. Findings suggest that:
  - Technical advice without good motivation is insufficient to encourage conservation.
  - Norm-based information, monitoring devices and social comparative feedback are effective; households receiving one or more of these types of information consumed significantly less water than those who did not.
  - Social comparative feedback is most effective when targeting high water users, and appears less effective or even counterproductive for low water users.
  - The effect of a single information intervention diminishes over time.
  - The method of communication seems to matter: households appear to be more responsive to information arriving by post than available online.
  - Effects of information interventions found in water conservation experiments are typically larger than those found in studies of energy.

- Limitations:
  - The number of studies conducting information-based conservation is small, hence findings above should be treated with caution.
  - The studies differ in sampling, length of intervention and ways of framing a particular type of information, etc., so that results may not be comparable.
  - Some of the experiments involve household self-selection for participation, which creates upward bias in the sample, ruling out the possibility of obtaining "true" effects of interventions.
  - Similar to effects of IBTs, effects of information interventions may also depend on local water availability and household profiles. Experiments conducted elsewhere may provide insights on methodology, but may provide less guidance on the direction and magnitude of effects for other contexts.
  - In none of these studies were interventions repeated. As single intervention has diminishing effects, evidence is needed about the effectiveness of repeated interventions.

IBTs in the UK: initial conclusions

- The complexities and challenges associated with adopting IBTs likely also exist in the UK. Therefore the design and effectiveness of IBTs crucially depends on local water demand and household profiles, such as:
  - The proportions of high water users and the level of discretionary water use.
  - Households' water consumption by income group.
  - Households' conservation initiatives and prosocial preferences.
  - Households' perception of and responsiveness to water tariffs and price changes.
- The very limited existing evidence of UK water demand and of consumer perceptions of the wider context of water and water prices appears to suggest that:
  - The level of discretionary water use in the UK is lower than that in Australia and the US, indicating a relatively smaller scope for IBTs to reduce consumption.
  - Households' expenditure on water does not vary substantially with income, and typically is a small share of total expenditure. This means financial savings from reduced water consumption may not be salient enough for households to consider carefully their water consumption.
  - However, low income households might suffer financial hardship from IBTs.
  - Households are responsive to environmental concerns and willing to take actions when facing immediate threat on own welfare, but less so when it comes to long-term impacts.
  - Households have very inaccurate perceptions of their water prices and water consumption, and are more sensitive to bill totals.
  - Limited IBT trials in the UK did not yield promising outcomes.
- Apart from the complexities associated with IBTs, the design and implementation of IBTs in the UK would also have to fit within the relevant regulatory, legislative and political context. This may give rise to additional challenges

  - Objectives on water affordability and distributional impacts of tariffs, as well as price limits set to regulated water companies, imply that high block prices and frequent adjustment of IBT rates and structures are difficult.
  - Limited penetration of smart meters may leave some households in a vulnerable situation.
  - Privatised utilities are in a less favourable position in obtaining up to date data on household demographics.

Potential next steps

- Taken together, the lessons from international applications of IBTs and the UK context suggest a sensible first step for UK water utilities may be to improve their understanding of consumer behaviour, both regarding water consumption and attitudes towards water conservation. This should allow water utilities to undertake targeted non-price interventions to enhance households' understanding of water prices, consumption, and/or the need for conservation.
- These non-price information interventions themselves may be useful ways to manage demand. If IBTs are considered as a further step, then the non-price interventions may generate some relevant information for the design of IBTs. Also importantly, they might have the effect of "setting the scene" by raising households' awareness of water conservation and water prices so that households are, to some extent, prepared for tariff changes in the future.
- Households' understanding of their consumption and bills may also be improved if they are able to access real-time information on both usage and the interaction of usage and price (in line with what may be available through smart meters).

1 Introduction

Balancing equity, efficiency and sustainability in the water sector has traditionally relied on supply-oriented policies. With the presence of water resource constraints which will tighten in the future, as well as the recognition that water is an economic good, residential water demand management has emerged beyond this form of regulation and legislation. The increasing penetration of water meters enables water utilities and policymakers to provide a range of price and non-price incentives to promote water conservation.[1] This report reviews the price and non-price approaches to residential water conservation, with a focus on evaluating the evidence regarding the effectiveness of Increasing Block Tariffs (IBTs) and behavioural non-price interventions. It then discusses how these approaches fit with the UK's political and regulatory setting.

2 Using prices to reduce residential water demand

2.1 Price and demand

A key element of residential water demand management is water pricing. By the law of demand, increasing water prices should reduce residential water demand. In theory, increasing water price is a natural way to limit water consumption and is less costly to implement than a command and control approach (Olmstead and Stavins, 2009). Rogers *et al*. (2002) suggests that putting a price on water could have positive effects on water conservation, water supply and allocative efficiency.

The effectiveness of water pricing is, however, in question. Conventionally one may argue water does not have price-sensitive demand since it has few substitutes. There are also potentially different policy objectives. A low price ensures water is affordable to the poor but may be less effective at recovering costs and moderating water consumption. A high price may be attractive for conservation effects but may be challenging politically. Given the multi-objective context, the design of water tariffs is a complex issue: it is expected to pursue social, political, economic and environmental objectives and yet be easy to implement and transparent to consumers (Arbués *et al*., 2003). Suppliers and consumers have different expectations of tariffs. As a single pricing instrument cannot meet all objectives, the policy challenge is to choose a tariff that makes the optimal trade-off in achieving the goals deemed most important for a particular community.

The effectiveness of water tariffs in achieving conservation ultimately depends on consumers' responses to price signals. Non-price conservation tools provide important support in conditioning households to follow a conservation-oriented attitude, so that

[1] Metering is advocated by most of the literature on water demand management which suggests the mere introduction of a water meter, regardless of tariff, reduces water consumption (see, e.g. Worthington and Hoffman, 2008).

the potential gains from water tariffs can be enhanced. We start by exploring water tariffs and price signals in this section.

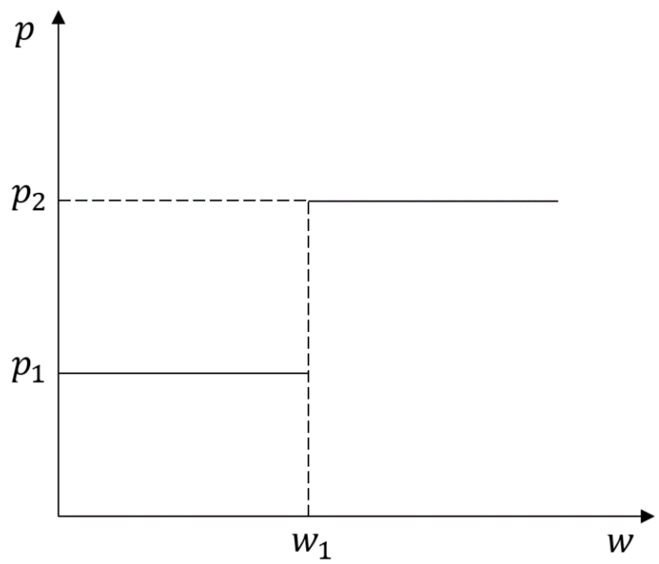
2.2 Water tariffs

Residential water tariffs typically consist of a fixed element and a variable element. The fixed element is usually a service connection charge. The variable element can be linear or non-linear, and is explained in more detail below.

2.2.1 Uniform pricing and block tariffs

Under uniform pricing, the variable element is determined by a single unit price for all levels of consumption. Under block tariffs, different unit prices are charged for two or more pre-specified blocks (quantities) of water. Block tariffs are increasing if the unit price increases with each successive block, and are decreasing if the unit price decreases with each successive block. When designing a block tariff, the utility needs to specify the number of blocks (≥ 2), the volume of water consumption within each block, the time period over which consumption is measured, and the unit price for each block (Boland and Whittington, 1998). Figure 1 illustrates an example of a two-block IBT: w_1 is the per period consumption threshold between blocks 1 and 2; p_1 and p_2 are unit prices for blocks 1 and 2 respectively.

Figure 1. A two-block IBT



In practice, both uniform pricing and block tariffs are employed in developed countries. In particular, IBTs are widely used in the US (Olmstead *et al*., 2007; Asci *et al*., 2017), some parts of the Europe, such as Spain (Arbués and Barberán, 2012; Suárez-Varela *et al*., 2015) and Portugal (Monteiro, 2010), and parts of Australia including Melbourne, Perth and Sydney (Brennan, 2006).

In 2000, around one-third of US urban households faced IBTs (Olmstead *et al.*, 2007). In Florida, 90% of utilities employ IBTs and in California, the number is 65% (Asci *et al.*, 2017).

2.2.2 IBTs – advantages and challenges

If a utility considers water conservation to be the primary objective then, in theory, it can simply increase the price of water until a point at which a sufficient reduction in water consumption is achieved. However, this may come at the expense of some households' affordability of essential water consumption – an outcome which is likely to create a political problem. In this context, a clear advantage of an IBT is that it attempts to find some balance between two objectives – water affordability and water conservation. However, as a compromise solution, there will still be a trade-off between these two objectives.

IBTs allow the utility to charge different prices for different levels of water consumption. The utility can set lower prices to support essential consumption for all households and higher prices for consumption considered non-essential. For example, if we regard w_1 in Figure 1 as essential water consumption, a low p_1 is chosen to make sure w_1 is affordable to all, whereas any consumption beyond w_1 corresponds to the higher block price p_2 to encourage conservation.[2] Additional blocks may be introduced to target households with even higher consumption. IBTs may therefore be an instrument for achieving a desirable balance among social, economic and political goals (Rogers *et al.*, 2002).[3]

According to the literature (e.g. Hall, 2009; Wichman, 2014; Asci *et al.*, 2017), the number of blocks under an IBT varies considerably across regions. For example, in the US, two-block is used in LA, four-block is used in Arizona, California and Florida, and five-block is used in North Carolina. IBTs in Asia are usually four-block, whereas in Latin America, they range between three and thirteen blocks.

Two-block IBTs are relatively simple and straightforward. Three-block IBTs start to offer some scope for sophisticated designs to achieve a more desired balance between affordability and conservation. Four- and five-block IBTs are more common in places

[2] w_1 is a free allowance when $p_1 = 0$.

[3] For IBTs to be effective, an assumption is that separate meters are available for each individual household. With households sharing a meter, the chance of the total metered consumption reaching high blocks is higher. According to Whittington (1992), this is a common adverse effect of IBTs found in developing countries. To some extent such adverse effects, however, seem to be unavoidable even with separate meters for each household. This issue is addressed further in Section 2.2.3.

with problems of water shortage and large population. Multiple blocks imply clearer conservation targets and it may be easier for consumers to infer that unnecessary consumption is expensive. They are however more difficult to understand and may be politically challenging.

Overall, while an IBT is theoretically attractive, its effectiveness in practice as a price signal depends on whether it is appropriately designed as well as received. Challenges may arise at both stages due to the complexity of an IBT.

Unlike uniform pricing under which the marginal price of water remains the same across all levels of quantity consumed, the marginal price under an IBT (e.g. in Figure 1) increases with each successive block ($p_2 > p_1$) but remains the same within each block. While under uniform pricing consumers make a consumption decision facing a single price, under an IBT consumers have to optimise their consumption while considering multiple prices that change with the consumption level (Cater and Milon, 2005).

The complex nature of IBTs typically requires consumers to have perfect information about the tariff structure, have real-time information regarding their current level of consumption, and can form unbiased expectations about consumption throughout a billing period, in order to make a rational decision (Hewitt and Hanemann, 1995; Wichman, 2014). This means that households must consider not only the marginal price of the next unit of water to be consumed, but also the likelihood that their total consumption will end up in a higher block involving a higher marginal price.

An underlying assumption which is common in economic models, is that information is costless and consumers are well-informed. This assumption is, however, unlikely to hold in many real life situations, e.g. in utility markets, where information acquisition can be costly. Table 1 presents some bill-related, income-related and psychological costs and benefits associated with information acquisition (Shin, 1985; Gardner, 2010). Costs or benefits under different factor groups may be correlated.

Table 1. Costs and benefits with information acquisition

Factors	Costs	Benefits
Bill-related	Efforts required to obtain and understand information	Some consumers enjoy controlling bills Some consumers enjoy understanding tariffs
Income-related	Opportunity costs of efforts required, weighted by marginal value of time and size of water bill relative to income	Financial need to budget Scope of increasing welfare
Psychology-related	Dislike engaging with bills or procrastination of reading bills for various reasons	Some consumers enjoy budgeting Conservation preferences

Source: adapted from Gardner (2010)

In light of this framework of costs and benefits, for a consumer who is not well-informed, facing an IBT to make a rational decision requires i) the consumer to be aware of the need to acquire price and consumption information, and ii) the net benefit of acquiring information to be positive. These two conditions are not necessarily satisfied for a number of reasons, but in particular, the small size of water bill relative to household income for the majority of households, and the difficulty in processing information due to complex structures of IBTs may imply that information acquisition is not worthwhile.

Since in practice it is common for IBTs to be more than two blocks, it is plausible that consumers face high costs of information acquisition and processing and so they fail to understand the entire IBT structure and its implications (Natarai and Hanemann, 2011; Nieswiadomy and Molina, 1989). Moreover, consumers may not be able to correctly predict consumption over a long period of time (Borenstein, 2009) and they "rarely have anything resembling real-time information about their current level of consumption" (Kenny, *et al*., 2008). As a result, households may end up with inaccurate perception on prices and their own consumption, which prevent them from making a rational decision even when they wish to.

A direct consequence of the above is that it is unclear how households respond to price signals under an IBT. Some possible scenarios are:

1) Consumers respond to the local marginal price only;
2) Consumers respond to an expected marginal price, which is a probability-weighted average of the marginal price in each block;
3) Consumers respond to an expected marginal price as in 2), but the weight they attach to the marginal price of each block may change as their consumption increases;
4) Consumers respond to the *ex post* average price;
5) Consumers respond to a probability-weighted average of the marginal price and the average price.

Given the costs and benefits framework above, when information acquisition is costly the average price appears to be a commonly used reference for water prices. When billing statements are available, the *ex post* average price of consumption over a billing period can be obtained at negligible cost.

The potential confusion over prices under IBTs from consumers' perspective suggests that IBTs are unlikely to work in as straightforward a manner as they appear in theory, although this does not rule out the possibility of IBTs being effective in reducing consumption. In fact, studies show that although most consumers do not accurately perceive price or consumption in utility markets (e.g. Whitcomb, 1999), IBTs may still achieve reductions in consumption – this will be discussed in later sections.

Price signals perceived: a numerical example

Suppose that a household consumer consuming more than w_1 units of water over one billing period faces a two-block IBT as in Figure 1, where $p_1 = 1$ and $p_2 = 4$. Even with the assumption that she has some knowledge of her consumption and the IBT structure, there are still a number of possible prices she may perceive and respond to, including:

- She considers one marginal price at a time only. She may perceive price as 1 for the first w_1 units of consumption (first block) and from the unit w_1+1, her perceived price has a sudden increase to 4.
- She may perceive the price as an average of p_1 and p_2 for all units of consumption, which is 2.5.
- She may attach varying weights to p_1 and p_2 over time depending on her consumption. For example, she may perceive the price of the first unit of water as $0.9p_1 + 0.1p_2 = 1.3$ and that of the last unit as $0.1p_1 + 0.9p_2 = 3.7$.
- She does not consider the detail of the IBT and refers to her last water bill to find an average price and regards this average price as her water price for all units of consumption.

However, costly information and complexities of IBTs can have negative consequences on households, especially in the short run. Depending on their water demand and their responses considering potential costs and benefits, the extent to which households are affected adversely by challenges posed by IBTs can differ substantially. Households are less likely to be affected adversely when their demand is well within the first block and they have clear knowledge on that, as they effectively face a single price. When their consumption exceeds the first block, it becomes more complicated.

Households who choose to figure out price and consumption information have to cope with the extra efforts required for calculation, budget planning and monitoring consumption. They may also be upset if they make the efforts but fail to understand relevant information. Households who do not understand IBT structures, whether this is because i) they are unaware of the need to, e.g. they are uninformed about the tariff change or they do not budget on water consumption, ii) they are aware of the need but the costs of trying to understand outweigh the benefits, iii) they fail after trying, may face some unexpected increases in their bills. Among them, low income households may suffer more from such financial losses.

Note that when information acquisition is costly, the average price appears to be a commonly used reference for water prices. When billing statements are available, the *ex post* average price of consumption over a billing period can be obtained at negligible cost. However, there are potential risks in doing so. Low billing frequency means delayed feedback on bill totals and consumption. Bills based on estimated rather than actual meter readings can further leave households in a vulnerable situation if their actual consumption is much higher. Observing a low bill total based on estimate readings may make them overlook the IBT's structure and also consume more. This not only limits the effectiveness of IBTs but can also have negative implications for households' welfare.

In addition to the challenge of making information more costly to obtain, IBTs may aggravate households' intertemporal decisions under uncertainty. It is likely that they value consumption today and at later points in time differently. Since the marginal price of water under an IBT does not go up until consumption reaches a higher block (i.e. something that happens later and with uncertainty), some consumers may not regard it as so relevant for the decision today, hence fail to establish a clear link between turning on a tap today and receiving a high water bill three months later. On the other hand, some consumers may emphasize not entering the next block so much that they suffer from over-saving.

Overall, learning plays an important role in households' understanding of an IBT and thus its effectiveness. IBTs are expected to be more effective in the long run as it takes time for households to learn. However, during the learning process, households may suffer from financial and psychological losses as discussed above. Even without behavioural bias, there may be delays in information acquisition and processing due to, e.g. billing cycles. Low frequency of billing may fail to alert households to the change in water tariffs and slow down the adjustment phase. Households responding to out of date price information can also suffer from sudden and large increases in bills.

One might consider learning to be more straightforward under two-block IBTs which are relatively less complicated, but two-block IBTs also come with less flexibility. Depending on the size of the first block, a moderate increase in the price might not be sufficient to induce conservation, but a sharp increase in the price might make learning very costly. In this regard, IBTs with multiple blocks but moderate escalation in prices might make learning more affordable.

Irrespective of whether a price increase is achieved at the second block or gradually over multiple increasing blocks, IBTs may be a more profitable option for utilities. Households who interpret the price increase as profit-making by utilities rather than an incentive to conserve water may respond differently.

While the price signal used by households in their decision making has clear implications for their behaviour and welfare, utilities may face challenges as they are less certain about what to expect from IBTs, given uncertainty around the correct model of consumer behaviour. Households' responses to price signals can vary with household characteristics, which indicates that the effectiveness of IBTs is conditional on variations in these characteristics across the population as a whole. It follows that for IBTs to be more effective, utilities are required to invest more on information provision and communication. This will be discussed in depth in later sections.

2.2.3 Water budgets

IBTs with fixed block sizes may affect households of different sizes differently. The price to maintain identical essential consumption for each individual in a household can be higher for large households than for small households since large households' total essential consumption may enter high blocks where the marginal price increases.[4] A relatively new pricing tool based on IBTs, namely water budgets, appear to be a solution to accommodate this equity problem.

Water budgets are IBTs but with tailored block sizes for each individual household. That is, the allowed consumption under each pre-specified block price is individualized on the basis of household-specific characteristics, e.g. household size and irrigated area, as well as environmental conditions. Hence, the essential amount of consumption for which households pay relatively low prices, differs across households at any given time, and also over time (e.g. due to environmental conditions), for any given household (Baerenklau *et al*., 2014). This in turn means that water budgets can keep the price for essential water consumption low for each household regardless of household size, as the block sizes are adjusted according to household characteristics (Hall, 2009).

Block 1 ("indoor") is determined by household size, personal water allowance (60 gallons/day), drought factor (≤ 1) and indoor variance; Block 2 ("outdoor") is determined by the size of block 1, evapotranspiration, conservation factor (evapotranspiration-related), irrigated area and outdoor variance; Block 3 ("excessive") is the size of block 2 times 1.5; and Block 4("wasteful") is water use in excess of block 3 (An example of four-block IBT with water budgets in Baerenklau *et al*.,2014)

Despite the potential advantages, water budgets have not been widely implemented with IBTs. Once considered to be technology-constrained, the implementation of water budgets has recently been argued to be "without significant efforts" for "most modern, database centred utility billing systems" (Mayer *et al*. 2008). However, the real challenge seems to be the availability of comprehensive and accurate data on household characteristics that are regularly updated. Not only can it be costly to maintain up to date data, households may not consent to provision of such data.

An early adoption of water budgets occurred in southern California in the 1990s. Although about half of all California utilities were using IBTs in 2005, fewer than 14 of them were using water budgets by 2008. From 2008 to 2011,

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[4] This effect of IBTs has caused some concerns over equity in water tariff design (e.g. Arbués and Villanúa, 2006). See Section 2.3.2 for evidence and some arrangements used in practice to mitigate this problem.

at least another 9 utilities started to use water budgets. This is partly driven by California's 20×2020 Water Conservation Plan which aims at reducing per-capita water use by 20% before 2020 (Baerenklau *et al*., 2014).

2.2.4 Seasonal pricing

As water demand is sensitive to seasonal fluctuations, by targeting some discretionary water use, especially seasonal outdoor water use such as filling swimming pools, seasonal pricing is suggested to promote efficient water allocation and conservation (Worthington and Hoffman, 2008). Seasonal pricing is also argued to be reasonable for cost and capacity reasons (Arbués *et al*., 2003). For example, as outdoor water demand increases in summer months to a level which exceeds a utility's base capacity, the utility will have to turn to more expensive sources of water to accommodate demand. A higher seasonal price helps to recover the cost of extra capacity (US EPA, 2016).[5]

There is an increasing adoption of seasonal pricing in the US, e.g. it is common across many water providers in the southwestern US (Kenney *et al*., 2008), but less so in Europe (Herrington, 2007). However, as price increases with consumption levels under IBTs and consumption levels are likely to increase in summer months, IBTs potentially capture some of the cost recovery aspect of seasonal pricing (US EPA, 2016).

2.3 IBTs to reduce residential water demand

2.3.1 Water demand estimation and price elasticity of demand (PED)

Whether or not an IBT meets its objectives depends on many factors. The economic literature has tried to shed light on the effects of different water tariffs by estimating water demand with a focus on measuring price elasticity of demand (PED)[6], and most studies include IBTs as a form of tariffs in their estimations (Worthington and Hoffman, 2008).

In residential water demand estimation, demand Q typically takes the form of $Q = f(P, Z)$, where P is some measure of water prices and Z denotes other determinants of household water demand which may or may not be in the control of water utilities. Table 2 presents specifications and a selection of variables under categories P and Z used in the literature to explain water demand Q, given alternative functional forms f. In addition, studies may include water consumption in the previous period, i.e. lagged variables of Q, to explain the dynamics in household water consumption and persistence due to habits (e.g. Asci *et al*., 2017).

[5] Note that as this report focuses on IBTs, we do not discuss seasonal prices *per se*, but rather in the context of their combination with IBTs.
[6] PED refers to the percentage change in the quantity consumed in response to a percentage change in price. Water is traditionally considered a highly price inelastic product, i.e. if the price increases by 10%, the quantity consumed will drop by substantially less than 10%.

In the vast literature, studies differ in one or more aspects of the specifications and variables detailed in Table 2.[7] In response, literature surveys (Arbués *et al*., 2003; Worthington and Hoffman, 2008) seek to offer a more comprehensive picture for estimations, whereas meta-analyses (Espey *et al*., 1997; Dalhuisen *et al*., 2003; Sebri, 2014) investigate which variables tend to be more significant and stable in their explanatory power, i.e. the identification of "genuine" variables (Waddams and Clayton, 2010).

Table 2. Water demand estimation –specifications and variables

$\boldsymbol{Q} = \boldsymbol{f}(\boldsymbol{P}, \boldsymbol{Z})$		
Water demand $\boldsymbol{Q}$	Data characteristics	e.g. summer data; outdoor data; household data; panel data; monthly data; long-run data
Water price $\boldsymbol{P}$	Price specification	e.g. marginal price (difference); average price; perceived price
Other determinants $\boldsymbol{Z}$ (controlled by utilities)	Water tariffs	e.g. uniform pricing; IBTs; decreasing block tariffs
	Billing frequency	e.g. monthly; quarterly
Other determinants $\boldsymbol{Z}$ (not controlled by utilities)	Income	e.g. low; middle; high
	Household characteristics	e.g. household size; household composition; population density
	Weather, seasonal and environmental factors	e.g. rainfall; temperature; season; evapotranspiration
	Property characteristics	e.g. property value; property age; garden size; number of bathrooms
	Non-price conservation tools	e.g. conservation programmes; irrigation restrictions
	Other	e.g. energy prices
Functional form $\boldsymbol{f}$	Linear or non-linear	e.g. log-log; log-linear

Empirical findings from water demand estimations provide insights on the effectiveness of IBTs in reducing residential demand; these insights are primarily on the effects of water pricing in general, and also, though less frequently, on the relative effectiveness of IBTs as compared to other water tariffs. PED is widely used as a measure of the effectiveness of IBTs as it indicates the scope of water pricing in

[7] In addition to differences in demand and price specifications, there is no general consensus in the literature on the proper methodology to estimate water demand. The econometric techniques adopted by different studies vary widely and heterogeneity in findings may arise from these technical choices as well. Inclusion of particular variables or particular specifications may give rise to complications in the econometric analysis. For example, IBTs create a number of specification and estimation issues; Section 2.3.3 provides a summary of these issues and the estimation techniques suggested to deal with them.

reducing water demand. Table 3 reports ranges of PED estimates from the existing literature (Espey *et al*., 1997; Dalhuisen *et al*., 2003; Sebri, 2014).[8] The mean and median values of PED estimates suggest that a 10% increase in water price generally results in a 3%-5% reduction in water consumption.[9]

Table 3. PED estimates

Meta-analyses	PED range	90% range	Mean	Median
Sebri (2014)	-3.054 to -.002	-	-.365	-.291
Dalhuisen *et al*. (2003)	-7.47 to 7.90	-	-.41	-.35
Espey *et al*. (1997)	-3.33 to -.02	-.75 to 0	-.51	-

Despite the heterogeneity in data and estimation techniques, the studies provide a few common themes regarding water conservation:

1) The price of water is a statistically significant factor in explaining demand and plays a crucial role in demand management, hence water tariffs are a relevant instrument to promote water conservation;
2) The range of PED estimates from the existing literature is wide and may not be informative of the responsiveness of a given household group in a given community to price changes under a given form of water tariff. Region-specific and household-specific studies are crucial for understanding the distributional effects of water tariffs;
3) Water demand is in general price inelastic and a large reduction in water demand may require price increases so large that they may not be politically feasible, hence the impacts of non-price conservation tools need to be quantified for them to be better designed to support water pricing.[10]

To shed light on a desirable form of water tariff, the literature further suggests that, PED estimates are higher under IBTs than under uniform pricing (e.g. Niewiadomy and Cobb, 1993; Espey *et al*., 1997; Dalhuisen *et al*., 2003; Olmstead *et al*., 2007). One possible explanation for this is that, in addition to the effect of a price increase, the design of increasing blocks enhances households' awareness that large non-essential consumption will lead to large bills, even if they do not fully understand the pricing structure (Kenney *et al*., 2008). Overall, consistent with theoretical predictions, empirical findings from this literature suggest the potential for IBTs to be a useful pricing instrument for water conservation.

[8] PED estimates in Table 3 have been obtained primarily using residential samples in the US, Europe and Australia. As discussed in Section 4, there is little UK based evidence in the existing literature.

[9] However, as also highlighted in many studies, e.g. Niewiadomy and Molina (1989), caution must be used in interpreting these PED estimates, due to the lack of consensus regarding the functional form of demand and estimation methodology. See Section 2.3.3 for details.

[10] Non-price conservation tools are discussed in more detail in Section 3.

However, PED estimates that vary over a wide range suggest that the effectiveness of IBTs to reduce water demand may also vary significantly with household and regional variables and over time. Whether IBTs can effectively manage water demand in a given region or targeted group of households crucially depends on how the effects of IBTs are related to these variables.

2.3.2 IBTs in practice – design and effectiveness

While variations in PED estimates may be related to data characteristics, demand specifications and estimation techniques, Waddams and Clayton (2010) suggest that variables under demand specifications, i.e. vector Z in Table 2, address potential differences in consumer behaviour and are significantly more relevant, while variations in estimation techniques are the least relevant of the three factors.

In this subsection, we focus on applications of IBTs and discuss how variations in certain cross-sectional variables may affect the effectiveness of IBTs regarding water conservation. This in turn sheds light on issues regarding the design and implementation of IBTs in practice. We leave discussions on estimation issues to Section 2.3.3.

- Income groups and high water users

IBTs aim to prevent excessive and non-essential water consumption, mainly in high income households (Suárez-Varela et al., 2015). Although high water users and high income households are not always the same households, in the context of water consumption there is a high level of overlap between the two groups. Wealthier households usually face a higher irrigation requirement as they tend to have larger gardens and swimming pools, and outdoor water use can account for a substantial proportion of total water consumption. While this may suggest the desirability of targeting these households to reduce consumption, these households are relatively less responsive to water price changes than low-income households, because water bills account for a smaller proportion of their total budget (Agthe and Billings, 1987; Worthington and Hoffman, 2008).

In 1995, the Water Department in Santa Cruz, California, introduced a third price block to the existing two-block IBT with a clear objective of water conservation. Nataraj and Hanemann (2011) exploit this transition and find that it led to a 12% decrease in water consumption among high water users, and suggest the introduction of additional higher blocks to be an effective method of water conservation while maintaining affordability. As Nataraj and Hanemann note, the fact that the city of Santa Cruz later switched to a five-block IBT seems to support this finding. However, in this transition, the marginal price faced by high water users increased by nearly 100%, which implies that a significant price increase is required to affect the demand of high residential water users.

Asci *et al*. (2017) studied the effects of IBTs in managing demand of high residential water users by examining the periods before and after a fifth price block was added to the IBT faced by households in Central Florida. Despite the significant price increase in high blocks, the IBT failed to generate noticeable demand reduction.

Renwick and Archibald (1998) estimate the distributional implications of water tariffs using data from households in Santa Barbara and Goleta, California, during California's drought from 1985 to 1992. In response to increasingly severe water scarcity, Santa Barbara moved from uniform pricing to a "moderate" IBT in June 1989 and then to a "steep" IBT in April 1990; Goleta moved from a "moderate" IBT to a relatively high uniform price in July 1990. As a result of the different water tariffs employed, the aggregate demand reduction and the reduction pattern across household income groups differed between the two communities. While the average water demand fell more in Goleta (26.2%) than in Santa Barbara (9.3%), this appeared to be driven by the high responsiveness of low income households facing price increases. In Goleta, lower income households reduced demand the most whereas in Santa Barbara, high income households reduced demand the most. Overall, PED estimates by income group indicate that low-income households were five times more responsive to price changes than high-income households.[11]

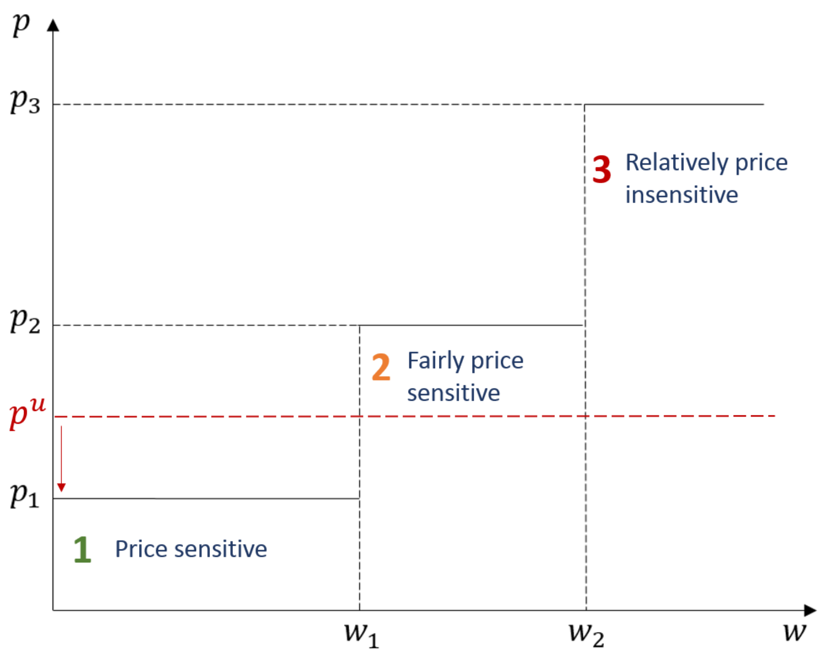
These studies emphasize the importance of designing water tariffs tailored to household water usage and income levels. Although low income households respond more to water price increases and thus tariffs targeting them could be more effective in reducing consumption, it may seem unfair and politically problematic to place the conservation burden on these households. Instead, IBTs that target high water users may be seen as a fairer option.

However, the heterogeneity in households' responsiveness to price changes indicates some real challenges for IBTs to be effective at an aggregate level. Figure 2 illustrates changes in water prices faced by households with different levels of water consumption, following a switch in tariffs from a uniform price p^u to a three-block IBT. Low water users participating in block 1 are sensitive to price changes. They face a reduction in price from p^u to p_1, hence they are likely to respond by consuming more water (Wichman, 2014; Asci *et al*., 2017). High water users participating in block 3 face a price increase from p^u to p_3. Since these households are relatively insensitive to price changes, whether p_3 can induce them to reduce consumption depends on whether it is sufficiently high. However, whether this IBT can achieve conservation at an aggregate level in addition crucially depends on the distribution of households over the different blocks. Depending on the design, when the number of households within block 1 is large, the perverse effect of increasing water consumption could result from

[11] This perhaps also helps to explain the wide range of PED estimates in Table 3.

introducing the IBT. If p_3 is not sufficiently high then, as found in Wichman (2014) when studying the effects of introducing an IBT in North Carolina in 2007, the IBT can raise overall water consumption and fail to achieve its main objective.[12]

Figure 2. Moving from a uniform price to a three-block IBT



It follows that, whether prices for high blocks are sufficiently high is highly relevant for the effectiveness of IBTs. The challenge here is that, even for blocks targeting high water users, there may exist a price ceiling above which further increases are politically problematic, and this ceiling may not be high enough to reduce water demand at the aggregate level. Specifically, regulated utilities are usually subject to price or revenue caps. When making price decisions, the overall average price that a regulated utility can charge needs to be less than its price limit set by regulators. [13] In relation to IBTs, this means that utilities may have limited ability to increase prices of high blocks, which potentially limits the effects of IBTs.

There is mixed evidence from this perspective on the effectiveness of IBTs (Nataraj and Hanemann, 2011; Asci *et al.*, 2017). The conclusion is that IBTs can be a risky option when there is limited information on local water demand and on how this demand varies with the socio-demographic characteristics of households; the less information there is, the harder it is to design effective IBTs.

[12] Note that this short run adverse effect might disappear in the long run.
[13] See Section 4.3.2.

Design of IBTs: choices, objectives and complexities

In addition to the choice of a fixed element to the tariff, the design of an IBT involves 1) the choice of the number of blocks, 2) the size of each block, including whether there is any free allowance, 3) the price applying to each block and 4) billing frequency[14]. All of these choices interact to influence the overall effect of the IBT, and they may be chosen to meet other concerns, e.g. the degree of price progressivity, that is, how quickly prices increase between blocks. (Suárez-Varela *et al.*, 2015).

Although IBTs are conservation-oriented tariffs which also intend to support affordability, they may in addition be required to satisfy objectives such as cost recovery[15] and equity, and therefore in practice the design of IBTs varies considerably. Setting higher prices for higher blocks is only one of many factors that must be considered when designing an IBT.

Arbués and Barberán (2012) provide information on water tariffs used in 52 Spanish provincial capitals in 2008. While 47 out of the 52 cities (more than 90%) were using IBTs, designs of these IBTs differ from one city to another. Block numbers vary from 2 to 8, but variances in block sizes and block prices are even more significant. For example, as presented in the table below, while 6 cities all employed five-block IBTs, the design of IBTs across these cities differs significantly.

City using five-block IBTs	Size of block 1 (m^3/mth)	Start of block 5 (m^3/mth)	Price of block 1 (€/m^3)	Price of block 5 (€/m^3)	P_5 / P_1
Avila	8.33	33.33	0.2582	0.7903	3.06
Ciudad Real	3.33	33.33	0.133	2.312	17.38
Melilla	20	50	0.35	4.8	13.71
Murcia	32.5	135	1.0094	1.42481	1.41
Santa Cruz de Tenerife	5	30	0.41	2.02	4.93
Toledo	5	20	0.1557	1.13248	7.27

The differences in design may be due to differences in the cost of providing water including environmental and managerial costs, and may also reflect

[14] Billing frequency might not appear to be as relevant as the first three choices, but since block sizes are typically chosen for a billing period, billing frequency in fact is a key choice under an IBT. This point will be addressed in more detail below under the heading “Billing frequency and information transparency”.

[15] The objective of cost recovery appears to be one of the priorities of policymakers in Australia and Spain, and can be political. For example, Arbués and Barberán (2012) argue that since in many Spanish cities water is directly managed by the local city council, water pricing can be “driven by financial and political considerations rather than economics ones, ensuring that revenues cover an ‘acceptable’ proportion of the costs of proving water services.” In Australia, to recover cost IBTs with low initial block prices usually imply a high fixed charge (Brennan, 2006).

differences in the prioritisation of alternative objectives in the design of IBTs. For example, IBTs used by Santa Cruz de Tenerife and Toledo have the identical first block size, but the *price* of the first block is 2.6 times higher in the former. It might be possible that the higher price is in part driven by higher cost. The last column showing the ratio of the highest block price to the lowest block price gives some idea of the vastly different degree of progressivity under each IBT. As Arbués and Barberán explain, the penalty for high water usage is low in Murcia (1.41), whilst substantial in Ciudad Real (17.38).

Suárez-Varela *et al*. (2015) conduct the first empirical analysis of the determinants of the degree of progressivity of Spanish IBTs by formally defining a progressivity indicator. They find that higher degrees of water scarcity and more economic activity in a region lead to more progressive block prices; political ideology (left-wing and right-wing) does not affect the chosen degree of progressivity but a negative relationship is found between longer-ruling local government officials and the degree of progressivity in tariffs. Furthermore, a positive relationship is found between privately managed utilities and the number of blocks.

- Household size and equity

As mentioned in Section 2.2.2, a potential adverse effect of using IBTs to manage water consumption is the problem of equity associated with variations in household size, especially for large households. Under standard IBTs with fixed block size, the price faced by each individual inside a household for essential water consumption increases with household size, as collectively there is a higher chance for total household consumption to enter higher blocks (Arbués and Barberán, 2012). This "unintended consequence" of IBTs is likely to lead to an "unfair" distribution of welfare since the *per capita* income is *ceteris paribus* lower for larger households, and yet they are charged high prices for essential water use (Dahan and Nisan, 2007). A descriptive study assessing Melbourne's three-block IBT concludes that it performed poorly on notions of equity (Edwards, 2006).

A counter argument is that the *per capita* price decreases with household size because of economies of scale in water use. Danhan and Nisan (2007) suggest that such economies of scale do not exist beyond households with two individuals. Barberán and Arbués (2009) consider the two opposing forces and suggest that the regressive effect of IBTs dominates the economies of scale for households with five or more individuals, thus discriminating against large households. In particular, *per capita* prices for households with six and seven individuals are 24% and 33% respectively higher than for households with four or fewer individuals. However, the data used is average monthly consumption which includes essential and non-essential water use, hence, if large households incur high non-essential consumption, e.g. they live in larger houses with larger gardens, then to some extent the price increase under IBTs may be mitigated through reduced consumption.

Nevertheless, these studies do not suggest abandoning IBTs if conservation remains an objective. Instead, they urge the introduction of special tariffs for large households, which have been put into practice in some areas.[16] For example, the city council of Zaragoza, Spain, has established a special rebate for large households (with 6 or more individuals). While its three-block IBT is applicable to large households, they receive 25% of their total bills as a rebate, conditional on that their consumption does not exceed an upper limit lying inside the second block (Barberán and Arbués, 2009; Arbués and Barberán, 2012). In a case study of Zaragoza, Kayaga and Smount (2014) show that its conservation plan including the use of an IBT managed to achieve a 27% reduction in overall water consumption between 1996 and 2008 (despite a population increase of 12%). But note that besides the IBT and special rebate for large households mentioned above, the Zaragoza City Council also adopted a reward scheme: households who reduced water usage by at least 40% in the first year of joining the scheme received a 10% discount off their bill, and a similar discount continued to apply to these households for each further 10% reduction in water usage achieved in each subsequent year.[17]

- Billing frequency and information transparency

Households who receive water bills more frequently and are exposed to more billing information are expected to have a better understanding of the relationship between their water use and water expenditure. Price transparency may allow consumers to be more responsive to price changes in general, and is particularly relevant for the effectiveness of IBTs which depend on households' awareness and understanding of IBTs' relatively complex tariff structure.

For example, Cater and Milon (2005) estimate water demand conditional on households' knowledge of prices, using survey data and billing records in North-Central Florida. They find that price information has the benefit of lowering water consumption, but this benefit is less pronounced under IBTs than under uniform pricing because households facing IBTs are less likely to know the marginal price of their service.[18] By using 1996 survey data from the American Water Works Association (AWWA) and billing information from utilities in 1995, Gaudin (2006) shows that having price information on the bill next to the consumption level increases PED by 30%.

[16] The introduction of special tariffs is subject to reliable information on household size, and city councils are more likely to have access to such information than private utilities.
[17] The dual approach of carrot and stick makes it difficult to identify which factor drives the results.
[18] The issue of whether households react to the marginal or average price has been discussed in a number of studies, as described in Section 2.3.3.

Billing frequency also matters for the effectiveness of IBTs. Depending on billing cycles, it is possible for similar households to make decisions on water consumption during similar time periods based on different price information (Wichman, 2014). Low frequency of billing may fail to notify households of the change in water tariffs and slow down the adjustment phase.[19] Consequently, not only may water conservation be adversely affected, households responding to out of date price information can also suffer from the sudden, unexpected increases in bills, i.e. a"shock effect" (Arbués *et al*., 2003).

While increased billing frequency enhances consumers' understanding of their consumption and allows them to respond to updated price signals, it does not necessarily lead to reductions in water consumption. Gaudin (2006) explains that two opposing forces operate here: frequent bills may increase the price sensitivity of demand as they help households to establish a clear relationship between tariffs and consumption; but they may decrease the price sensitivity of demand because bills become smaller. Empirical studies on whether increasing billing frequency reduces water consumption do not obtain conclusive results (Kulshreshtha, 1996; Arbués *et al*., 2003).

Since choices under an IBT, such as block sizes and prices, are made for a given billing period, an issue that seems to be overlooked is that changing billing frequency usually requires changes in block size and/or prices as well. Figure 3 illustrates the changes in the IBT employed by Durham, North Carolina, when billing frequency changed from bimonthly to monthly in 2011. While block prices remained unchanged, each block was halved in size to ensure that households were charged in a consistent manner.

Wichman (2016) exploits this transition in billing frequency and estimates the effect of increased billing frequency on household consumption. He finds that the switch from bimonthly to monthly billing increased water consumption by 3.5% to 5%.

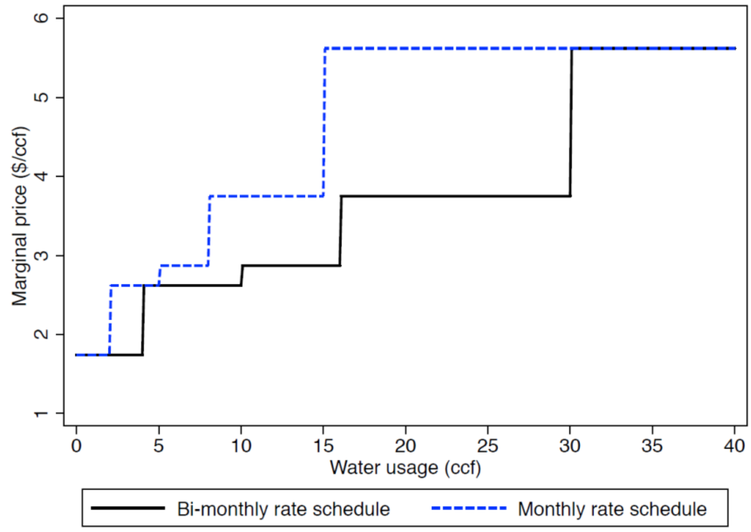
However, a comment is made in relation to changes in block sizes following the change in billing frequency: halving block size following a halved billing period is "a mechanical interpretation" that does not control for the possible effects of billing frequency on consumer behaviour. The change in block sizes may have affected households' perception and, depending on their consumption pattern, it is possible for some households to experience an increased total water bill over two months after the change, despite identical consumption.[20] This raises a relevant issue of the periodicity of

[19] For example, Gaudin (2006) notes that in the AWWA 1996 sample, billing frequency could be as low as twice a year.

[20] An example is that a consumer consumes no water in the first month and high units of water in the second month. With bimonthly billing her total consumption of the two months will not enter the high block, but under monthly billing her consumption in the second month will enter the high block, thus bill totals are higher under monthly billing.

water demand. Households' learning and understanding of IBTs may also depend on how cyclical their demand is.

Figure 3. IBT structure after transition to monthly billing



Source: Wichman (2016)

Wichman suggests that this issue does not affect the validity of the empirical findings as the likelihood of households possessing such a consumption pattern is low and it remains unclear how the block structure influences their decisions. Nevertheless, there is sufficient reason to treat billing frequency as an endogenous factor when designing an IBT, as changing billing frequency does appear to affect consumption.

- Seasonality and outdoor water use

Residential water use is usually shown to be sensitive to seasonal fluctuations. Season, weather and outdoor water use are correlated and collectively contribute to the seasonality in residential water demand, which is found to significantly influence PED estimates (Espey *et al*., 1997; Worthington and Hoffman, 2008). Summer demand is significantly more elastic than winter demand (Griffin and Chang, 1990) and outdoor demand is more elastic than indoor demand (Renwick and Green, 2000). If higher PED indicates that the associated water demand involves more discretionary use, then there is more scope for IBTs to be effective.

Estimating residential water demand in Aurora, Colorado, between 1997 and 2005 (including the drought period 2000-2005), Kenney *et al*. (2008) show that water consumption is 30% higher in summer than the rest of the year, regardless of temperature and rainfall, and thus suggest water demand management should target summer months. Xayavong *et al*. (2008) estimate residential water demand in Perth, Australia and suggest that a high proportion of water use in Perth involves discretionary outdoor demand. Two meta-analyses (Espey *et al*., 1997; Sebri, 2014) suggest seasonal pricing to be an effective tool for water conservation. It follows that an IBT can take advantages of seasonality in water demand by varying its block prices accordingly, i.e. seasonal pricing based on IBTs.

Klaiber *et al*. (2014) measure the effect of seasonal changes in block prices under a two-block IBT by exploiting a natural experiment in Phoenix, Arizona from the year 2000 to 2003. In particular, they focus on how the responsiveness of high water users varies with seasonal pricing, and how it may differ under different weather conditions. They find that while high water users are indeed more responsive to prices in summer months, such responsiveness reduces substantially if the year is dry. They further conclude that high water users are less responsive to price across all seasons and weather conditions. This is consistent with the earlier discussion on effects of IBTs by income group.

Although this report focuses on water consumption, a significant proportion of water consumption involves energy (e.g. boiler). Prices of gas and electricity thus indirectly affect households' use of water, e.g. in the shower. Households who budget water and energy consumption together – in the UK energy consumption is relatively higher in winter months and water consumption is relatively higher in summer months – might be less responsive to seasonal prices of water, albeit seasonality exists. They might consider that variations in water and energy consumption over time "offset" each other, and this potentially undermines water pricing policy.

- Long-run effects

While many studies obtain short-run measures of the effectiveness of IBTs, there are reasons to believe that IBTs could be more effective in the long run. Empirical findings show that price sensitivity is significantly higher in the long-run than in the short-run (Espey *et al*., 1997; Sebri, 2014), and this is mainly due to information accessibility and water-related investments by households (Carver and Boland, 1980).

Households may have a clearer understanding of the tariff structure of IBTs and their own consumption patterns over a longer period of time. Even if they are willing to respond to price signals and engage in conservation-orientated practices, their water use habits may sustain over a long time period before any substantial changes take place. Studies including lagged variables in their estimations, e.g. Asci *et al*. (2017), offer evidence supporting this argument.

As discussed earlier, households' responses to an IBT can lead to a net increase in water consumption in the short run, when the increased consumption among low water users (due to lower initial block prices) outweighs the reduced consumption among high water users (Wichman, 2014). Since IBTs focus the conservation burden on high water users and given that they become more responsive to price over time, it is possible for the short-run adverse effect to disappear in the long run. Higher water prices can help to induce households to invest in water-efficient appliances. This income-related activity is also expected to have more significant effects in the long run after households understand their consumption and realize the need to invest, especially high income households who have the resources to pay for investment (Worthington and Hoffman, 2008).

Baerenklau *et al*. (2014) investigate the effects of introducing an IBT in southern California in 2009 and find that water demand under the IBT is 17% lower than what it would have been under a uniform price. The average price under the IBT increased by less than 4% during the reduction. If the uniform price was to achieve the same level of demand reduction, average price would need to increase by nearly 34%. However, as Baerenklau *et al*. also point out, the reduction was achieved gradually over more than three years. They suggest that for IBTs to be an effective conservation tool, a considerable amount of time is required. Given that in this case study the average price increase over the period of demand reduction was low, one might wonder whether the magnitude of price increase and the time frame allowed are, to some extent, substitutes in achieving a similar conservation goal.

- Summary

In this sub-section we have reviewed case studies of IBTs, the majority of which are from the US while a few are from Spain and Australia. The purpose of the review is to demonstrate how IBTs have been designed and used in practice, as well as to discuss the challenges when designing and implementing IBTs.

Mixed evidence is found regarding the effects of IBTs. There are cases in which IBTs effectively reduced residential water consumption, while there are cases in which IBTs did not achieve noticeable demand reduction, or even increased overall consumption, or led to concerns around equity.

Overall the key challenge is the complexity, both for water tariffs in general and, in particular, for IBTs as a more sophisticated form of tariff. The complexity is not only for household but also for IBT designers who must balance multiple objectives and make multiple inter-related choices. This complexity may be mitigated with good knowledge of water demand and of the socio-demographic characteristics of a population when designing an IBT, and a good understanding of price signals among households when the IBT is in place. However, both conditions are difficult to achieve in practice, which in turn aggravates the challenge of complexity by adding a layer of uncertainty.

Case studies suggest that, *ceteris paribus*, the following matter for the effectiveness of IBTs:

1) Whether the design of an IBT has incorporated local demographics and, in particular, whether block prices faced by high water users are sufficiently high, and whether large households are charged fairly;
2) Whether households are provided with clear and up to date price information so that they are aware of any price signal they wish to respond to;

3) Seasonal changes of block prices are likely to increase the effectiveness of IBTs by targeting more elastic demand;
4) Whether IBTs are employed for a sufficiently long period;
5) The presence of non-price conservation tools.

Note that so far we have not yet addressed point 5). Compared to pricing instruments such as IBTs, non-price tools involve attitude-led, rather than expenditure-led demand reduction, which may be advantageous. It is possible for some households to interpret an increase in water prices as profit-making by the utility rather than an incentive to engage in prosocial activities. Households who can afford the price increase and view it as profit motivated are less likely to reduce consumption. If instead they receive a message telling them that reducing consumption is for a good cause, they may be more willing to do so.

Renwick and Archibald (1998) suggest that the failure to account for effects of non-price conservation tools may result in an overestimate of the effectiveness of pricing on water conservation. In fact, in the event of water shortage, utilities and policymakers usually implement a variety of price and non-price tools in combination in order to boost desirable effects. For example, water demand management programs including various price and non-price tools implemented by Aurora Water, Colorado in 2002 successfully reduced water consumption by 8% in 2002 and by a striking 26% in the following year (Kenney *et al*. 2008). We leave the discussion of non-price tools to Section 3.

2.3.3 Methodological issues in the presence of IBTs

As mentioned in the preceding sections, in addition to the heterogeneity due to differences in datasets and choices of explanatory variables (e.g. Z in Table 2), the lack of consensus on the proper methodology to estimate water demand in the literature has led to heterogeneity in empirical findings. While there are issues applying to water demand estimations in general, such as the choice of data and functional form f (Table 2),[21] some specific difficulties arise because of the use of non-linear pricing, such as IBTs.

- Simultaneity, instrumental variables (IVs) and price specification

Since under IBTs the price of water determines and is also determined by consumption, i.e. different levels of consumption can correspond to different block prices, there is a simultaneity problem between price and quantity demanded. A necessary condition to obtain accurate results from the main regression method, Ordinary Least Squares (OLS)

[21] Linear functional form is easy to estimate but is often criticized for consistent price responsiveness of demand at all price levels. Log-log and log-linear are popular functional forms. In particular, log-linear has the advantage of being able to account for some minimum amount of water demand regardless of how high prices are (Arbués *et al*., 2003; Worthington and Hoffman, 2008).

(Worthington and Hoffman, 2008) is violated. Knowing this problem, researchers have to decide whether to perform estimation using OLS or adopt more complex estimation techniques. The challenge for a review of the evidence is that results on IBTs are based on a variety of methods and it is sometimes difficult to know the extent to which differences in results are driven by differences in methodology rather than real world factors. The main alternative technique considered for estimating the impact of IBTs is the IV approach. This deals with the simultaneity problem by identifying an 'exogenous' variable[22] which effectively substitutes for one of the variables which suffers the simultaneity problem.

Additionally, some studies (e.g. Taylor, 1975; Nordin, 1976) argue that, when the price specification is marginal price, a difference variable should be included to account for the perceived price. As explained in the numerical example in Section 2.2.2, a consumer may perceive prices of the first and last unit of water within the same block to be different, even if the actual price remains unchanged throughout the block. The difference variable has been included in estimations using OLS and IV models in a number of studies (e.g. Hewitt and Hanemann, 1995; Renwick and Archibald, 1998).

At the heart of the debate on whether the inclusion of a difference variable is necessary is the question of whether households react to the marginal price and whether their perceived marginal price changes within a block where the actual price remains constant, here there are a mixture of arguments. Using Shin (1985)'s price perception model, Nieswiadomy and Molina (1991) suggest that households respond to the marginal price under IBTs. Natarai and Hanemann (2011) find evidence that even facing complex price structures such as IBTs, households respond to the marginal price. On the other hand, some other studies show that households make decisions according to the average price or the total bill (Wichman 2014). Households are said often to lack an understanding of not only their tariffs but of their current level of consumption (Cater and Milon, 2005; Kenney *et al*., 2008), correlating to the fact that it is common for utility bills not to include detailed price structures of IBTs. Similar issues exist also for electricity (Ito, 2014).[23]

- Demand discontinuity

Demand discontinuity is another issue in estimating demand in the presence of IBTs. Since households shift from one price block to another, households' responses to the non-linear price structure have a discrete and discontinuous nature which differs from

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[22] For the 'exogenous' variable to be legitimately used as an instrument it must be shown to have a statistically significant relationship with the variable, say quantity, for which it is substituting, but have no statistical relationship with the other variable of interest, here price.

[23] The lack of consensus on the appropriate price specification to use in estimation (the average price, the marginal price and the marginal price with a difference variable) corresponds to the confusion of price perception that households may have in facing IBTs, which is discussed earlier in this report in Section 2.2.2.

that under uniform pricing. The utility maximisation problem is no longer subject to a conventional budget constraint with a single price. Instead, households need to decide both which block to choose and how much to consume conditional on being in that block. The first choice is characterised in a discrete-choice fashion while the second choice is characterised in a continuous way. The structural maximum likelihood model of discrete/continuous choice (DDC) is regarded as the theoretically appropriate method to deal with non-linear piecewise demand such as IBTs (Hewitt and Hanemann, 1995; Olmstead *et al*., 2007).

The DDC model has the benefit of allowing simultaneously for the effects of price and of various sociodemographic variables on consumption behaviour, but this comes at the expense of the ease of estimation. It is costly to estimate the DDC model due to the sociodemographic specifications and the possible experimentation with various sociodemographic forms (Hewitt and Hanemann, 1995). In fact, to this date, very few studies estimate water demand using this "correct" model (Arbués *et al*., 2003). Those that do use the DDC model, such as Hewitt and Hanemann (1995) and Olmstead *et al*. (2007), produce relatively higher PED estimates implying more elastic demand. In particular, Hewitt and Hanemann (1995) estimate demand using the same data as in Nieswiadomy and Molina (1989) and include different econometric models. By comparing PED estimates across different models and comparing to estimates in previous studies including Nieswiadomy and Molina (1989), they find PED estimates under the DDC model to be significantly higher.

- Endogeneity: PED as a function of the chosen tariff

Water tariffs as an endogenous choice of water utilities is not only an issue in the presence of IBTs. However, since IBTs are tariffs with a clear objective, they may be more prone to the endogeneity problem. To be specific, the fact that an IBT is chosen over alternative forms of tariffs may itself be a behavioural response to tariff forms. For example, it is chosen because there is an urgent need to conserve water or because the local community has active conservation initiatives, and these local characteristics are reflected in the utility's chosen tariff – it is an endogenous choice.

Furthermore, not only the form of tariffs, but also the specific design can be endogenous. For example, an IBT with several blocks and very high prices for top blocks may imply the community's strong preference for conservation (Kenney *et al*., 2008). An unfortunate outcome associated with such endogeneity is that, when demand is found to be more elastic under an IBT, it is difficult to tell whether it is indeed due to the effect of the IBT, or simply because the local community has a prosocial preference. Olmstead *et al*. (2007) highlight this endogeneity issue and its implications. They estimate two samples of households, one facing IBTs and one facing uniform prices, and find evidence that PED appears to be higher under IBTs, but they are unable to conclude definitively due to unresolved endogeneity issues in their data.

The issues specified above associated with demand estimation in the presence of IBTs have no implication for the effectiveness of IBTs, but rather restrict the ability of utilities or researchers to capture or be certain about the true effect of IBTs. They explain that part of the heterogeneity in findings on the effectiveness of IBTs may be due to differences in price specification, econometric models and estimation techniques used in different studies.

2.4 Section summary

This section reviews and discusses evidence of water prices as a residential water demand management tool, and assesses IBTs as a conservation-oriented form of water tariff.

Water prices are identified by the literature on water demand estimation as a genuine variable in explaining demand. While this means that policymakers and water utilities may wish to take advantage of water prices to reduce water consumption for conservation purposes, low values of PED estimates suggest that the effect may be limited unless price increases are large. It follows that careful and innovative designs of water tariffs are needed for a balanced outcome between affordability and distributional issues of tariffs, and the sustainability of environment and resources.

IBTs, as a form of tariff targeting both affordability and conservation, have become popular in the US, Spain, Portugal and Australia, among others. Despite being theoretically attractive and frequently adopted in practice, IBTs are associated with challenges fundamentally due to their complexity.[24] They:

1) Involve multiple inter-related choices, including the number of blocks, the size of each block, the price of each block and the time period over which consumption is measured;
2) Should incorporate characteristics of local demand and local population, as well as models of consumer behaviour;
3) Require sufficiently clear and frequent communication with households to enhance their understanding of tariff structures;
4) Lead to difficulties in measuring IBTs' true effects because:
    i. IBTs may be an endogenous choice of local populations,
    ii. of the concurrent use of IBTs and non-price conservation tools,
    iii. of econometric issues in estimations.

Related to point 2) on characteristics of local population, an adoption of IBTs can also be subject to preferences and dynamics of local democracies, and thus political buy-in. Given the above challenges, it is not surprising that designs of IBTs can vary

[24] Also for conservation purposes, IBTs have been used as tariffs for electricity and gas in, e.g. the US, where the complexities and challenges discussed in this section apply. See, e.g. Borenstein (2009) and Ito (2014).

significantly from region to region, and that mixed evidence is found regarding the effectiveness of IBTs. In some cases IBTs effectively reduced residential water consumption, while in other cases IBTs did not achieve noticeable demand reduction, increased overall consumption, or led to concerns on equity as low income households of large size were affected negatively.

The effectiveness of IBTs depend on many factors, including but not limited to those controlled by utilities. Nevertheless, successful IBTs appear to share a few common factors:

1) Adoption as a response to severe weather conditions, such as a drought;
2) Sufficiently high unit prices for high blocks;
3) Continuous adjustments of rates and structures when needed;
4) Clear price information included on households' bills;
5) Adoption for a sufficiently long period;
6) Adoption alongside non-price conservation tools.

Overall a good understanding of local demand and household profiles is the key for designing an effective IBT. Sometimes when such understanding is inadequate initially, adjustments through the course are inevitable as a trial-and-error process. This however, comes at the expense of high adjustment costs, which may or may not be worthwhile. Also, because of the relevance of local demand and household profiles, effects of IBTs are likely to be region-specific, thus caution is needed when interpreting the success and failure of a particular IBT.

Note that in all case studies reviewed in this section, the utilities were the monopolist water supplier in their local communities (some were owned directly by city councils). The evaluation and summaries thus are built on this basis.[25]

3 Non-price approaches to reducing residential water demand

3.1 Non-price tools

The non-price approach to residential water conservation is a broad term that includes various tools. It could be a command and control (CAC) approach which involves regulatory restrictions, e.g. irrigation bans; it could be technological tools, e.g. the installation of water efficient household appliances; and it could also be information interventions such as campaigns and conservation programmes that aim at increasing public awareness of water conservation (Inman and Jeffrey, 2006).

One of the consistent arguments from the literature on water demand management and conservation is the need to adopt non-price conservation tools to

[25] Local competition is expected to undermine utilities' incentive and ability to adopt IBTs. However, empirical evidence from the energy market in Texas, US, shows that even after the introduction of competition in the retail market in 2002, IBTs continued to be used. See, Puller and West (2013).

support water pricing. On the one hand, utilities may be reluctant to rely solely on water pricing for conservation, especially in the presence of political pressure, equity concerns and legal limitations (Kenney *et al*., 2008). On the other hand, due to a number of issues as discussed in Section 2.3.2, even if designed specifically to target conservation, water pricing may not be sufficiently effective (e.g. Wichman, 2014; Wichman, 2016; Asci *et al*., 2017). In many case studies in which conservation plans successfully reduced water demand (e.g. Renwick and Archibald, 1998; Kenney *et al*., 2008; Kayaga and Smount, 2014), the success was collectively achieved by multiple price and non-price interventions.

"Major decreases in water use per capita occur only where a major price increase is accompanied by major public awareness of the action surrounding the passage of the increased price schedule" (Martin *et al*. (1984) commenting on the "Beat the Peak" conservation campaign in Tucson in the 1970s).

The use of non-price conservation tools may generate some direct effects such as those coming from CAC restrictions,[26] but more importantly, it is to convey a behavioural signal, which works in a similar way as water pricing conveying a price signal. The signal delivers the desired conservation attitude that gradually allows for changes in consumer behaviour (Renwick and Archibald, 1998; Nataraj and Hanemann, 2011). Hence, there has been increasing interest in information-based and norm-based conservation programmes.

3.2 Information-based conservation experiments

There is a growing body of literature in behavioural economics and environmental psychology on the relationship between water consumers' behavioural attitudes to water use and their water consumption. While general environmental concerns might induce some conservation-orientated behaviour, households are found to be more responsive to their specific beliefs about water (Corral-Verdugo *et al*., 2003). For this

[26] Olmstead and Stavins (2009) compare water pricing and the use of mandated technology installation and specified water use restrictions in managing water demand, and argue the latter to be less cost-effective and requiring monitoring and enforcement. Nieswiadomy (1992) argues that the potential flaw of mandated technology installation and water use restrictions is that they may not encourage desired behaviour changes and may trigger rebound effect. For example, after a utility installs water efficient appliances, consumers may manipulate the potential conservation impact by consuming more water. On the other hand, some studies suggest the CAC approach to be effective, especially when the conservation need is urgent and one aims at significant reduction in demand (e.g. Renwick and Green, 2000). The CAC approach, however, is not the focus of this report.

reason, there is mixed evidence on the effectiveness of community-level educational campaigns that may have limited influence at the household level.[27]

Since many conservation programmes seek to promote water saving initiatives and encourage water saving activities through providing information-based incentives, there is the highlighted need for research on behavioural and experimental interventions to identify which aspects of information are most effective, as stated in the two questions below:

1) Which type of information offers stronger incentives that help households form desired attitudes?
2) Will socioeconomic characteristics of households lead to heterogeneity of household responses to conservation experiments?

Table 4. Information types considered in this section

Information type	Example
Technical advice	Information leaflets containing water-saving tips
Norm-based information	Letters stating importance of water conservation and how individual household's effort matters for conservation in a community
Monitoring device tailored to specific appliances	Devices or labels with technical and conservation information made for refrigerators, showers, washing machines, etc., for households to monitor usage at the actual point of consumption
Feedback	Feedback sheets containing total household water usage, sometimes including a break-down by water-using activities
Socially comparative feedback	Feedback sheets containing how household water usage compares to average usage of neighbours
Emoticon	Happy faces for households whose water consumption is below community average, and sad faces for those whose consumption is above average

Interventions can take both "antecedent" and "consequence" approaches to induce behavioural changes (De Young, 2000). Antecedent interventions supply information which aims at increasing awareness and offering knowledge so as to encourage a particular pattern of behaviour in an activity taking place subsequently. Consequence interventions, on the other hand, are about using feedback to inform the outcome of an action, with the intention of motivating more desirable outcomes.

In relation to water conservation, as listed in Table 4, common antecedent interventions are educational, such as pure disseminations of water-saving tips, but can also involve norm-based languages containing social identity and prosocial preferences;

[27] For example, these campaigns worked in Renwick and Green (2000) and Syme *et al*. (2000), worked only in a specific region where the awareness of water scarcity was high as in Nieswiadomy (1992), and did not work in Howarth and Bulter (2004).

feedback can be of different types, ranging from usage tracking to social comparison and social approval (or disapproval) (Russell and Fielding, 2010; Seyrannian *et al*., 2015). Monitoring devices or labels are made to be placed inside homes, on or near water-use appliances. They may be message only, or they may in addition be visual monitors to indicate real-time feedback on water consumption, e.g. in the shower.

Given the wide choice of information types, it remains an empirical question which type is the most effective in encouraging water conservation. Also, just as different household groups may respond to price signals differently, the socioeconomic characteristics of households may also affect the influence of information interventions (Renwick and Archibald, 1998). Recognising the heterogeneity of household responses to incentives offered by information interventions is important for improving the concurrent use of water pricing and conservation programmes through distributing the conservation burden in an efficient and yet fair manner.

Using an experimental approach, a handful of studies have attempted to address the question of the relative effectiveness of different types of information on household water consumption.[28] In these studies, households are usually grouped into different treatments and receive different types of information. By comparing the treatment effects to a control group, studies can conclude whether the information types used are effective in achieving reduction in water consumption.

Kurz *et al*. (2005) conduct an experimental programme with 166 households from a local community in Perth, Western Australia, in which they compare the conservation impacts of providing households with information leaflets (technical and norm-based), monitoring labels and socially comparative feedback to participated households, over a period of 6 months. They find that while information leaflets had no significant effects, monitoring labels with the identical information (as on the leaflets) but placed at the actual point of water consumption, reduced household consumption by 23%. However, unexpectedly in a social-ecological framework, socially comparative feedback was not found to have significant effect.

Erickson *et al*. (2012) evaluate a 15-week pilot with 303 households in Dubuque, Iowa, using a web portal designed for water conservation. The portal site offers a range of information, including near real-time feedback on water usage, social comparison with "Neighbours Like You", posts of households' communication and weekly games between households on water conservation. Compared to households who did not engage with this web portal, households who participated in this pilot reduced consumption by 6.6% during the first 9 weeks. However, while the different information types were collectively effective, this study cannot reveal which particular type of information led to the reduction.

[28] Given the increasing number of pro-environmental behaviour experiments and the importance of water conservation, there is a surprising paucity of experimental research related to water conservation (Osbaldiston and Schott, 2012).

Fielding *et al*. (2013) compare the effects of technical advice, norm-based information and feedback on water consumption in an experimental programme with 221 households in South East Queensland, Australia, with the aim of capturing the long-run effects of conservation programmes. All three treatment groups received technical advice, whereas two treatment groups in addition received norm-based information or feedback. Despite low water usage before the experiment, they find that, relative to the control group, all treatment groups consumed significantly less water during the intervention. Surprisingly, the absolute reduction in consumption was the highest for the group receiving technical advice only, although Fielding *et al*. find no significant differences among treatment groups, suggesting technical advice alone appeared to be as effective as combined with norm-based information or feedback. The consumption of treatment groups remained low for some months after the end of the experiment, but returned to pre-experiment level after a year.

Although offering evidence on the relative effectiveness of different types of conservation information, the above studies do not come up with a clear picture. One possible reason is regarding sample selection. Kurz *et al*. (2005) and Erickson *et al*. (2012) involve voluntary participation, whereas in Fielding *et al*. (2013), participating households were from a region where water scarcity had been an issue and they actually had participated in an earlier study in 2009. As a result, in these three experiments, household samples appeared to be *ex ante* conservation-minded and some of them were even informed about the study prior to any intervention. Given that they generally had a strong intention to reduce consumption, true treatment effects were likely to be small. A second possible reason is that these studies do not examine the heterogeneity of treatment effects across household groups.

Conservation experiment in Atlanta, 2007

An experiment involving more than 100,000 households implemented by a water utility in Atlanta, Georgia in 2007 controlled for the sample selection problem by randomising households into three treatment groups and one control group.

Your own total consumption June to October 2006: 52,000 gallons

Your neighbors' average (median) consumption

June to October 2006: 35,000 gallons

You consumed more water than 73% of your Cobb County neighbors

(Part of a sample letter sent to group 3)

Group 1 received technical advice, group 2 received norm-based information in addition to technical advice, group 3 received usage feedback and social comparison, as well as technical advice and norm-based information, whereas the control group did not receive any type of information.

Three studies exploit this natural experiment with different focuses. Ferraro and Price (2013) primarily compare the effects of three information types, i.e. the treatment effects; Ferraro and Miranda (2013) examine the heterogeneity in treatment effects across households; and Ferraro et al. (2011) examine the persistence of treatment effects over time.

Ferraro and Price (2013) find that, first, while average water consumption in summer 2007 reduced relative to summer 2006 for all groups, the reduction in treatment groups was 7.4% to 53.4% greater than that in the control group. Note that the consumption in the control group reduced as well and this may have been driven by the utility's introduction of an IBT to replace uniform pricing in early 2006. While treatment differences denote the relative effectiveness of different information types, the absolute changes in consumption resulted from the implementation of both the IBT and information intervention, and it is impossible to separate out the two effects.

Also, there are significant differences between treatment effects. Receiving norm-based information is evidently more effective in reducing water consumption than receiving technical advice only, and receiving social comparison in addition reduces consumption significantly even further. Authors suggest that the estimated conservation effect of social comparison is as strong as a 12%-15% increase in the average price.

Ferraro and Miranda (2013) find strong evidence of heterogeneity in household responses to information containing social comparison, and higher responsiveness is observed with households that are wealthier, living in their own properties and with higher water consumption. In particular, high water users are found to be 94.1% more responsive to this type of information than low water users. However, no evidence of heterogeneity in response is found when the information type is pure technical advice or technical advice with norm-based information.

While Ferraro and Price (2013) identify the short-run treatment effects, Ferraro et al. (2011) suggest that only information containing social comparison has a strong long-run effect. Short-run treatment effects of information without social comparison disappeared within a year, but that of information with social comparison persisted for more than two years. Although the size of effects wane over time, the result is striking given the fact that letters containing any type of information were sent to households only once.

In a one-week field experiment in San Diego with a sample of 301 households, Schultz *et al*. (2016) compare the effects of technical advice, social comparative feedback, and the use of a happy or a sad face. The use of emoticons is argued to be a message conveying social approval or disapproval. Their treatment design is similar to, e.g. Ferraro and Price (2013) in that the treatment receiving emoticons also received the first two types of information. They find that technical advice has no significant effect in reducing water consumption. The treatment group receiving social comparative feedback in addition to technical advice consumed 26% less water than the control group who did not receive any information. The treatment groups receiving all three types of information consumed 16% less water than the control group. As it appears, emoticons conveying social approval/disapproval reduces the effectiveness of social comparison. While social comparison seems to be a promising information tool, Schultz *et al*. further show that low water users receiving social comparative feedback increased their consumption. Another feature of this study is that treatment effects are controlled for how information was sent, i.e. by post or online. They find that information distributed online was less effective than that sent by post.

With a sample of 374 households from a community in Los Angeles during summer months, Seyranian *et al*. (2015) compare the effects of technical advice, social comparative feedback accompanied with a happy face or a sad face, norm-based information, and norm-based information with an emphasis on personal identity (e.g. use “I” and “you” instead of “we”). The difference in treatment design of this study compared to Ferraro and Price (2013) and Schultz *et al*. (2016) is that households assigned to a treatment group received one type of information only. They find that technical advice does not affect consumption of high water users. Social comparative feedback with social (dis)approval and norm-based information using inclusive language are found to have similar significant effects in inducing high water users to reduce consumption. Seyranian *et al*. further suggest that providing norm-based information in a way that emphasizes personal identity rather than social identity does not reduce the effectiveness. On the other hand, treatment effects are less significant for low water users.

Unlike previous studies that compare alternative types of conservation information, Otaki *et al*. (2017) seek to identify which element of feedback information is most effective for water conservation. For this purpose, 246 residents from different households in Tokyo, were randomly sampled to participate in a monitoring survey between October and March. The survey required participants to self-report water meter readings once every two weeks for 24 weeks, and the participants received feedback regarding their water consumption shortly after each report of readings, i.e. they received feedback 12 times. Depending on the type of feedback they would receive, participants were assigned to three different treatment groups: feedback with social comparison; feedback with ranking among a smaller group of 100 households, e.g. ranking was 57th of 100 households[29]; and feedback with emoticons (four emoticons ranging from “crying face” to “perfect smiley face”). There was also a control group that received no feedback. Note that all feedback was given on water consumption per

[29] The rankings sent out, however, were not real. Otaki *et al*. explain that real rankings did not exhibit noticeable fluctuations, hence it would be difficult to examine this treatment effect if real rankings were used.

person per day in a household. Feedback effects are evaluated by consumption level (high vs. low water users) and by duration of intervention (3 vs. 6 -month). They find that feedback with emoticons is effective for high water users to reduce their water consumption, whereas feedback with ranking is effective for low water users, but feedback with only a descriptive message on own consumption and mean consumption in the community is not found to be effective.

3.3 Section summary

While information-based interventions have been used to affect individual decision-making, so far there is a limited number of information-based water conservation experiments with randomized controlled samples. Even fewer experimental studies examine beyond the average treatment effects by investigating the heterogeneity of responses across household groups (Ferraro and Miranda, 2013).

Existing studies that have made pair-wise comparisons among different types of information incentives, depending on variations in sample, length of experimental intervention and the language used to deliver a type of information, may reach different findings. For example, even when both are examining the effects of norm-based information, one study may frame the information more strongly than the other in terms of the degree of social norm involved. For these reasons, more experimental studies are needed for more comprehensive and robust evidence on the effectiveness of information incentives. Nevertheless, existing studies have tried to shed light on the effects of different information types[30], which are summarised below together with the associated implications for utilities and policymakers:

1) Technical advice without a good motivation on why one should reduce water consumption does not appear to be sufficient to reduce household water usage,[31] hence conservation initiatives should focus on motives of conservation before offering knowledge and tips;
2) Norm-based information and social comparative feedback are good information-based intervention tools, with mixed evidence on which one is more effective. Whether there is any additional benefit from including emoticons is unclear;
3) It may be sensible to choose information types by household water consumption. Social comparative feedback is most promising for targeting high

[30] Note that treatment effects obtained in water conservation experiments (e.g. Ferraro and Miranda, 2013; Schultz *et al*., 2016) are typically larger than those obtained in experiments with similar designs on energy (Allcott, 2011; Schultz *et al*., 2007). One potential reason is that one can visually observe water, e.g. running tap, but not electricity, thus one interacts with water and electricity in different ways (Benzoni and Telenko, 2016).

[31] Technical advice alone may even create some counterproductive effects as households may not enjoy being educated without motivations, or they may feel that their freedom to use water is affected (Seyranian *et al*., 2015)

water users, but appears to be less effective or even counterproductive to low water users, hence utilities may consider including feedback on bills for high water users;

4) Information-based non-price tools and price tools such as IBTs appear to be complements to water conservation
   i. High water users are less price-sensitive but are more responsive to information on social comparison,
   ii. The effect of information-based intervention diminishes over time whereas IBTs can become more effective over time; [32]
5) The method by which information reaches households seems to matter: households appear to be more responsive to information arriving by post than available online. While many utilities have persuaded consumers to switch to online billing, this may come at the expense of households' rate of accessing information from utilities.

So far there is no clear evidence on whether the presence of a price incentive such as an adoption of IBTs is required for an information-based incentive to be effective. However, the finding that high water users who are less price-sensitive tend to be responsive to social comparison seems to suggest not, indicating that price and behavioural signals work through different channels, though may interact with each other.

4 The applicability of IBTs to the UK

In most of the IBT case studies on which we draw insights regarding the effectiveness of IBTs and which we review above, IBTs (and changes to IBTs) were implemented in response to a case of distress, such as a severe drought.[33] This immediately creates a problem when drawing on the experience from elsewhere and implies that one should proceed with caution. Moreover, the IBTs were usually used in conjunction with various other non-price tools (e.g. Renwick and Archibald, 1998; Kenney *et al*. 2008; Nataraj and Hanemann, 2011), which makes it difficult to disentangle the main sources for success.

The general lessons from the international experience of IBTs as summarised in section 2:

1) With complexities in the design, implementation, consumer perception and estimation of IBTs, there is risk and uncertainty associated with the use of IBTs;
2) Successful IBTs share some common factors;

[32] Nevertheless, it would be difficult to separate out the two effects.

[33] For example, in response to "one of the worst drought years on record", Aurora Water, Colorado implemented a number of water demand management programs from 2002. Price tools included the change from uniform pricing to IBTs, multiple changes of IBT rates and the adoption of water budgets, while non-price tools included limits on outdoor water use, incentive programs and introductions of new technologies (Kenney *et al*. 2008).

3) The concurrent use of price and non-price demand management tools in response to severe droughts can be effective in reducing water consumption.

This section focuses on to what extent the above learning can be transferable to the UK context. A series of questions can be posed, such as: do we expect complexities and uncertainty associated with IBTs to apply to the UK? Are factors contributing to the success of IBTs plausible in the UK? To what extent do severe weather conditions act as a prior condition for effective conservation programmes? How do price and non-price tools interact? Answers to these questions depend on a wide range of conditions, including but not limited to factors controlled by utilities.

4.1 The presence of extreme weather conditions

In the presence of extreme weather conditions such as droughts, water demand management and conservation programmes are usually adopted to mitigate the problem of water shortage. In addition, drought events can change households' perception and understanding of water and water consumption.

As discussed at the beginning of Section 3.2, households' specific beliefs about water can affect their attitudes and decision-making in consumption. It is plausible that the perception of droughts and water use differ substantially between households who have experienced droughts or near drought conditions and those who have not. Those who have experienced droughts may have a deeper understanding of the importance of conservation, and may feel more responsible and thus are more willing to engage in water-saving activities. Gilg and Bar (2006) study how water-related attitudes are formed in light of social, psychological and environmental factors based on a survey of 1200 households in the UK. They find that individuals who perceive environmental issues as a genuine threat to their own welfare are likely to save resources.

Households' conservation initiatives and prosocial preferences are an endogenous factor contributing to the effectiveness of IBTs. Severe weather conditions can be sufficient in inducing conservation behaviour and can *ceteris paribus* justify some sharp increases in water prices which households may be prepared for and tolerant to. On the other hand, the absence of extreme weather conditions or a lack of understanding of drought and climate change may make water tariffs a less attractive option.

UK share the global problem of water constraints which are likely to be tightened in the future (Defra, 2009; Ofwat, 2010). There is an increasing risk of water shortage in certain regions in England, including the southern region which was primarily affected by the 2004 - 2006 drought. In Dessai and Sims (2010)'s study on public perception of drought in southeast England, comparison has been made between St Edmundsbury and Sevenoaks District regarding residents' opinions of "the seriousness of the water situation in their locality in 2006". Responses to questionnaire surveys suggest that the seriousness of the local water situation was perceived to be significantly higher in the

Sevenoaks District. This is consistent with a finding by the UK Environment Agency that Sevenoaks was more negatively affected by the drought.[34]

While the small sample in Dessai and Sims (2010) prevents strong conclusions, a sensible starting hypothesis to test, would be that beliefs on the water situation in local communities correlates with the actual weather conditions. The implication of this hypothesis is that conservation tools, such as IBTs, are more likely to be effective in periods of drought, and that their effectiveness increases with the severity of droughts. This comes not only from households, but also from utilities who may generally be reluctant to use prices to manage demand but are more likely to do so given strong conservation preferences of the local community as discussed above.

However, population growth, climate change and decreasing supply mean that it is inadequate to manage water resources only during crises and that pre-emptive actions should be taken. Since households' conservation initiatives and prosocial preferences are an endogenous factor, information-based interventions can be used to "educate" and influence households by raising awareness and providing incentives, when extreme weather conditions are absent. They might have the effect of "setting the scene" so that households are to some extent prepared for and willing to respond to price changes such as the adoption of IBTs.

Nevertheless, the concern remains that there is little reliable evidence on long run effects of information-based interventions, which we discuss next.

4.2 Interactions of price and information interventions

The common concurrent use of price and information interventions in the event of droughts may have the advantage of boosting the potential reinforcing effects of the two. This however means that it is difficult to separate out the effects coming from the two channels.

As mentioned earlier, there is only a limited number of studies conducting information-based water conservation experiments, in none of which are information interventions repeated, which prevents quantified and robust conclusions from being drawn. It is not clear how households interact with different information types over time: do repeated interventions yield stronger, similar or diminishing effects compared to the first one, and does the answer vary with the type of information? Once habits are formed in light of information, do repeated interventions offer reinforcing or adverse effects? If it is helpful to repeat information interventions, what is the appropriate frequency?

[34] According to Dessai and Sims (2010) the UK Environment Agency classified St Edmundsbury in the Anglian region with a 'moderate' water stress status and the Sevenoaks District in the southern region with a 'serious' water stress status.

On the other hand, characteristics of local populations can also influence the effectiveness of information interventions. This explains why randomized samples are needed to quantify the true effects of different types of information, and why similar types of information may have different effects in different local communities. In this context, in addition to “setting the scene”, implementing information interventions before introducing tariff changes may allow one to capture relatively purer effects of information on conservation.

4.3 UK water industry – evidence and facts

4.3.1 Residential water demand

Despite the extensive international literature on water demand estimation, there is very little UK-based evidence. Hence there is little information on how water demand would change with price in the UK, and how such change would differ across income groups or with the level of consumption.

Baker and Toft (2003) provide PED estimates that are considered to be unsuitable, as they include unmetered households in the sample and treat them as price insensitive (Waddams and Clayton, 2010). This indicates that the limited research in this area may be partly due to historically low meter coverage in the UK.

Gardner (2010) discusses descriptive proxies of UK PED using international evidence, especially estimates from France, which shares similar cultural and climatic conditions with the UK, i.e. the “marine west coast” climate. The mean PED estimate of France is -.261 which is lower in absolute value than the international mean of -.379.

Gardner then provides “the first UK elasticity estimates” using quarterly data from 2007 to 2010 of 622 metered households given by Veolia Water South East. Note that from April 2008, a two-block IBT was trialled against uniform pricing for half of the sample. The first block included 80 m^3, and an average household consuming 100 m^3 would enter the second block.

Table 5. Tariffs under uniform pricing and the IBT

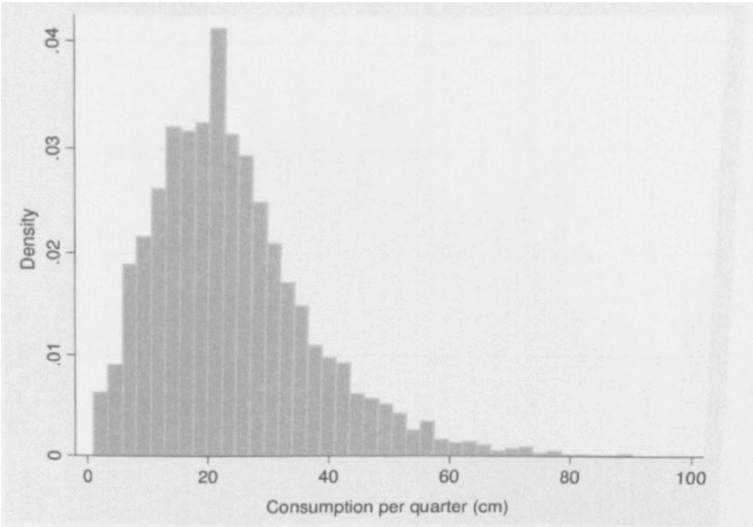
	2007-08	**2008-09**	**2009-10**	**2010-11**
Quarterly standing charge (£)	27.68	28.16	29.22	28.27
Unit price (£/m^3)	1.23	1.26	1.30	1.28
Block 1 price (£/m^3)	-	0.94	0.98	0.96
Block 2 price (£/m^3)	-	2.12	2.49	2.51

Source: Gardner (2010)

The model estimated includes variables such as water prices, household size, property value, temperature and a dummy variable of summer, but no income data are available. Depending on functional forms, the estimated marginal price elasticity ranges from -.177 to -.286, which is close to the mean estimate of France and lower in absolute value than the international mean. This suggests the scope for price to reduce water demand, but the effect is likely to be small.

Several findings in relation to water demand and effects of IBTs do not appear consistent with the picture obtained from international experience. First, average consumption was higher for IBT household than uniform pricing households for all periods. Apart from mean household size being slightly higher for IBT households (2.49) than for uniform pricing households (2.44), no clear reason is given to explain this finding.

Figure 4. Histogram of quarterly consumption



Source: Gardner (2010)

Linked to our learning from international experience of IBTs, this might be a joint effect of many possibilities: i) IBT households consumed more water before the trial and the IBT trial failed to reduce consumption, ii) the second block price was not sufficiently high, iii) the IBT was misunderstood by households, iv) households' awareness of water conservation was low, given that only 10% of the sample chose to be metered whereas 90% were compulsorily metered (despite this being a region with "water scarcity status") and v) the number of households with large discretionary water use was low, as the histogram in Figure 4 is skewed to the right (quarterly consumption ranged from 1 to 90 m^3 with a mean of 24 m^3).

Second, summer demand is found to be less price responsive than demand all year around. General finding in the literature suggests the opposite. Gardner explains that this may indicate that UK households value summer consumption highly. Third, low income groups are least responsive to prices, but the literature usually suggests them to be most responsive to price changes. Since income data are not available for estimation, this finding is obtained by using four ACORN (A Classification of Residential Neighbourhoods) groups as a proxy – "Wealthy", "Comfortable Off", "Moderate Means" and "Hard Pressed". Numbers of households belonging to the four groups were 538, 2729, 1605 and 2513, respectively, suggesting low number of wealthy households.

As Gardner notes, this study may not be representative of general UK metered demand due to the sample size and limited variables included. However, it may to some extent reveal the characteristics of water consumption in the UK as discussed above.

Levell and Oldfield (2011) report household spending patterns on water across income groups in the UK. As Figure 5 illustrates, while water bills account for a small amount of income for all income groups, they account for a higher share of income and total expenditure for lower income groups. In particular, richest households typically spend less than 1% of their total expenditure on water while the percentage is between 2.5-3% for the poorest.[35]

Figure 5. Share of expenditure on water by income quintile

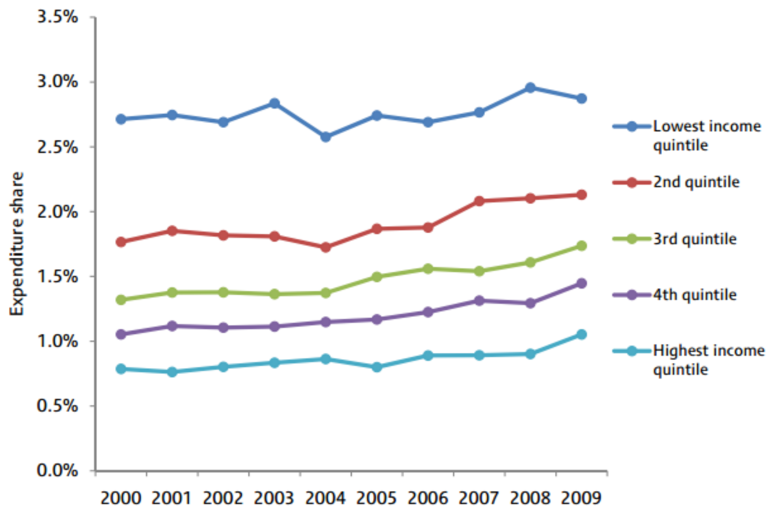
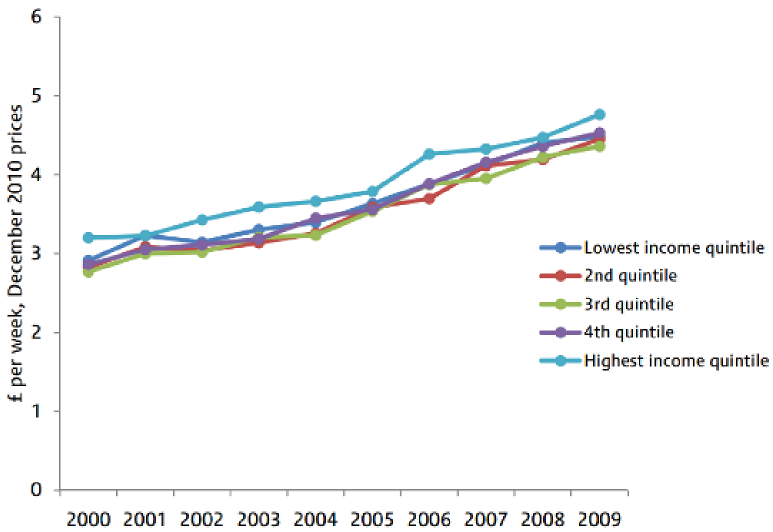


Figure 6. Weekly spending on water by income quintile



Source: Levell and Oldfield (2011)

[35] Levell and Oldfield also note that benefit-dependent households with residents unemployed spend more on water as a share of their total expenditure.

However, when it comes to consumption across income groups, the differences become much less pronounced. Figure 6 shows how weekly expenditure on water differs across income groups. The richest households spend only slightly more on water than other households, and it is difficult to rank water spending across income groups over time.

Herrington (2007)'s report on "Water Tariffs for Sustainability" in the UK suggests that two-block IBTs may benefit from being simple and straightforward, three-block IBTs may have the advantage of clearer distinctions between essential, discretionary and wasteful water uses, but a fourth block may require additional justification given that "garden irrigation use is generally sub-Australian and sub-American." Taken together with the low variation on water spending across households in Figure 6, this appears to indicate that UK residential water demand generally involves relatively low discretionary use.

These stylized facts can have important implications for the design of IBTs. Large numbers of high water users usually create the scope for IBTs to be effective. To what extent this is the case for the UK requires further information such as the break-down of water consumption by income group, household size and the level of consumption, as well as more up to date information on proportions of high water users.

Low income households with high water consumption might be able to benefit from IBTs especially in the long run, if a significant amount of the high consumption is driven by inefficient and nonessential use of water. Evidence from IBT case studies also suggests low income households to be relatively responsive to price changes. However, IBTs would be to the detriment of low income households if their high consumption is largely essential water use (such as due to high occupancy). The emphasis on affordability in the UK regulatory context means that special caution is needed when water tariffs may potentially negatively affect low income groups.

4.3.2 Water sector

The limited evidence and stylized facts about UK residential water demand do not appear to suggest that IBTs are particularly likely to be successful in the UK, and the IBT trial in the UK did not reduce water consumption.

Varying with many inter-related factors, such as characteristics of local water demand, local population and democracy, optimal designs of IBTs inevitably require trial-and-error. How feasible this is given the political and regulatory setting of the water sector in the UK remains a question.

The residential water sector in England and Wales consists of privately-owned, regulated companies, many of which are regional monopolists. The regulator of this sector, Ofwat, has placed greater emphasis on water demand management in recent years by explicitly stating that the solution to sustainable water service is not simply about building more reservoirs, and that changes have to be made in the way one values and manages water (e.g. Ofwat, 2010a), and by actively seeking views regarding its new role in resilience (e.g. Ofwat, 2015).

Despite the need and emphasis, there have been slow developments in conservation-oriented tariffs, and this is due to a number of reasons. First, metering is optional in the UK. This unusual feature (compared to other European countries) makes increasing meter penetration the essential first step of a broader implementation of demand management strategies including tariffs. This in itself may have a positive effect on conservation, as there is evidence that metring in itself lead to greater awareness of water use. While both Ofwat and Defra (the UK Government Department for Environment, Food & Rural Affairs) have argued for more metering, a cost-benefit justification is crucial (Ofwat, 2008; Defra, 2009). Herrington (2007) argues that affordability appears to be a "barrier" to increasing meter penetration.

Second, price limits are reviewed every five years by Ofwat in an *ex ante* approach, which effectively limits the amount of revenue a company can raise (Ofwat, 2010b; Ofwat, 2014). Thought may need to be given to whether the implied limit on revenue has implications for the feasibility of introducing and designing IBTs. This might partly explain why second block prices in the IBT trialled by Veolia Water South East were not high.

Moreover, both Ofwat and Defra have expressed clear views on IBTs:

> *"Rising block tariffs attempt to distinguish between essential and discretionary water use. They are much more likely to be successful in doing so if the first, cheaper block of water varies with the number of occupants in a household. Such tariffs might help to address affordability concerns without compromising the objective that charges should be cost-reflective. They present some practical difficulties, but we think that they merit further investigations……" (Ofwat, 2005)*

> *"In this context, it has often been suggested that rising block tariffs are the best way to address the affordability of metered water bills for low-income households, as they provide the first block of water at a reduced price. However, rising block tariffs that do not size the cheaper block of water according to occupancy do not distinguish between small households with high discretionary use and large households with high essential use." (Defra, 2009)*

From the above statements, what is so appealing about IBTs in the regulatory context for water charging in the UK seems to be their potential effects on affordability rather than on conservation. A major concern from stakeholders on IBTs is the equity issue regarding essential water consumption (size of the first block) and household size.

The practical obstacle of adopting IBTs, conditional on metering, is the lack of routinely updated data on household size in England and Wales, and obtaining these data can be very costly in practice. This leads to Defra (2009)'s conclusion that IBTs "may merit trial and development in specific water company areas" instead of being a "national system of charging".

This may potentially explain why only companies granted "water scarcity status" by Defra – Veolia Water South East and Wessex Water – have trialled IBTs (and seasonal tariffs). Likewise, frequent adjustments of tariffs would entail high transaction costs that seem difficult to justify in the absence of severe water shortage, especially when there is uncertainty with the potential benefits of tariff changes.

4.4 Consumer perceptions

Consumer perceptions include those on prices, consumption and water situations. As discussed previously, they are highly relevant for the effectiveness not only of IBTs but also of information interventions. Also, understanding consumer perceptions can help utilities to improve information provision and communicate more effectively with consumers.

Various studies find that UK households are not aware of their utility prices or consumption. For example, survey data suggest that 82% of British energy consumers are unaware of their tariff (Energy Saving Trust, 2008). Waddams and Clayton (2010) argue that UK households have low understanding of price, consumption and billing information, and that they have limited ability to rank water-using activities.

Gardner (2010) investigates UK households' perceptions on water price and consumption using survey data from Veolia Water South East. 200 respondents completed self-completion questionnaires, 60% of whom were part of the IBT trial discussed above. The majority of respondents chose not to answer questions in relation to perceptions (112 out of 200), those who answered in general gave very inaccurate perceptions. In particular, water prices were systematically overestimated: while the average of two block prices was £1.59, the mean price perception ("best guess") of the IBT was £8.57. The accuracy of perception did not improve for uniform pricing. Further, 74% of respondents failed to answer correctly which tariff they were on (uniform pricing or the two-block IBT). Meanwhile, respondents had significantly more accurate perception of their water bills. This appears consistent with the fact that most respondents (77%) stated that they would look at bill totals, but only 15% stated that they would look at water prices.

Since respondents in the survey self-selected to complete questionnaires, the survey sample might be biased towards those who have a better understanding of tariffs and their consumptions; Gardner suggests that in general UK households may have even worse understanding of their water prices. This may be explained by the framework of costs of benefits discussed in Section 2.2.2: the small value of water bills relative to total budget for the majority of households may not justify the potential efforts required to acquire and understand relevant information.

Households' better understanding on bill totals implies that any price signal is likely to reach households indirectly, which might suggest less effectiveness of tariffs such as IBTs where the marginal price changes with the level of consumption. Also, households are put in a vulnerable situation if bill totals are based on estimated rather than actual meter readings which have little relevance to IBT rates – they may receive small bills for many periods without watching their consumption and suddenly face an unexpectedly high bill once actual readings are taken.

The above suggests the need to find out more about households' understanding of water prices and consumption. To improve the performance of IBTs and to reduce potential adverse effects IBTs may have on uninformed households, smart meters are expected to be installed for real time accurate readings; and communication should target households' awareness of tariff structures and their own consumption directly, rather than indirectly through bill totals. This can be done by reducing costs of price information acquisition and by increasing benefits of doing so. For example, non-price approaches to draw households' attention to water conservation might increase the potential benefits as households are motivated to understand water prices and watch consumption for a good cause.

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