Price and Behavioural Signals to Encourage Household Water Conservation in Temperate Climates

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Abstract

Water scarcity is a global concern. Even in non-drought environments the political and economic costs of developing water resources may favour water conservation. Using a single high price to constrain demand raises distributional and political challenges. Increasing block tariffs (IBTs) have been proposed as a potential solution, balancing incentives for water conservation with an equitable distribution of costs across households. An alternative approach that may side-step affordability concerns is to use non-price conservation interventions. We survey the literature on IBTs and behavioural interventions (a subset of non-price interventions) to assess their effectiveness, thereby highlighting the operational challenges of implementing effective IBTs. Robust evidence on behavioural interventions is limited, although, social comparisons appear to be effective for conservation. We discuss the implications of the evidence for the UK, a country with a temperate climate. We note that existing interventions have been typically implemented in response to drought situations, so one may question the validity of existing evidence for designing interventions in non-drought situations. We suggest an essential first step before implementing an IBT is research to understand a locality's water consumers and their water demand. That many UK households have an unmetered water supply presents challenges both for gaining this understanding of demand and producing an evidence base around behavioural interventions.

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Abstract

Water scarcity is a global concern. Even in non-drought environments the political and economic costs of developing water resources may favour water conservation. Using a single high price to constrain demand raises distributional and political challenges. Increasing block tariffs (IBTs) have been proposed as a potential solution, balancing incentives for water conservation with an equitable distribution of costs across households. An alternative approach that may side-step affordability concerns is to use non-price conservation interventions. We survey the literature on IBTs and behavioural interventions (a subset of non-price interventions) to assess their effectiveness, thereby highlighting the operational challenges of implementing effective IBTs. Robust evidence on behavioural interventions is limited, although, social comparisons appear to be effective for conservation. We discuss the implications of the evidence for the UK, a country with a temperate climate. We note that existing interventions have been typically implemented in response to drought situations, so one may question the validity of existing evidence for designing interventions in non-drought situations. We suggest an essential first step before implementing an IBT is research to understand a locality's water consumers and their water demand. That many UK households have an unmetered water supply presents challenges both for gaining this understanding of demand and producing an evidence base around behavioural interventions.

Key words: Increasing block tariffs; behavioural interventions; water conservation

JEL codes: D10; L95; Q21; Q25; Q28

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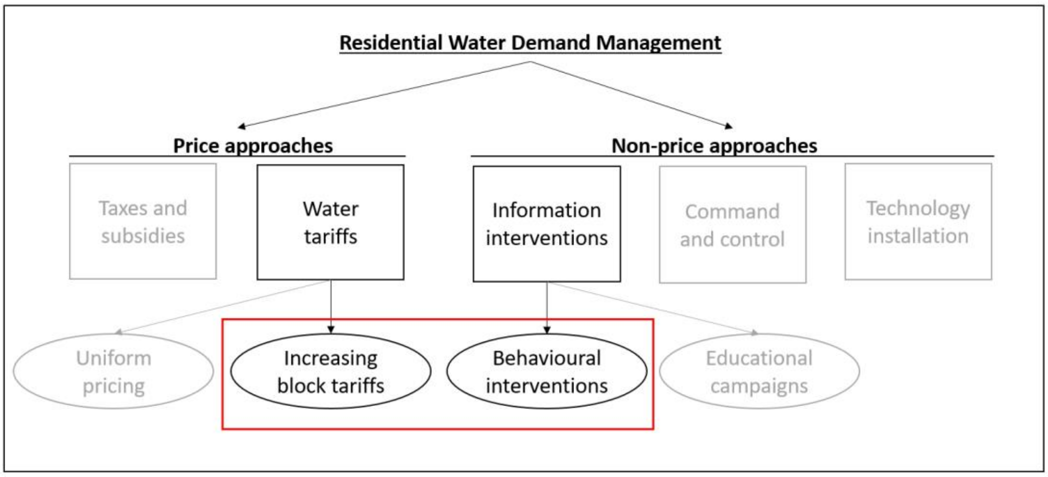
"There are growing pressures on our water resources. A changing climate makes it uncertain how much water will be available for supply in the future. Droughts will become more commonplace by the 2050s. Water demand is becoming more uncertain too, with changing weather patterns, population growth, and lifestyle and demographic shifts."[1]

1. Introduction

The quote above highlights the UK in general, and the south-east/east of England in particular, face an increasing drought risk over the next 50 years. The reliance on increasing supply to meet water demand has encountered ever greater challenge due to the economic and environmental costs involved and has led to political opposition[2] to the further exploitation of resources. One policy response to this issue is to use demand-side measures, involving both price and non-price tools, to reduce household water use. The current paper explores how measures trialled in other developed countries already facing a high drought risk may prove useful in the UK setting.

The increasing penetration of water meters in the UK enables water utilities and policymakers to create a range of incentives to promote water conservation to households.[3] Figure 1 presents a typography of price and non-price tools that can be used individually or in combination to manage residential water demand. Some interventions can be pursued through price or non-price means. For example, while installation of water efficient household appliances funded through general taxation is a non-price approach, tax breaks and subsidies specifically for these appliances represent price interventions.[4]

Figure 1: Price and non-price approaches to residential water demand management



Water tariffs are the most common price intervention in the EU (EEA, 2017) with higher prices on water directly reducing demand. However, there are a number of reasons to be cautious about using a high uniform price to constrain demand. A minimum level of water consumption is essential for life and so water is viewed as a necessity by the public. This leads to two points: (i) demand is price

[1] Paragraph 3, Ofwat: Water Resource Planning, http://www.ofwat.gov.uk/regulated-companies/resilience-2/water-resource-planning/.

[2] For example, there has been significant opposition to Thames Water proposals for a reservoir near Abingdon in Oxfordshire. See Group Against Reservoir Development website, http://www.abingdonreservoir.org.uk/.

[3] The literature on water demand management suggests the introduction of water meters, regardless of tariff, reduces water consumption, see e.g. Worthington and Hoffman (2008).

[4] A number of recent interventions, particularly in the US, to incentivise consumers to buy more efficient cars or appliances find rather disappointing results, see e.g. Houde and Aldy (2017).

inelastic and (ii) political concerns about ensuring equitable access to water are significant. Furthermore, there is a potential interplay between point (i) and point (ii). Since water demand is fairly price inelastic[5] to achieve a significant reduction in quantity demanded the water price would have to increase significantly, with potentially regressive distributional implications. The potential regressive impact on poorer households is of great concern, which has already been reflected by the unusual feature of optional, rather than compulsory, metering in the UK water industry (Medd and Chappells, 2007).

While the probability of a drought in any given summer may be increasing over time, the realised severity of droughts will fluctuate over the decades. Charging high prices in non-stressed periods may be politically problematic, but varying prices to deal with short-run excess demand is also generally disliked by consumers.[6] Also, price increases raise revenue as well as reducing demand. With the UK's privatised monopolist water utilities, increased profitability is likely to face significant public opposition.[7] If competition is introduced (as has been suggested in England), it may remove firms' ability to raise prices unless they enter into an illegal price-fixing agreement. Using taxation to directly raise prices or to extract monopoly profits may still be politically problematic and is likely to lead to conflicts between using the taxation to curb consumption and raise revenue.[8]

Similar concerns have led areas experiencing severe droughts to implement a more sophisticated pricing structure, referred to as an Increasing Block Tariff (IBT).[9] In an IBT initial consumption is priced low to ensure essential demand is not constrained but subsequent consumption is priced high to discourage discretionary use. At least theoretically this makes an IBT an attractive structure for a price intervention with a social conscience. In terms of implementation, there are a number of challenges and one of the contributions of this paper is to set these out systematically. IBTs are used in practice and with some success. Studying Zaragoza, Kayaga and Smount (2014) show that its conservation plan, which included an IBT, reduced total water consumption by 27% between 1996 and 2008 (despite a population increase of 12%).[10] While the large literature on water demand

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[5] Meta-studies report wide ranges of price elasticity estimates for household water demand in the existing literature. These ranges are -3.33 to -.02 (Espey *et al*., 1997), -7.47 to 7.90 (Dalhuisen *et al*., 2003), and -3.054 to -.002 (Sebri, 2014).

[6] The aftermath of Hurricane Harvey provides a number of examples such as: "Price gouging during Hurricane Harvey: Up to $99 for a case of water", Michelle Fox, CNBC, 28 August 2017, available at: https://www.cnbc.com/2017/08/28/price-gouging-during-hurricane-harvey-up-to-99-for-a-case-of-water-texas-ag-says.html. Price gouging, the raising of prices in a crisis, is illegal in some places, including Texas. That this is controversial is evident from two headlines following hurricane Harvey: "DON'T OUTLAW PRICE GOUGING AFTER HARVEY. LET THE MARKET WORK" (Newsweek, 28/8/17) and "Memo to economists defending price gouging in a disaster: It's still wrong, morally and economically" (LA Times, 28/9/17).

[7] Research by Utility Week illustrates this: "When respondents were asked why they approved of the idea of renationalising UK utilities, many pointed, unsurprisingly, to perceived profiteering and fat cat cultures.", see 4 August 2017, "The challenge of trust in utilities", available at: http://utilityweek.co.uk/news/the-challenge-of-trust-in-utilities/1308792#.WeDYbmhSyUk.

[8] Grossman *et al*. (1993) discuss this issue in relation to alcohol and cigarette taxes.

[9] These have been also used extensively, but with mixed effects, in energy markets in developed countries, including the US, again in an attempt to balance conservation incentives with distributional implications, see e.g. Borenstein(2012, 2016).

[10] Beyond an IBT and a rebate for large households Zaragoza also adopted a reward scheme. Households who reduced water use by at least 40% in the first year after joining the scheme received a 10% discount on their bill; a similar discount was obtained for each further 10% reduction in water use in each subsequent year. The combination of measures makes it difficult to identify how much of the demand reduction should be attributed to the IBT.

estimation has been surveyed extensively,[11] no one has brought together the analysis on IBT introductions. In addition to surveying the insights from past introductions of IBTs, a second contribution of this paper is to assess whether these are generalizable in settings beyond drought prone areas.

While our survey findings suggest IBTs are challenging to implement and may be slow to show tangible results on water conservation, non-price tools may prove useful either as a substitute for price interventions or as a complement. They can, however, face their own implementation challenges. For example, large-scale educational campaigns and technology installation require direct investment, whereas command and control measures, such as hose pipe bans, usually involve high monitoring costs. Another set of non-price, information-based tools – often referred to as behavioural interventions – aim to convey behavioural signals to encourage households to follow policy driven conservation behaviours. [12] While an educational campaign usually promotes a core slogan and/or sets a clear goal of decreasing water consumption at a regional or national level (EEA, 2017), behavioural interventions usually focus on smaller communities and vary in the type of information they provide, indeed, some are household specific, e.g. usage feedback. A third aim of the paper is to survey the literature on behavioural interventions in residential water markets to assess their relevance as a means to reduce residential water consumption in the UK. In addition to identifying the behavioural interventions analysed in the literature, we consider which ones can be effective in stimulating water conservation and their impact on poorer households. We aim to uncover how the non-price interventions interact both with each other and with the pricing mechanisms and how persistent any effects are.

The remainder of the paper is organised as follows. Section 2 discusses the benefits and challenges of using IBTs, drawing on both theoretical and empirical insights. Section 3 evaluates the evidence on information-based behavioural interventions. Section 4 applies the insights from the surveyed price and behavioural interventions to the UK to assess which interventions are best suited to provide the appropriate incentives for water conservation. Finally, section 5 concludes.

2. Using IBTs to conserve water

In theory, increasing the water price is a natural way to limit water consumption. By the law of demand, increasing water prices should reduce the quantity of water consumed, however, the extent of demand reduction depends on consumers' response to price movements. Conventionally water is viewed as price-inelastic since it has few substitutes.[13] Residential water tariffs typically consist of a fixed element and a per unit (variable) element. The fixed element is usually designed to cover the fixed costs of connecting to the water network.[14] The per unit element can be a constant uniform price or a price which varies with consumption. Uniform pricing is unlikely to satisfy all policy objectives. A low unit price ensures water is affordable to the poor but may create challenges around recovering costs and conserving water.[15] A high price should conserve water but may lead to poor households

[11] See the literature surveys by Arbués *et al*. (2003) and Worthington and Hoffman (2008) and meta-analyses in footnote 4.
[12] Behavioural interventions also have been used in the energy sector, see e.g. Allott and Rogers (2014).
[13] See footnote 11.
[14] For simplicity of exposition, our discussion of IBTs does not refer to the fixed fee.
[15] Cost recovery appears to be a priority of Australian and Spanish policymakers, but can be political. For example, Arbués and Barberán (2012) argue that since water is directly managed by local city councils in many Spanish cities, 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 providing water services."

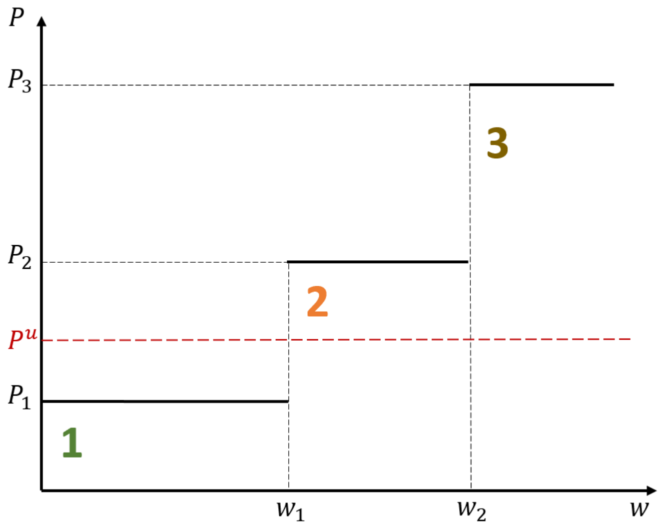
consuming below an advisable level and/or facing financial hardship. The adverse distributional effects of a high uniform price are likely to be challenging politically.

A price mechanism where the per unit price varies with consumption, such as an IBT, attempts to find a balance between the affordability and conservation objectives. However this balance comes at the cost of complexity when designing IBTs (Arbués *et al.*, 2003).

2.1. IBTs in theory

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.[16] The utility can set lower prices to support essential consumption for all households and higher prices for consumption considered non-essential. Additional blocks may be introduced to target households with ever higher consumption.[17] Intuitively the idea is to construct a first block corresponding to the section of water consumption during a billing period which is essential and then consider subsequent blocks of consumptions as increasingly a luxury which is priced accordingly. IBTs aim to prevent non-essential water consumption, mainly in high-income households (Suárez-Varela *et al.*, 2015).

Figure 2: A three-block IBT



Formally, an IBT is defined by a set of *k* (≥ 2) consumption levels, $w_1 \dots w_k$, where $w_1 < w_2 < \dots < w_k$, a set of k associated prices $P_1 < P_2 < \dots < P_k$ and a billing period, *t*, after which the consumption level is returned to zero so that at the start of billing period *t+1* consumers revert to the first block where price is P_1 (Boland and Whittington, 1998). Figure 2 below illustrates a three-block IBT. Compared to the uniform price tariff, P^u, the IBT involves a lower price for consumption up to

[16] Taking account the fixed fee in most water tariffs, the average price of water is strictly decreasing as consumption increases under uniform pricing, whereas an IBT can lead to an increasing average price after some level of consumption. While the fixed fee primarily designed to recover the cost of connecting to the water network, its magnitude may also have implications on water demand management. The impact of the fixed fee is not the focus of this paper nor the IBT literature.

[17] The literature, e.g. Hall (2009), Wichman (2014) and Asci *et al.* (2017), indicates the number of blocks varies considerably across regions. For example, in the US, a two-block tariff is used in Los Angeles, four blocks are used in Arizona, California and Florida, and five blocks are used in North Carolina. IBTs in Asia usually involve four blocks, whereas in Latin America, they range between three and thirteen blocks.

w_1, a higher price for additional consumption up to w_2, and a much higher price for consumption above w_2.[18]

The designer has to decide on a number of features of the IBT. These include the number of blocks, the length of the billing period, the size of each block per billing period, and the price of each block. The success of an IBT in meeting both distributional and conservation objectives depends on many issues, including consumer responses and the information available to both consumers and designers.

2.1.1. IBT design with rational consumers

The decision on pricing each block depends on the responsiveness of demand to price. Low-income households, unsurprisingly, are far more price sensitive than high-income households. Renwick and Archibald (1998) estimate water tariffs' distributional implications using data from Santa Barbara and Goleta, California, during California's 1985 to 1992 drought. Overall, elasticity of demand (PED) estimates indicate that low-income households were five times more responsive to price changes than high-income households. While it might be tempting to target the households with the greater price response, doing so would place the burden of conservation predominantly on the poorer households, who also tend to have consumption close to what one might consider the minimum desirable level. The socially more desirable target for water conservation would be high water users.[19] Existing experience suggests a positive correlation between income and consumption (Asci *et al.*, 2017), although the correlation can be weak (Nauges and Whittington, 2017). Wealthier households usually have a higher irrigation requirement as they tend to have larger gardens and outdoor water use can account for a substantial proportion of water consumption. Targeting high income households to conserve water creates its own challenge as these are likely to be relatively unresponsive to water prices because water bills account for a smaller proportion of their total expenditure/income (Agthe and Billings, 1987; Worthington and Hoffman, 2008).

Figure 3 illustrates potential changes in water price following a switch from a uniform price p^u to a three-block IBT. Low water users in block 1 are sensitive to price. Facing a price reduction from p^u to p_1, consumers who have traditionally consumed within the first block are likely to increase consumption (Wichman, 2014; Asci *et al.*, 2017). High water users in block 3 face a price increase from p^u to p_3. Since these households are relatively price insensitive, whether p_3 reduces consumption by a large amount depends on whether it is sufficiently high. Overall whether this IBT can reduce water consumption in the aggregate depends on the distribution of households across the different blocks. If the number of households traditionally consuming within block 1 is large, total water consumption could increase with a poorly designed IBT. Similarly, if w_2 were set so there were very few households in block 3 even a very high p_3 would not reduce aggregate water demand. Highlighting that increased consumption is not just a theoretical possibility, Wichman (2014) found the introduction of an IBT in North Carolina in 2007 led to water consumption increasing overall.

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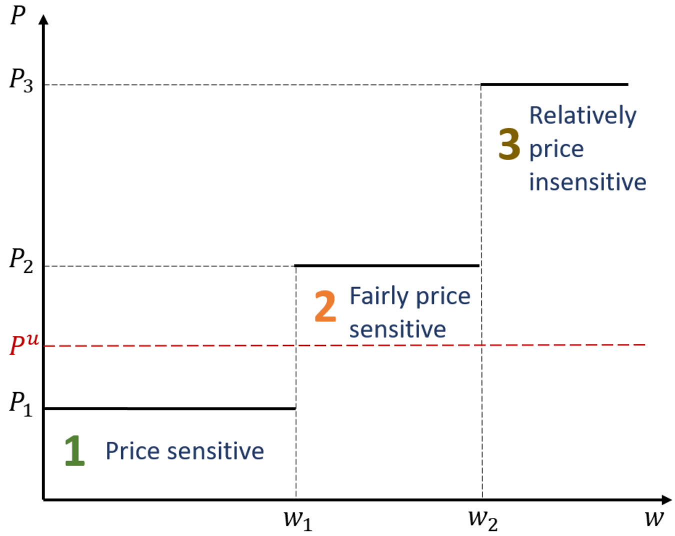
[18] Note that Figure 2 illustrates an example of IBT with conservation objectives. In theory an IBT can look very different e.g. featuring an initial block price above P^u or a final block price only slightly higher than the initial block price. Such design, however, would not fit for the purpose of balancing water conservation and affordability.

[19] There is no standard definition of 'high water users' in the literature. Since the structure of IBTs varies considerably across geographical areas and time periods, 'high water use' is a relative term specific to each study. For example, among Spanish provincial capitals employing a five-block IBTs in 2008, the starting point of the 5th block (which clearly targets high water users) differed from 20 to 135m^3 per month (Arbués and Barberán, 2012).

Figure 3. Moving from a uniform price to a three-block IBT



The heterogeneity in households' responsiveness to price thus generates several challenges. First, the price aimed at choking off high demand may have to be very high to be effective. In 1995 Santa Cruz, California introduced a third price block to its existing two-block IBT. Nataraj and Hanemann (2011) find this change led to a 12% decrease in water consumption among high water users. However, the marginal price facing high water users increased by nearly 100% implying that a significant price increase is required to reduce significantly the demand of high water users. Following a similar method, Asci *et al*. (2017) studied the addition of a fifth price block to the IBT in Central Florida. While there was a significant price increase in the high blocks, the percentage of households entering the highest block was almost unchanged[20] and the IBT failed to reduce aggregate demand noticeably.

Second, the initial block may have to be very carefully designed to limit the number of consumers who consume well within this block. Essentially the initial block has to "fit tightly" to the "desirable" consumption for a specific household. A one-size-fits-all IBT with the same block for all households is unlikely to deliver this. For example, essential water consumption is likely to increase with the number of household members (household size). As there is a higher probability that total household consumption will enter higher priced blocks in larger households (Arbués and Barberán, 2012), the average price for essential water will increase with the size of the household under standard IBTs with a fixed block size. This may be considered "unfair" since *per capita* income is lower for larger households (Dahan and Nisan, 2007).[21]

In practice, different strategies have been used to deal with equity across households of varying sizes when designing IBTs. For example, the city council of Zaragoza, Spain, established a special rebate for large households (6 or more members) (Kayaga and Smount, 2014). In some areas "water budgets" have been used which are effectively IBTs with tailored block sizes for individual households. Under water budgets the allowed consumption under each block price is individualized using household-specific characteristics and environmental conditions (Baerenklau *et al*., 2014). This

[20] Before adding the 5th block, 16.5% of households entered the 4th (highest) block and after adding the 5th block, 16.3% of households entered the 5th block.

[21] A counter-argument is that *per capita* price decreases with household size due to economies of scale in water use. However, Danhan and Nisan (2007) suggest that economies of scale do not exist once a household has two individuals.

means the price of essential water consumption remains low regardless of household size (Hall, 2009).[22] Despite the potential advantages, water budgets have not been widely implemented.[23] The challenge seems to be the availability of comprehensive, current and accurate data on household characteristics. Where consent is required to collect personal data, households may choose not to provide this. Furthermore, if households understand that the information they provide will determine their water price, there is an incentive not to truthfully report their characteristics. As a result, water budgets may be determined by using less finely granulated official government data, resulting in less precise estimates and hence less well designed budgets.

Thirdly, the combination of a tightly designed initial step combined with the need for a high price for the final block raises issues regarding the optimal number of blocks. A two-block IBT would have the benefit of simplicity. However, when uncertainty or imperfect information are considered the large price step between the two blocks can be a cause for concern. Take first the case where there are either errors in estimating the size of the initial block or 'errors' in consumption, possibly arising from a household's uncertainty about actual consumption during a billing period or fluctuating weather conditions. If there were no errors, a simple two-block IBT would be adequate; however, with the risk of a potentially large financial penalty for those who unintentionally consume more water than assigned in the initial block, it may be prudent to introduce one or more intermediate blocks with smaller price increases. Consider Figure 2 or 3 above, the three-block structure means there remains a meaningful disincentive to exceed the initial block, but the consequence of doing so is less alarming than if the second block were removed. This may explain why most observed IBTs have multiple blocks.

A second case arises from the effect of uncertainty about consumption within a billing period. Households' intertemporal decisions in response to uncertainty can lead to different behavioural patterns. For some households, there is an option value from reducing consumption today.[24] In essence, at any point in time within a billing period, the consumer will rationally constrain consumption to guard against hitting the next consumption block and its higher price.[25] For low income consumers who are more likely to consume within the initial block and who tend to be particularly price sensitive, the consequence of the option value created by uncertainty is particularly problematic as it implies they will be consuming below their estimated minimum recommended consumption. This effect is likely to be particularly pronounced when expected consumption is close to the boundary of a block, the price increase from moving into the next block is large, or the impact of a higher bill on a household is significant. This suggests that having a second block with a relatively small price step is advisable.

A final effect arises when rational consumers are learning about their demand or are learning about how an IBT functions. The larger are the price steps between blocks, the more costly are mistakes during the learning phase. While painful mistakes may offer a good incentive to learn quickly, households clearly differ in terms of their ability to cope with these error costs. This in itself may make a large step between the initial and the second block untenable. In addition, if we think of the high

[22] It is down to policymakers to decide which household-specific characteristics should be considered.

[23] There are currently over 100 regulated utilities in California. Those in Southern California first adopted water budgets in the 1990s. While about half of all California utilities were using IBTs in 2005, fewer than 14 used water budgets by 2008, although, between 2008 and 2011 at least another 9 started to use them (Baerenklau *et al*., 2014).

[24] For an explanation of the option theory, see Dixit (1992).

[25] This logic leads to the testable empirical prediction that as consumers reach the end of a billing period, and uncertainty is resolved, their daily consumption should increase as the value of the option declines.

price of the second block as the "punishment for over-consumption", then the punisher (the water company) will actually enjoy higher revenue from meting out the punishment.[26] The politics of this issue when firms are privately owned are probably challenging as how can a consumer be sure that the punishment is reasonable rather than a sign of corporate greed?

2.1.2. Consumers' decision-making under IBTs

The effectiveness of IBTs to conserve water depends not only on how the price signal is designed but also how it is received and interpreted. The complexity of IBTs presents a challenge both for their designers and consumers. A key requirement for the success of an IBT is that consumers are engaged in a predictable manner with the water sector.

Under uniform pricing, the price per unit is independent of the number of units consumed making decisions about future consumption relatively easy. Under an IBT, the marginal price (price of an additional unit) increases with each successive block but remains the same within each block; hence, the cost of an additional unit depends on the number of units previously consumed within a billing period. Households must consider not only the marginal price of the next unit to be consumed, but also the likelihood that their total consumption will end up in a higher block involving a higher marginal price (Cater and Milon, 2005). To make a fully rational decision, as assumed in the previous sub-section, consumers need perfect information about the tariff structure, real-time information regarding their consumption, and the ability to form unbiased expectations about future consumption up to the end of a billing period (Hewitt and Hanemann, 1995; Wichman, 2014). Meeting all of these requirements for rational decision making is challenging.

While acquiring information about an IBT's structure is relatively costless, understanding current consumption is more difficult, although this may improve with new metering technologies. Where the size of a water bill as a proportion of household income is small for the majority of households, the cost of processing information to fully understand a complex IBT may make the effort of doing so not worthwhile for many consumers. Instead, households may form inaccurate perceptions of prices and consumption, preventing them from making a fully rational decision (Nieswiadomy and Molina, 1989; Natarai and Hanemann, 2011).[27] Even with consumption data available, consumers may struggle to predict consumption over the long-term (Borenstein, 2009) and uncertainty about future consumption can further complicate decision-making. Equally, some households may fail to establish a link between day-to-day consumption and block price increases. Since the marginal price does not increase until consumption reaches a higher block, households may not regard it as particularly relevant for the consumption decision today (the price increase happens in the future and is uncertain). These challenges can have negative consequences on households, especially in the short run. For example, they have to exert effort to calculate and monitor consumption, while budget planning may be harder. Households who do not understand their IBT may face unexpected bill increases. These unexpected 'bill shocks' may be particularly difficult for low-income households. Consumer learning may mitigate these negative consequences and so IBTs are expected to be less problematic in the long run.

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[26] Whether this leads to higher profits that reach shareholders depends on how firms are regulated.

[27] When information acquisition is costly the average price appears to be commonly used for water. This is because, when billing statements are available, the *ex post* average price is obtainable from a bill at negligible cost (Shin, 1985). However, this approach risks poor decision making when bills are estimated rather than based on actual meter readings.

Short billing periods together with clear and accurate billing information are likely to aid learning and reduce the uncertainty facing households.[28] However, providing consumers with more timely information comes at a cost which must be accounted for in any decision to increase both frequency and potentially transparency. Households who receive water bills more frequently, are exposed to more relevant information on their bill and actually read this information may be expected to have a better understanding of the relationship between their water use and water expenditure. Price transparency may make consumers more responsive to price changes. Cater and Milon (2005) estimate water demand conditional on households' knowledge of prices, using survey data and billing records from North-Central Florida. Cater and Milon find that price information lowers water consumption, but this effect is less pronounced under IBTs than under uniform pricing because households facing IBTs are less likely to know the marginal price of water. Using 1996 survey data from the American Water Works Association and billing information in 1995, Gaudin (2006) shows that having price information next to consumption on bills increases PED by 30%.

Low billing frequency may slow down consumption changes.[29] Infrequent billing may not only limit water conservation, but households responding to out of date price information could suffer from sudden, unexpected increases in bills (Arbués *et al*., 2003). However increased billing frequency does not necessarily reduce water consumption. Gaudin (2006) explains that two opposing forces operate: frequent bills may increase price sensitivity as they help households establish a clear relationship between tariffs and consumption, but equally they may decrease price sensitivity because bills become smaller and so receive less attention.[30] Empirical studies on whether increasing billing frequency reduces water consumption are inconclusive (Kulshreshtha, 1996; Arbués *et al*., 2003).

Since design choices regarding an IBT, such as block sizes and prices, are made for a given billing period, an overlooked issue is that changing billing frequency usually requires changes in block size and/or prices. Wichman (2017) estimates the effect of increased billing frequency on household consumption. Halving block size after halving the billing period is "a mechanical interpretation" that does not control for the effect of billing frequency on consumer behaviour. Depending on households' consumption pattern, it is possible for some households to have increased bills, despite identical annual consumption.[31] Thus the periodicity of water demand becomes important. Households' learning and understanding of IBTs may also depend on how variable their demand is through time.

2.2. IBTs in practice

Among developed countries, IBTs are widely used in the US (Olmstead *et al*., 2007; Asci *et al*., 2017),[32] 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,

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[28] An unresolved issue is whether consumers are more likely to learn from a print-out of the bill received through the post than an electronic bill available to download. A field study conducted by Schultz *et al*. (2016) on how information may help to reduce household water consumption concludes that online billing is less effective than bills arriving in the post. Postal billing is clearly more costly for a water utility to provide and the cost increases with the frequency of bills.

[29] For example, Gaudin (2006) found that in the 1996 sample bills might be sent only twice a year.

[30] Moreover, if bills are sent too frequently, one might expect householders to start ignoring them.

[31] An example scenario generating this result would be if a consumer consumes no water in the first month and a high quantity of water in the second month. With bimonthly billing her total consumption across 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 the total bill is higher under monthly billing.

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

2006). Unsurprisingly, these areas are associated with an existing high drought risk. This section reviews some insights from IBTs in these areas.

The structure of IBTs can vary considerably across geographical areas and time periods. For example, Arbués and Barberán (2012) describe the water tariffs in Spanish provincial capitals in 2008. While more than 90% of cities used IBTs, their designs varied: the number of blocks varied from two to eight, while the variance in the size and price of blocks was even more significant. In an attempt to understand these design differences Suárez-Varela *et al*. (2015) analysed the determinants of the degree of progressivity[33] in Spanish IBTs. They found that greater water scarcity and greater economic activity led to more progressive block prices; longer-ruling local government officials were related to less progressive tariffs. While this evidence suggests IBT design is influenced by local circumstances, some general lessons can still be drawn in relation to income, usage, household size, billing frequency and dynamics.

2.2.1. Dynamics: Seasonality and long-run effects

Season, weather and outdoor water use are correlated, and collectively contribute to seasonality in residential water demand, which in some countries is found to influence PED estimates significantly (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 during summer months.

Estimating residential water demand in Aurora, Colorado, between 1997 and 2005 (this includes a drought period covering 2000-2005), Kenney *et al*. (2008) show that water consumption is 30% higher in summer, regardless of temperature and rainfall, suggesting water conservation might target summer months.[34] Two meta-analyses (Espey *et al*., 1997; Sebri, 2014) suggest seasonal pricing is effective. It follows that an IBT could take advantage of water demand seasonality by varying block prices by season. Klaiber *et al*. (2014) measure the effect of seasonal changes in block prices by exploiting a natural experiment in Phoenix, Arizona between 2000 and 2003. They find that while high water users are more price responsive in summer months, responsiveness reduces substantially if a year is particularly dry.

While many studies obtain short-run measures of IBTs' effectiveness, there are reasons to believe that IBTs may be more effective over 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), mainly due to information accessibility and water-related investments by households (Carver and Boland, 1980). Households may have a clearer understanding of how IBTs work and their own consumption over a longer time period. Even if households ultimately respond to price signals and engage in conservation-orientated practices, water use habits may be sustained over a long time period[35] before substantial change takes place. Studies including consumption in previous periods in their estimations, e.g. Asci *et al*. (2017), offer evidence consistent with this argument.

[33] In other words, how the price increases between blocks.
[34] Even if some of the summer demand is essential, higher prices during 'drier' periods may be more politically acceptable due to householders appreciating the presence of water scarcity.
[35] For example, Gregory and Di Leo (2003) look at the relationship between habits and water use.

As discussed earlier, households' responses to IBTs can lead to an increase in aggregate water consumption in the short-run (Wichman, 2014). Since IBTs focus the conservation burden on high water users and they become more responsive to price over time, it is possible for the short-run consumption increases to disappear in the long run. For example, higher water prices can induce households to invest in water-efficient appliances. IBTs make sense here since they focus price rises on households with higher incomes (assuming these are high water users), who disproportionately are the households with the financial resources available to make investments (Worthington and Hoffman, 2008). Illustrating the impact of time, Baerenklau *et al*. (2014) investigate the effects of introducing an IBT in southern California in 2009 finding that water demand was 17% lower than under a uniform price, however, they note the reduction occurred gradually over more than three years. One might wonder whether the magnitude of price increase and the time frame allowed are, to some extent, substitutes when achieving a particular demand reduction.

2.3. Lessons from theory and empirics

Despite being theoretically attractive, IBTs face challenges due to their complexity – they 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. This complexity may not be an obstacle if there is good knowledge of water demand and households' socio-demographic characteristics, and households have a good understanding of an IBT's price signals. However, these conditions are difficult to achieve. The uncertainty regarding demand response aggravates the challenge of complexity when designing IBTs.[36]

The evidence regarding IBTs' effects is mixed. While IBTs have become established in the US, Spain and Australia, and some IBTs have effectively reduced residential water consumption, other IBTs did not reduce demand, or even increased overall consumption.[37] Because of the relevance of local demand and household profiles, IBTs' effects are likely to be region-specific and caution is needed when drawing lessons from the success or failure of individual IBTs. Nevertheless, our review of the empirical evidence on IBTs suggests successful IBTs share some common features. First, the high blocks must have sufficiently high prices, especially when non-essential water consumption is found mainly in high-income households. In practice, there often needs to be frequent adjustment of blocks and block prices to reflect changing environmental and socio-economic conditions. For example, by adding a higher block with a higher price to an existing IBT (Nataraj and Hanemann, 2011; Asci *et al*., 2017). Second, appropriate billing frequency and transparent price information in bills are likely to accelerate and improve households' learning about their consumption and an IBT's structure. This helps households to respond to price signals, and also minimises the adverse effects of households

[36] Uncertainty about IBTs' effectiveness also arises due to methodological issues regarding water demand estimation in the presence of IBTs. Briefly, the main issues are: 1) the fact that under IBTs the price of water determines and is also determined by consumption which creates a simultaneity problem between price and quantity demanded; 2) the block design of IBTs means that households' decisions include a discrete choice of blocks and how much to consume within a block; 3) the choice of IBTs over alternative forms of tariffs, as well as the specific design of a IBT, is potentially endogenous – IBTs may reflect a community's attitude towards water conservation. These issues lead some researchers to perform estimation using more complex estimation techniques and the lack of consensus on the 'correct' price specification, econometric models and estimation techniques has increased heterogeneity in the empirical findings. This heterogeneity restricts the ability of utilites or researchers to be certain about IBTs' true effects. For example, see Arbués *et al*. (2003) and Sebri (2014) for an in-depth discussion of these issues.

[37] IBTs have also been used for electricity and gas, e.g. in the US, where the complexities and challenges discussed in this section also apply, for example, see Borenstein (2009) and Ito (2014).

having poor knowledge, e.g. unexpected increases in bills. Third, IBTs need to be implemented for a sufficiently long period. This allows utilities to make the necessary adjustments, and more importantly, allows households to gradually engage, change water use habits and possibly make water-related investments.[38] While these features may not guarantee an IBT's success, they are likely to improve its effectiveness.

In all the studies reviewed, the water utilities were monopolists. Local competition[39] might be expected to undermine utilities' incentive and ability to adopt IBTs. In particular, if one utility introduced an IBT with a high price for high-use consumers, a sensible competitive response by rivals would be to charge a relatively low price for high units of consumption. Rather than water conservation the likely end result would be the sorting of households across utilities by the level of consumption. However, empirical evidence from the energy market in Texas, US, shows that even after the introduction of competition, IBTs continued to be used (e.g. Puller and West, 2013). This evidence from the electricity market is consistent with either: (i) firms consciously aiming to segment the market by consumption level (IBTs could be a good tool to do this), or (ii) limited consumer engagement implying that imposing an IBT does not automatically cause high usage consumers to switch to rivals.

A note of caution is relevant when evaluating the empirical results. Often an IBT is implemented alongside other (non-price) interventions. Renwick and Archibald (1998) suggest that failing to account for the effects of non-price conservation tools alongside water pricing may lead to overestimates of the effectiveness of pricing on water conservation. In response to water shortages, utilities and policymakers usually implement a variety of price and non-price tools in a short space of time to achieve the desired demand reduction. The next section reviews the evidence on the effect of non-price interventions on water conservation.

3. Using behavioural interventions to conserve water

3.1. The non-price approach

The academic literature and policy reports have both argued for the need to adopt non-price conservation tools to support water pricing (Renwick and Archibald, 1998; EPA, 2016; EEA, 2017). Also, utilities may be reluctant to rely solely on price instruments due to political pressures, equity concerns and legal limitations (Kenney *et al*., 2008). These issues mean that, even if designed specifically to reduce consumption, price signals alone may be insufficient to deliver the reductions in aggregate consumption required (e.g. Wichman, 2014; 2017; Asci *et al*., 2017). In many cases where 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. Non-price approaches to residential water conservation encompass a variety of tools (Figure 1). It could be a Command-and-Control (CAC) approach involving regulatory restrictions, e.g. irrigation bans; it could be technological tools, e.g. the installation of water efficient appliances; or it could be information interventions to increase public awareness of water conservation (Inman and Jeffrey, 2006).

[38] As previously discussed, while these features may make IBTs more effective in reducing demand, they are not always feasible, once political factors, equity concerns and transaction costs are considered.
[39] The possibility of introducing competition to the water sector is being considered in the UK, for example, see Ofwat (2016).

The CAC approach and technology installation serve as direct ways to reduce water consumption. Some studies suggest the merit of these tools, especially when the conservation need is urgent and a significant demand reduction is required (e.g. Renwick and Green, 2000). On the other hand, Olmstead and Stavins (2009) compare water pricing against mandated technology installation and water use restrictions, arguing the latter is less cost-effective due to the need for monitoring and enforcement. Nieswiadomy (1992) argues a potential flaw of mandated technology installation and water use restrictions are that they may not encourage the desired attitude changes and may trigger a rebound effect in the case of technology installations. For example, after a utility installs water efficient appliances, the conservation impact may be partially offset by households increasing the frequency/length of use of the appliances. A further concern is that the use of these policies is constrained by the need for substantial financial resources, as highlighted by the European Environment Agency (2017).

Educational campaigns can induce some conservation-oriented behaviour.[40] However, several studies suggest households to be more responsive to their specific beliefs about water and hold behavioural attitudes favourable to water saving (Corral-Verdugo *et al*., 2003; Gilg and Barr, 2006). Targeted behavioural interventions may be more cost-effective and easier to implement, and can be a desirable complement to publicity campaigns and the approaches mentioned above.

Using demand side interventions to correct for market failures has increased in popularity over the past 20 years. Fletcher (2017) summarises the current evidence on the power and appropriateness of these behavioural interventions. Assessment of these policies are increasingly carried out through natural or constructed experiments. This section reviews experiments addressing water conservation, while addressing two questions:

(i) Which types of household-level information offer particularly strong conservation incentives?
(ii) Do households' socioeconomic characteristics influence the response to interventions?

3.2. Information-based conservation experiments

In water conservation experiments, households are usually grouped into different "treatments" which receive different types of information. By comparing treatment groups to a "control" group where no intervention is applied, studies can assess whether the information types used reduce water consumption. Table 1 lists the types of information considered in the existing literature.

Table 1. Information types

Information type	**Example**
Technical advice	Information leaflets containing water-saving tips
Norm-based information	Letters emphasising social identity and prosocial preferences, such as the importance of water conservation and how individual households' effort matters for a community's water conservation.
Monitoring device tailored to specific appliances	Devices or labels with technical and conservation information made for refrigerators, showers, washing machines, etc., enabling households to monitor usage at the actual point of consumption

[40] There is mixed evidence on these campaigns' effectiveness. For example, Renwick and Green (2000) and Syme *et al*. (2000) find they worked, Nieswiadomy (1992) finds they worked only in a region where awareness of water scarcity was high, and Howarth and Bulter (2004) find they did not work.

General feedback	Feedback on total household water use, sometimes including a break-down by activity
Socially comparative feedback	Feedback comparing water use to the average usage of (similar) neighbours
Emoticon feedback	Happy faces indicating social approval for households whose water consumption is below a community average, and sad faces indicating social disapproval for those whose consumption is above average

There is a surprising paucity of experimental research on water conservation, given the increasing number of pro-environmental behaviour experiments in general and the importance of water conservation (Osbaldiston and Schott, 2012). Only a handful of experiments assess the relative effectiveness of different information types on household water consumption. The most comprehensive experimental evidence comes from Atlanta, Georgia in 2007 and we describe this research in some detail in subsection 3.2.1, followed by a more general overview of existing evidence in subsection 3.2.2. While these studies offer some initial learning, caution is needed when generalising from the evidence currently available.

3.2.1. Conservation experiment in Atlanta, 2007

Probably the best experimental evidence comes from the work of Ferraro and co-authors. Their research involves more than 100,000 households in Atlanta, Georgia in 2007 and overcomes issues of sample selection[41] by randomly assigning households into three treatment groups and one control group. Compared to the control group, group 1 received technical advice, group 2 received norm-based information and technical advice, while group 3 received usage feedback and social comparison, technical advice and norm-based information.

Three studies utilise this data, each with a different focus. Ferraro and Price (2013) primarily compare the effects of different information types, i.e. variation in the treatment effects; Ferraro and Miranda (2013) examine 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, while average water consumption in summer 2007 fell relative to summer 2006 for all groups, the reduction across treatment groups compared to the control group varied considerably, from an additional 7.4% to 53.4%.[42] The differences between treatment groups indicate the relative effectiveness of different information types. However, the absolute changes in consumption resulted from the combination of an IBT and information intervention, and it is impossible to separate the two effects. Indeed, one cannot rule out the possibility that an IBT is a necessary pre-condition for the effectiveness of the interventions.

Receiving norm-based information was more effective than solely receiving technical advice and additionally receiving social comparison reduced consumption still further. The authors suggest the effect of social comparison could be equivalent to a 12%-15% increase in average price. Furthermore, social comparison is found to have changed consumption in high and low water user

[41] If the households in a water conservation trial have actively chosen to be part of the trial, it may mean that they have a pro-conservation preference and so evidence from the trial will over-estimate the effectiveness of interventions in the general population.

[42] The reduction in the control group's consumption between 2006 and 2007 may have resulted from the introduction of an IBT in early 2006.

groups[43] in a "fundamentally" different way, with a 94.1% difference in the relative treatment effect. This finding is reinforced by Ferraro and Miranda (2013)'s finding of greater responsiveness to social comparison in households that are wealthier, living in their own properties and who have higher water consumption. On the other hand, no heterogeneity in response was found when only technical advice or technical advice with norm-based information were used.

While Ferraro and Price (2013) identify short-run treatment effects, Ferraro *et al*. (2011) suggest that only social comparison has a strong long-run effect, as the treatment effects of the two treatment groups without social comparison disappeared within a year, but the effect of social comparison persisted for more than two years. Although the size of the effect fell over time, the result is striking as letters containing social comparison were sent to households only once. That social comparison had a stronger impact on wealthier households, might suggest the long-run effect of social comparison is partly due to it triggering investment in water saving devices by those who could afford them.[44]

3.2.2. Other studies

The remaining studies are all characterised by relatively small samples. They vary in the type of intervention they consider and in the results they obtain. We describe each one in turn before summarising the effects in Table 2.

Kurz *et al*. (2005) conduct an experiment with 166 households from 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 over a period of 6 months. While information leaflets had no significant effects, monitoring labels (with identical information) at the physical location of water consumption reduced household consumption by 23%. Socially comparative feedback did not have a statistically significant effect.

Fielding *et al*. (2013) compare the effects of technical advice, norm-based information and feedback on water consumption in 221 households in South East Queensland, Australia, over the long-run. All three treatment groups received technical advice, while two treatment groups additionally received norm-based information and feedback respectively. Relative to the control group, all treatment groups consumed significantly less water during the intervention period (September 2010 – January 2011). Fielding *et al*. found no significant differences among treatment groups, suggesting norm-based information or feedback offers no additional benefit over technical advice. The consumption of treatment groups remained low for some months after the end of the intervention, but returned to the pre-experiment level after a year.

[43] In Ferraro and Price (2013), low water users were those who consumed below the county median in summer 2006 and high water users were those who consumed above median. Median consumption in summer 2006 is not clearly specified, although using figures from Table 1 of the paper suggest average water consumption was around 39,000 gallons.

[44] Another randomised controlled behavioural intervention to household water consumption took place in Burbank, California is documented by Jessoe *et al*. (2017). The intervening period of May 2015-May 2016 coincided the worst drought in California to date. Unlike the other studies reviewed in this section, this study focuses on the spillover effects of the intervention to electricity consumption and seeks to explain the spillovers. While they find the combined use of multiple types of information leads to a 4.4% reduction in water consumption over the year and 2.9% in the summer, they do not compare the effectiveness of alternative information types. Benefitting from real-time data, they in addition find that the reduction was achieved significantly more between 5-7am and at 7pm.

In a one-week field experiment in San Diego involving 301 households, Schultz *et al*. (2016) compare the effects of technical advice, social comparative feedback, and the visual cue of a happy or a sad face. Emoticons are argued to convey social approval or disapproval. The treatment receiving emoticons also received the first two types of information. Schultz *et al*. find that technical advice had no significant effect on water consumption. The treatment group receiving social comparative feedback in addition to technical advice consumed 26% less water than the control group of no information. The treatment groups receiving all three types of information consumed 16% less water than the control group suggesting emoticons *reduced* 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. This finding suggests that households potentially consider having 'average' consumption as desirable/most acceptable. Further it suggests a utility might want to offer social comparison in a non-uniform way, i.e. only give the comparison to high usage households. The ethics of such interventions clearly need careful consideration. The study also found information distributed online was less effective than that sent by post.

With a sample of 374 households 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. the use of "I" and "you" instead of "we"). Unlike Ferraro and Price (2013) and Schultz *et al*. (2016), households assigned to a treatment group received only one information type. Seyranian *et al*. find that technical advice did not affect consumption of high water users. Social comparative feedback with social (dis)approval and norm-based information using inclusive language were found to have similar significant effects in inducing high water users to reduce consumption. Seyranian *et al*. further suggest that providing norm-based information emphasizing personal rather than social identity does not alter effectiveness.

Unlike earlier studies comparing alternative information types, Otaki *et al*. (2017) seek to identify which element of feedback information is most effective. Otaki *et al*. randomly sampled 246 Tokyo residents 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 participants received consumption feedback after each self-report, i.e. they received feedback 12 times. The treatment groups varied according to the feedback they received: feedback with social comparison; feedback with ranking among a group of 100 households, e.g. 57th out of 100 households; and feedback with emoticons (four emoticons ranging from "crying face" to "perfect smiley face"). There was also a control group that received no feedback. Feedback effects were compared by consumption level (high vs. low water users) and by duration of intervention (3 vs. 6 months).

Otaki *et al.* find that feedback with emoticons was effective at reducing water consumption for high water users, whereas feedback with ranking was effective for low water users. However, the rankings provided were not real. The real rankings did not exhibit noticeable fluctuations, hence, it was felt they might not reveal a treatment effect. In real policy settings such a lack of variation might block the use of social comparison since it is not clear that 'fake' rankings, i.e. lying to consumers, would be acceptable. Also, over time, consumers may learn that the rankings are false and then choose to disregard them.

Table 2. Evidence on demand reduction from experiments

Information type	**Studies**	**Locations**
Technical advice	Kurz *et al*. (2005): No effect.	Western Australia
	Ferraro and Price (2013): Significant demand reduction.	Atlanta, Georgia
	Fielding *et al*. (2013): Significant demand reduction.	Queensland, Australia
	Seyranian *et al*. (2015): No effect.	Los Angeles
	Schultz *et al*. (2016): No effect.	San Diego
Norm-based information	Kurz *et al*. (2005): No effect.	Western Australia
	Ferraro and Price (2013): Significant demand reduction.	Atlanta, Georgia
	Fielding *et al*. (2013): No effect.	Queensland, Australia
	Seyranian *et al*. (2015): Significant demand reduction.	Los Angeles
Monitoring device tailored to specific appliances	Kurz *et al*. (2005): Significant demand reduction.	Western Australia
General feedback	Fielding *et al*. (2013): No effect.	Queensland, Australia
Socially comparative feedback	Kurz *et al*. (2005): No effect.	Western Australia
	Ferraro and Price (2013): Significant demand reduction.	Atlanta, Georgia
	Ferraro and Miranda (2013): Significant demand reduction; higher for high water uses.	Atlanta, Georgia
	Seyranian *et al*. (2015): Significant demand reduction.	Los Angeles
	Schultz *et al*. (2016): Significant demand reduction; low water users increase consumption.	San Diego
	Otaki *et al*. (2017): Significant demand reduction for low water users.	Tokyo
Emoticon feedback	Schultz *et al*. (2016): Reduced the effectiveness of other intervention.	San Diego
	Otaki *et al*. (2017): Significant demand reduction for high water users.	Tokyo

One study did not enable a clear classification of the source of the effects. Erickson *et al*. (2012) evaluate a 15-week pilot with 303 households in Iowa, using a web portal designed for water conservation. The portal offered 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 based on water conservation. Compared to households who did not engage with the portal, the pilot participants reduced consumption by 6.6% during the first 9 weeks. However, this study cannot identify the particular piece of information leading to the reduction. Also, it is impossible to determine how much of the consumption reduction is related to self-selection, as those engaging with the portal thereby demonstrated a pre-existing higher awareness of water use and conservation, compared to those who did not engage.

The existing studies suggest the following initial conclusions. Technical advice on its own and without a good motivation for consumption reduction rarely generates significant reduction of household water use. Among the tools tested, social comparative feedback appears to be the most likely intervention to generate significant effects. It is also apparent that one-size-fits-all approach may not be effective and varying information types by consumption level may be sensible. Social comparative feedback is most promising for high water users, but appears less effective or even counterproductive for low water users. Interestingly when comparing short-run against long-run effects of interventions, there appears to be a subtle complementarity between price and non-price interventions. First, high water users are less price-sensitive but more responsive to social comparisons. Second, the effect of information-based interventions diminishes over time whereas IBTs can become more effective over time, so that combining the two may lead to both an immediate effect and a sustained effect.

3.3. Insights from the implementation of non-price interventions

There are only a limited number of information-based water conservation experiments involving truly Randomized Control Trials (RCTs); those with household self-selection potentially have upwardly biased treatment effects. Even fewer experimental studies examine beyond average treatment effects to look at the heterogeneity of responses across household groups.

The studies discussed above differ in terms of intervention length, climatic context, and the framing of particular information types[45] etc., so the results may not be directly comparable. Similar to the effects of IBTs, the effects of information interventions may depend on local water scarcity and household profiles. Experiments conducted in arid conditions may provide insights on methodology, but provide less guidance on the magnitude and significance of effects in other contexts.

The main insight from current research, as illustrated by Table 2, is that no robust general conclusions emerge and that more experimental studies are needed to form comprehensive and robust conclusions on the effectiveness of information interventions. Some of the interventions work some of the time, but none all of the time. There is no clear evidence on how different price incentives, such as IBTs, influence information-based measures' effectiveness.

The persistence of the effects are either weak, unclear or not explored. Additionally, some of the studies have a clear limitation regarding sample selection. Kurz *et al*. (2005) and Erickson *et al*. (2012) involve voluntary participation, while in Fielding *et al*. (2013) participating households were from a region where water scarcity had previously been an issue and the households had participated in an earlier 2009 study. As a result, in these three experiments, the samples are likely to consist of households with pre-existing conservation-minded attitudes compared to the general population. Also the participants are likely to be aware that an experiment is being conducted. This implies the treatment effects of the interventions when applied to the general population are likely to be smaller and possibly statistically insignificant. It is for this reason that the evidence of Ferrero and co-authors stands out.

[45] For example, even when two studies examine the effects of norm-based information, one study may frame the social norm more strongly than the other.

4. The applicability of IBTs to the UK

The UK is a temperate "marine west coast" climate, which implies a relatively steady temperature range throughout the year and typically the absence of a dry season (Peel *et al.*, 2007).[46] However, changing weather patterns and a growing population suggests UK water constraints will tighten in the future (Defra, 2009; Ofwat, 2010a).

The residential water supply sector in England consists of privately-owned, regulated utilities, which are licensed monopolies in their areas. Most utilities offer optional metering to households, and meter penetration shows substantial geographic variation. As of 2014-15, meter penetration ranged from 25.3% to 82.5% across utilities, with the average being 51.4% (Consumer Council for Water, 2015). [47] By definition, the absence of water meters precludes the unit pricing of water and the conservation effects unit pricing can create. Although metered charges, usually involving a standing charge and a unit price, are based on water usage, whether households receive bills based on actual or estimated meter readings depends largely on whether households voluntarily submit meter readings to their water utility sufficiently frequently.[48] While infrequent meter reading might not impact significantly on households' budgets currently – water bills typically account for a small share of household income in the UK[49] – it indicates an additional challenge to overcome before price signals can be effective.

Regarding average consumption, in 2006 it was estimated that daily water consumption *per capita* in the UK was 150 litres, a level identical to that of France. As comparisons, the figure for Germany was 127 litres, for Italy was 190 litres and for Belgium was 108 litres. Estimated average consumption in Spain was a notable outlier at 265 litres.[50] In 2008 the UK government's future water strategy hoped that with current levels of technology water consumption could be reduced to 130 litres *per capita* per day by 2030.[51] Advancing technology was thought to enable an additional 10 litre consumption reduction over the same time frame. In 2017 the Anglian Water website reports that, within its region (Eastern England) where 80% of consumers have a metered water supply, average daily *per capita* water consumption is 133 litres.[52]

The studies reviewed in this paper typically involve IBTs (and changes to IBTs) implemented in response to water stress, such as severe droughts. This creates a problem when using existing evidence to draw lessons on the impacts of IBTs in currently temperate areas such as the UK. Moreover, IBTs are usually used in conjunction with non-price tools (e.g. Renwick and Archibald, 1998; Kenney *et al.*, 2008; Nataraj and Hanemann, 2011), making it difficult to isolate the main source of demand reductions.

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[46] This is in contrast to the geographical areas of the IBT studies. For example, Santa Barbara, California, has a warm-summer Mediterranean climate; Los Angeles has a hot-summer Mediterranean climate; and Zaragoza, Spain, has a semi-arid climate. These areas usually feature hot and dry summers.

[47] The relative lack of metering may explain the lack of data and study of water demand, as highlighted by Reynaud (2015).

[48] Some UK water utilities guarantee their customers one bill per year based on an actual reading.

[49] See section 4.1.

[50] Figure 3, page 21, "Future Water: The Government's water strategy for England", HM Government / Defra, February 2008.

[51] Paragraph 15, page 21, "Future Water: The Government's water strategy for England", HM Government / Defra, February 2008.

[52] See, http://www.anglianwater.co.uk/environment/how-you-can-help/calculate-usage.aspx.

Considering the environmental, political and regulatory context explained above, we now discuss the extent to which existing IBT evidence is transferable to the UK. Relevant questions include:

(i) Do the complexities and uncertainties associated with IBTs apply to the UK?
(ii) Are factors contributing to IBT effectiveness present in the UK?
(iii) To what extent are drought conditions a pre-requisite for effective conservation programmes?

4.1. Challenges from introducing an IBT in the UK water industry

A key determinant of success for price based water conservation mechanism is that consumers respond sufficiently to price signals. There is very little evidence on the price responsiveness of water demand in the UK, and how responsiveness varies across income groups and/or consumption. The only available PED estimates range from -.177 to -.286 in Gardner (2010) and -.181 to -.276 in Reynaud (2015), both of which are below the international mean of -.379 (Gardner, 2010).[53] This suggests the scope for water tariffs to reduce demand in the UK is less than in some other areas of the world.

Existing research highlights the importance of having a sufficiently large group of high income/high usage consumers who are sufficiently price sensitive. Levell and Oldfield (2011) report household spending on water across income groups in the UK. While water bills account for a small share of household expenditure for all income groups, they account for a higher share among lower income groups. The richest 20% of households typically spend less than 1% of total expenditure on water while the figure is 2.5-3% for the poorest 20% of households. However, when water expenditure in absolute terms is considered, the richest households spend slightly more on water than other households. This low variation in water expenditure may indicate that in UK households' water demand there is generally a low level of discretionary use. However, the result could also reflect a low unit price for water in the UK and/or the comparatively low proportion of metered households.[54] International experience suggests having a large number of high water users usually creates the opportunity for effective IBTs and sufficiently high unit prices for high blocks contribute to IBTs' success. High quality UK data at the regional level on water consumption by income group, the relationship between household size and consumption and the proportion of high water users are required before IBTs can be introduced without significant downside risks.

The ability of firms to experiment with new pricing structures depends on the regulatory regime. Price limits are reviewed every five years by Ofwat using an *ex ante* approach, which effectively limits the revenue a water utility can raise in the following five years (Ofwat, 2010b; Ofwat, 2014). IBTs require experimentation to develop an effective block pricing schedule, however, the feasibility of experimentation within the political and regulatory setting of the UK water sector remains an open question. Despite greater emphasis on sustainable water use in recent years (e.g. Ofwat, 2010a), development of conservation-oriented tariffs in the UK has been slow. Central to this is a concern about whether water is affordable for all under IBTs. Both Ofwat (2005) and Defra (2009) have expressed clear views that IBTs must accommodate the affordability/equity issue regarding large households. Similarly, Herrington (2007) argues that affordability for larger low income households appears to be a "barrier" to metered water charges.

[53] Gardner (2010) provides "the first UK elasticity estimates" using quarterly data over the period 2007 to 2010 for 622 metered households. Reynaud (2015) obtains the estimates using panel data from 16 water utilities in the UK over the years 2002 to 2009.
[54] The water charges of unmetered households are fixed amounts linked to the value of a household's dwelling.

The current lack of regularly updated data on household size in England and Wales is a clear practical obstacle to adopting IBTs of an acceptable form, i.e. water budgets. Obtaining this data may be very costly and present legal/public relations issues. Defra (2009)'s conclusion was that IBTs "may merit trial and development in specific water company areas" instead of being a "national system of charging". Possibly linked to this conclusion only utilities granted "water scarcity status" by Defra – Veolia Water South East and Wessex Water – have trialled IBTs (and seasonal tariffs).[55]

4.2. Further challenges: Consumers' lack of engagement

As discussed above, consumers' engagement with price signals is central to IBTs' effectiveness and also supports the effectiveness of information interventions. However, consumer engagement in the UK appears low. Studies find UK households lack awareness of utility prices and/or consumption. Survey data suggests a low level of awareness of (social) tariffs among British water consumers (Consumer Council for Water, 2017). Further, Waddams and Clayton (2010) argue that UK households have a low understanding of water price, consumption and bills, while they have limited ability to rank household activities by water use.

Gardner (2010) investigates UK households' knowledge of water prices and consumption using survey data from Veolia Water South East. 200 respondents completed questionnaires, 60% of whom were part of an IBT trial. The majority of respondents (112 out of 200) chose not to answer questions asking for estimates of prices[56] and those who answered generally gave very inaccurate answers. In particular, water prices were systematically overestimated. Households were asked to 'guess' the price of a cubic metre of water without referring to their water bill. While the average of the two block prices in the IBT was £1.59, the mean "best guess" was £8.57. Since the second block price was £2.51 and the mean guess of households with a uniform price tariff was £8.13, it is clear that a generally poor understanding of water pricing dominated any additional confusion created by the IBT structure. Furthermore, 74% of respondents failed to correctly identify which tariff (uniform pricing or IBT) they were on. However, respondents had a significantly more accurate (though still inaccurate) perception of their water *bills*: the mean perceived quarterly bill was £43.47 compared to an actual mean quarterly bill of £35.96. The greater accuracy of bill perceptions probably reflects most respondents (77%) stating they looked at bill totals, while only 15% stated they looked at water prices.

Since the respondents self-selected to complete questionnaires, the survey sample may be biased towards households with a relatively better understanding of tariffs and water consumption; Gardner suggests the general UK population may have an even worse understanding of water prices. However, the small value of water bills relative to households' expenditure may not justify the effort required to acquire and understand the relevant information. In other words, householders' ignorance may be entirely rational. If householders only focus on their total bill, rather than the unit price, their demand response will, most likely, be related to the average price of water.

Households' better understanding of bill totals implies that any price signal is likely to reach households indirectly, which suggests IBTs where the marginal price changes with consumption are less likely to be effective in the UK. It also suggests that obtaining a larger sample of data on UK households' understanding of water prices and consumption is a priority. As a condition for the

[55] Page 154-159 of Gardner (2010) suggests the IBT trialled was not successful.

[56] Households were asked to state the total cost of their water bill in the last quarter, the price of water per cubic meter, and the price of petrol per litre. Unlike the inaccurate knowledge on water prices, the average of respondents' petrol price estimate (£1.41) was closely related to the actual average (£1.05). The relative accuracy of petrol price knowledge is unsurprising given that most petrol stations clearly state the unit price.

introduction of IBTs in the UK, a communications effort would be needed to educate households about tariff structures and the need to understand their own consumption directly, rather than indirectly through bill totals.

The relative awareness of water bill totals, and therefore average prices, might enable an alternative tariff structure in the UK to balance the needs of water conservation and affordability. Each household would face a single unit price for water, but this unit price could vary across households according to either: (i) property value or (ii) income. Both (i) and (ii) would require a utility to have access to government data, but this is unlikely to insurmountable, at least in the case of (i), as water charges for unmetered properties are already set according to property values (rateable values). Within individual water regions there should be a reasonable correlation between property value, property size and therefore water use. If there is a greater emphasis on ensuring households' ability to pay, especially avoiding excessive charges for elderly individuals living in under-occupied large houses, the unit price could be linked to income with higher income households paying a higher price.

4.3. Will attitudes to water conservation depend on weather experiences?

Many of the empirical or experimental papers reviewed above use or generate data from a drought situation. Besides the natural conditions that define a drought, e.g. measures of rainfall, a more precautionary dimension relates such conditions to supply and demand, e.g. a risk of water shortage, thus bringing in different disciplines in drought and water management (Medd and Chappells, 2007). It follows that the strategies adopted when facing a drought may reveal how resilience is understood given a particular institutional context of water management (Taylor *et al*., 2009).

Drought experiences matter for conservation as they help to shape households' beliefs about water, water consumption, and the burden of responsibility in conserving water. In turn, households' specific beliefs about water can affect their attitudes and decision-making regarding consumption.[57] While "there is no history of water conservation in the UK" (Howarth, 1999), there have been a number of droughts as recorded in Marsh *et al*. (2007) and Taylor *et al*. (2009). It seems plausible that the perceived importance of water conservation will differ substantially between households who have experienced droughts and those who have not. Gilg and Bar (2006) study how water-related attitudes are formed in light of social, psychological and environmental factors utilising a survey of 1200 UK households. They find that individuals who perceive environmental issues as a genuine threat to their own welfare are likely to conserve resources.

Several southern areas of the UK were affected by drought from 2004 to 2006. In Dessai and Sims (2010)'s study on drought perception in southeast England, comparison was made between St Edmundsbury and the Sevenoaks District regarding residents' opinions of "the seriousness of the water situation in their locality in 2006". Survey responses suggest the seriousness of the local water situation was perceived to be significantly higher in the Sevenoaks District. This is consistent with a UK Environment Agency finding that Sevenoaks was more negatively affected by drought.[58] However, while significantly more respondents in the Sevenoaks District stated they had changed their

[57] For example, the requests by Yorkshire Water to conserve water in the drought of 1995 "were ignored by an angry public who believed the situation was caused not by the weather but by management ineptitude" (Howarth, 1999).

[58] The UK Environment Agency classified St Edmundsbury in the Anglian Water region as under "moderate" water stress and the Sevenoaks District in the Southern Water region as under "serious" water stress. However, the difference in awareness between the two areas may result from different actions by the two water utilities as much as the public's independent perception of water stress.

consumption due to the drought, there is little evidence suggesting their willingness to accept price increases or water use restrictions had changed.

The extent of water stress also affects water utilities' promotion of water conservation. While there is a general move by water companies to adopt a charging policy based on metering, which was a notable political debate following the 2006 drought, the Water Industry Act 1991 (Section 144B) only allows water companies granted "water scarcity status" by Defra to install meters on a compulsory basis. Unsurprisingly, companies supplying areas under water stress have been more proactive in increasing meter penetration. For example, 75.2% of Southern Water households had a meter in 2013-14 (an area with "water scarcity status"), whereas only 29.7% of Northumbrian Water households had a meter. This low meter penetration probably reflects Northumbrian Water having "few water resource issues" (Consumer Council for Water, 2015). With growing recognition of the importance of sustainable water use, there has been an increasing emphasis on "co-management" of water resources between companies, regulators and consumers (Medd and Chappells, 2007; Taylor *et al*., 2009). While the currently low level of consumer understanding of water prices and consumption in the UK may be influenced by limited experience of extreme weather conditions, "co-management" requires the involvement of consumers, who not only face interventions but also play a part in defining possible interventions.

In the UK there are debates over the appropriate degree of institutional coordination of water management between different levels of organisation (Medd and Chappells, 2007; Taylor *et al*., 2009). That is, the appropriate interplay between highlighting areas of national significance and using local relevance and sensitivities to engage consumers with social norms and everyday water conservation practices. Howarth (1999) suggests that households show willingness to participate in water conservation trials if given the correct incentives and that through water conservation programmes UK water companies may also build better relations with their customers.

Overall, since it appears households' attitudes to water conservation are affected by experience of droughts, caution is needed when drawing inferences from interventions performed in other countries, especially when undertaken in different weather conditions. Weather conditions are likely to affect both how consumers respond to interventions and the ability of firms to plan their demand management strategies.

5. Conclusion

This paper has reviewed the international evidence on price and non-price approaches to manage residential water demand, with a focus on IBTs and information-based behavioural interventions. Compared to some jurisdictions already experiencing regular drought conditions, the use of these tools in the UK has been modest and there is a general lack of evidence on how tariffs and behavioural signals interact in temperate locations.

While IBTs are common in the US, Spain, Portugal and Australia, there is mixed evidence regarding their effectiveness. Applying the lessons of the existing evidence to the UK, several issues become apparent. First, compared to the drier locations, water stress in the UK is not an immediate threat to households' living standards, hence, households, quite reasonably, have less awareness of any need for water conservation and are less willing to change water use habits.

Second, water bills are typically small relative to household income. The limited evidence on the price sensitivity of UK water demand suggests the magnitude of price increases required to reduce water use significantly may be politically challenging. This links to the third issue that the design and implementation of IBTs in the UK would need to fit within the existing regulatory, legislative and political context.[59] Fourth, the stylized facts suggest that there may be insufficient variation in water use across households to create the scope for IBTs to be effective. Fifth, UK policymakers have expressed concern about how to ensure affordability and equity for high-occupancy, low-income households facing IBTs. Only with accurate data on household size could a water budgeting approach be followed.

Last, and most fundamentally, limited water metering is a primary obstacle for nationwide IBT trials, as well as some non-price alternatives. While IBTs could be trialled in particular regions there must be some doubt about the political viability of substantially raising water prices in only some parts of the country. In contrast to the US, Spain and Australia, regional government is limited in the UK and historically there has been significant aversion to 'postcode lotteries', i.e. geographic variation in service provision. Even where households possess meters, the limited evidence suggests households have very inaccurate perceptions of water prices and consumption, with any knowledge reflecting bill totals (average prices) rather than marginal prices.

For IBTs to be possible in the UK, first, penetration of sufficiently smart meters[60] would need to be maximised. After the introduction of an IBT, regular and clear information on block prices, the size of blocks and consumption would be crucial. The relative difficulty of introducing IBTs in the UK increases the attractiveness of non-price interventions to constrain water use, although, even for these high meter penetration can be an important pre-condition. Also, attitude-led behavioural interventions that highlight the importance of water conservation to households may help to 'set the scene', prior to the introduction of IBTs, especially in the absence of drought conditions, and enable UK utilities to learn how to maximise the effectiveness of delivering water conservation messages to households.

More fundamentally, experimentation with behavioural interventions should improve the evidence base available to select the interventions to deploy when significant water stress actually occurs. When selecting interventions to pursue it is critical the costs of alternative interventions are assessed. Frequently, behavioural interventions are assessed in small experimental studies assessing the quantity of water saved, but for policymaking the critical knowledge relates to any challenges to large scale deployment and whether the water saving is achieved at a lower cost than through alternative non-price interventions. Indeed, since in the UK costs are recovered through bills, costly non-price interventions will have an upward impact on prices and it is essential these cost driven prices are small/minimised if the political and distributional challenges of increased uniform water pricing are to be avoided.

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[59] In the absence of political and policy actors who view water stress as a key issue a supportive policy landscape to enable IBTs may be in doubt.

[60] Energy smart meters in the UK are designed to record and send consumption data every 30 minutes due to variations in the cost of supply throughout the day, in water less frequent near-time, rather than real-time, data transmission is probably sufficient, if manual reading of meters is prohibitively expensive.

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