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Price and Behavioural Signals to Encourage Household Water Conservation: Implications for the UK

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Abstract
Water scarcity is a global concern. Even in non-drought situations the political and economic costs of developing water resources may favour conservation. Using a single high price to constrain demand raises distributional and political challenges. Increasing block tariffs (IBTs) have been proposed as a solution, balancing incentives for conservation with an equitable distribution of costs across households. Our survey indicates the international evidence on using IBTs to conserve water is mixed, highlighting the operational challenges of implementing effective IBTs. An alternative approach that may side-step affordability concerns are non-price conservation interventions. Robust evidence on behavioural interventions to conserve water is limited, although social comparisons appear effective. Nevertheless, existing price and behavioural interventions have typically been implemented in response to droughts, thus caution is needed when generalising this evidence to non-drought situations. We discuss the applicability of IBTs to the UK, highlighting an essential pre-condition is detailed research to understand a locality's water consumers and their water demand.

Keywords Increasing block tariffs · Behavioural interventions · Water conservation

JEL Classification D10 · L95 · Q21 · Q25 · Q28

1 Introduction

"There are growing pressures on our water resources…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] This quote highlights that

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

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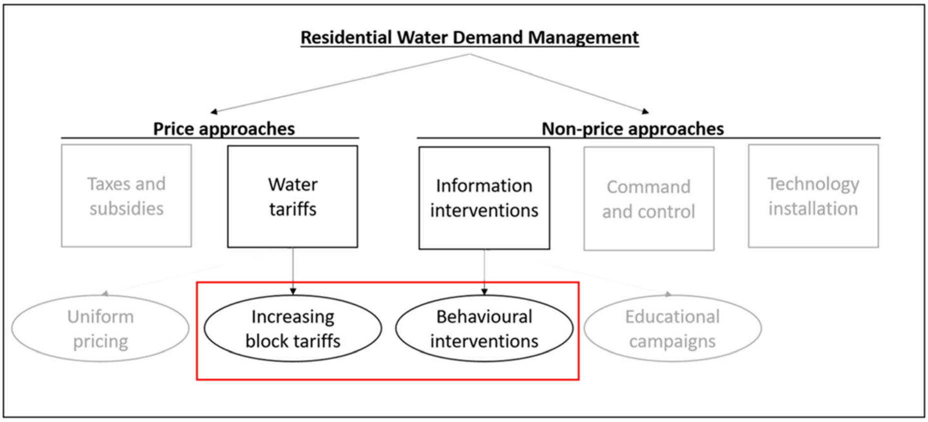

Fig. 1 Price and non-price approaches to residential water demand management

the UK in general, and the south-east/east of England in particular, face an increasing drought risk. 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] One policy response is to use demand-side measures, as presented in Fig. 1, to reduce household water use.

High water tariffs to reduce demand directly are the most common price intervention in the EU (EEA 2017). Future use of a high uniform price to constrain demand may be problematic as a minimum level of water consumption is essential for life and, hence, viewed as a necessity by the public. Water's necessity leads to two related points: (i) demand is fairly price inelastic[3] and (ii) equitable access to water is politically salient. To achieve a significant reduction in demand the water price would have to increase substantially, with potentially regressive distributional implications. Price increases may also raise company revenues, something which is likely to face significant public opposition.[4] While the probability of a drought in any given summer may be increasing over time, the realised incidence and severity of droughts will fluctuate over the decades. Charging high prices in non-stressed periods might be viewed as water companies abusing their monopoly position, while varying prices to deal with short-run shortages may also be viewed as exploitative.[5,6]

[2] For example, opposition to Thames Water' proposals for a reservoir near Abingdon, Oxfordshire, see: http://www.abingdonreservoir.org.uk/.

[3] Meta-studies report a wide range of price elasticity estimates for household water demand: −3.33 to −.02 (Espey et al. 1997), −7.47 to 7.90 (Dalhuisen et al. 2003), and − 3.054 to −.002 (Sebri 2014).

[4] For example, Utility Week notes: "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 http://utilityweek.co.uk/news/the-challenge-of-trust-in-utilities/1308792#.WeDYbmhSyUk.

[5] Hurricane Harvey provides examples, such as "Price gouging during Hurricane Harvey: Up to $99 for a case of water" (CNBC 28/8/17). Price gouging (the raising of prices in a crisis) is illegal in some US states, including Texas. These pricing practices raise strong emotions as indicated by the following two headlines: "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).

[6] Using taxation to raise prices or to extract profits may be politically problematic and is likely to lead to conflicts between using the taxation to curb consumption and raise revenue. Grossman et al. (1993) discuss this conflict in relation to alcohol and cigarette taxes.

Areas experiencing severe droughts have implemented more sophisticated pricing structures: IBTs.[7] In an IBT initial consumption is priced low to ensure essential demand is not constrained, while subsequent consumption is priced high to discourage discretionary use. In theory, IBTs appear to provide a price intervention with a social conscience. Various non-price tools have also been widely adopted (see Fig. 1), among which a set of information-based tools – often referred to as behavioural interventions[8] – aim to convey signals to encourage water conservation by focusing on smaller communities and varying the type of information provided.[9]

This paper reviews the international evidence on IBTs and behavioural interventions to manage residential water demand. While the literature on water demand estimation has been surveyed extensively,[10] we are the first to bring together the analysis on IBT performance. We highlight the challenges of implementing effective IBTs, linking issues around design and consumer response. We discuss how behavioural interventions may have value either as a substitute or complement to price interventions. Furthermore, we assess whether the evidence is generalisable to settings beyond drought-prone areas. In particular, we are the first to discuss the challenges of implementing IBTs in the UK. These challenges likely result from the currently low value of water in the UK leading to water metering being partial, public awareness being low and limited research regarding residential water demand.

2 IBTs to Conserve Water

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.[11] 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 water conservation[12]; a high price should conserve water but may lead to poor households consuming below an advisable level and/or facing financial hardship.

A price mechanism where the per-unit price varies with consumption, such as an IBT, attempts to find a balance between affordability and conservation. An IBT is defined by a set of k ($\geq$2) consumption levels (or blocks), $w_1 \ldots w_k$, where $w_1 < w_2 < \ldots < w_k$, a set of k associated prices $P_1 < P_2 < \ldots < P_k$ and a billing period, t, after which the consumption level is returned to zero (Boland and Whittington 1998).

Figure 2 illustrates a three-block IBT. Compared to a uniform price, P^u, the IBT involves a lower price for consumption up to w_1, a higher price for additional

[7] These have also been used extensively, for similar reasons and with mixed effects, in energy markets, for example, see Borenstein (2012, 2016).
[8] Behavioural interventions also have been used in the energy sector, for example, see Allcott and Rogers (2014).
[9] This differs from large-scale educational campaigns, which usually promote a core slogan and/or a target consumption reduction at a national level (EEA 2017).
[10] See Arbués et al. (2003), Worthington and Hoffman (2008) and the papers in footnote 3.
[11] For simplicity, our discussion does not refer to the fixed element.
[12] Cost recovery can be a political issue. For example, Arbués and Barberán (2012) argue that since water is managed by local 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".

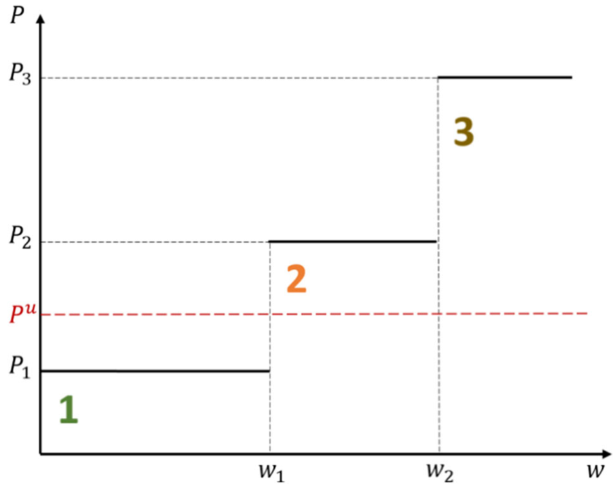

Fig. 2 A three-block IBT

consumption up to w_2, and a much higher price for consumption above w_2. Intuitively the aim is to construct a first block corresponding to the essential consumption during a billing period and then price subsequent blocks of consumption increasingly as a luxury.[13]

2.1 IBT Design Issues

The success of an IBT in meeting both distributional and conservation objectives depends on its design and consumer response.

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 the price required to choke off demand may have to be very high.

Renwick and Archibald (1998) find low-income households to be five times more responsive to water price changes than high-income households. If under the uniform price, p^u, there are consumers who consume less than w_1, an IBT which lowers the price for the first block is likely to increase these consumers' consumption (Wichman 2014; Asci et al. 2017). Consequently, prices for subsequent blocks, where households are relatively less price sensitive, may have to exceed p^u very significantly, otherwise total demand would increase.[14] Wichman (2014) found the introduction of an IBT in North Carolina in 2007 led to an increase in water consumption overall.

[13] The literature, e.g. Hall (2009), Wichman (2014) and Asci et al. (2017), shows 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.

[14] Furthermore, Asci et al. (2017) note a significant price increase for high blocks only reduces total water demand if sufficient households consumed within the high blocks prior to the IBT.

To avoid an unplanned expansion in demand, the initial block size has to closely match the 'recommended' consumption for a specific household. A one-size-fits-all IBT with the same block size (w_1) for all households is unlikely to deliver this, as essential water consumption increases with the number of household occupants. In some areas 'water budgets' have been used where the consumption allowed at each block price is individualised using household-specific characteristics and environmental conditions (Baerenklau et al. 2014). The main challenge is the availability of comprehensive and current data on household characteristics to set water budgets. Where consent is required to collect personal data, households may choose not to provide this. Also, if households understand that the information they provide will determine their water price, there is an incentive not to report their characteristics truthfully. One could set water budgets using less finely granulated government data, although at the cost of a less precise IBT design. Another approach for ensuring equity across households of varying sizes when using IBTs is to offer special rebates for large households (Kayaga and Smout 2014).

The need for a tightly designed initial block, combined with a high price for the final block, raises questions regarding the optimal number of blocks. First, consider where there are either errors in estimating the initial block size or 'errors' in consumption (see section 2.2). Given the large financial penalty for those 'unintentionally' consuming more water than assigned in the initial block, it may be sensible to introduce intermediate blocks with smaller price increases. This may explain why most observed IBTs have more than two blocks.

Second, 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.[15] At any point in time within a billing period, a consumer will rationally constrain consumption to guard against hitting the next consumption block and its higher price. For low-income consumers who are more likely to consume within the initial block and who tend to be price sensitive, the consequences of the option value are particularly problematic since it implies they will consume below the minimum recommended level of water. This uncertainty 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, and/or the impact of a higher bill on a household is significant.

Third, it takes time, even for rational consumers, to learn about their demand and how an IBT functions. The larger the price increase between blocks, the more costly are mistakes during any learning phase. While painful mistakes may offer incentives to learn quickly, households differ in their ability to cope with cost shocks.

If we think the high price of subsequent blocks is a 'punishment' for over-consumption, there is the issue that the water company will benefit from higher revenue when meting out a harsher punishment.[16] The politics of this issue for privately owned firms (as in England and Wales) are probably challenging, as how can a consumer be sure the punishment is reasonable rather than a sign of corporate greed?

Finally, since the design choices above 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 the block size after halving the billing period does not control for the effect of billing frequency on consumer behaviour. Depending on households' consumption patterns, it

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

[16] Whether this results in higher profits for shareholders depends on firms' regulation.

is possible for some households to have increased bills, despite identical annual consumption.[17] Thus the periodicity of households' water demand becomes important.

2.2 Consumers' Decision-Making Under IBTs

Under an IBT, the marginal price increases with each successive block but remains the same within each block; hence, 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 priced block (Carter and Milon 2005). To make a fully rational decision, consumers need perfect information about the IBT's 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 is challenging. Where a water bill is small relative to household income, the time and mental effort to fully understand an IBT may exceed the potential monetary saving.

Also, households may form inaccurate perceptions of prices and consumption, preventing them from making a fully rational decision (Nieswiadomy and Molina 1989; Nataraj and Hanemann 2011).[18] Even with consumption data available, consumers may struggle to predict consumption over the long-term (Borenstein 2009) as they may fail to establish a link between day-to-day consumption and block price increases. These challenges can result in unexpected 'bill shocks', which will be particularly difficult for low-income households.

Clear and accurate water bills should aid learning and reduce uncertainty. Cater and Milon (2005) estimate water demand conditional on households' knowledge of prices, using data from North-Central Florida. They find price information lowers water consumption, but this effect is weaker under IBTs than uniform pricing because households facing IBTs are less likely to know the marginal price of water. Using American data, Gaudin (2006) shows having price information next to consumption on bills increases price elasticity by 30%. However, increased billing frequency does not necessarily reduce water consumption. Gaudin (2006) explains two opposing forces operate: frequent bills help households establish a clear relationship between tariffs and consumption, but as bills become smaller they receive less attention. Empirical studies on whether increased billing frequency reduces water consumption are inconclusive (Kulshreshtha 1996; Arbués et al. 2003).[19]

2.3 IBTs in Practice

Among developed countries, IBTs are widely used in the US (Olmstead et al. 2007; Asci et al. 2017),[20] some parts of the Europe, such as Spain (Arbués and Barberán 2012; Suárez-Varela et al. 2015) and Portugal (Monteiro 2010), and parts of Australia including Melbourne, Perth and Sydney (Brennan 2006). Unsurprisingly, these areas are associated with an existing high drought risk.

[17] For example, consider a consumer who consumes no water in month one and a high quantity in month two. With bimonthly billing her total consumption across the two months will not enter the high block, but with monthly billing her consumption in the second month will, thus the total bill is higher under monthly billing.

[18] When information acquisition is costly the average price appears to be commonly used by consumers since the *ex post* average price is obtainable from a bill at negligible cost (Shin 1985). This approach risks poor decision-making when bills are estimated rather than based on actual meter readings.

[19] An unresolved issue is whether consumers are more likely to learn from a bill received through the post than an online bill. Schultz et al. (2016) conclude that online billing is less effective than postal billing. However, postal billing is more costly and its cost will increase with billing frequency.

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

Reviewing existing IBTs offers two general observations: first, IBTs' structures can vary considerably across geographical areas and time periods, and second, IBTs' effects are mixed[21] – some IBTs have reduced residential water consumption, while others have not, and some have even increased aggregate consumption.

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 ranged from two to eight, while the variance in the size and price of blocks was even larger. To understand these differences Suárez-Varela et al. (2015) analyse the determinants of the progressivity of Spanish IBTs. Greater water scarcity and greater economic activity led to more progressive block prices, while longer-ruling local government officials were related to less progressive tariffs. This suggests IBTs' design and effects depend on local and household characteristics, and caution is needed when attempting to generalise results. Nevertheless, our review suggests some lessons can be drawn.

First, the high blocks must have sufficiently high prices, especially when non-essential water consumption lies mainly in high-income households. Second, there needs to be frequent adjustment of blocks' sizes and prices to reflect changing environmental and socio-economic conditions (Nataraj and Hanemann 2011; Asci et al. 2017). Third, season, weather and outdoor water use are correlated, resulting in seasonality in residential water demand, which in some countries is found to influence price elasticity estimates significantly (Espey et al. 1997; Worthington and Hoffman 2008).[22] It follows that an IBT might vary 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. Fourth, an appropriate billing frequency and clear price information on bills should improve households' learning. Fifth, IBTs need to be implemented for a sufficiently long period. While many studies obtain short-run measures of IBTs' effectiveness, there are reasons to believe IBTs are more effective over the long-run. Empirical findings show price sensitivity is significantly higher in the long-run (Espey et al. 1997; Sebri 2014), mainly due to information accessibility and water-related investments by households (Carver and Boland 1980), while water use habits may take a long time to change (Gregory and Di Leo 2003; Asci et al. 2017). Illustrating the role of time, Baerenklau et al. (2014) investigate an IBT's effects in southern California finding water demand was 17% lower than under a uniform price, however, the reduction occurred gradually over more than three years.

In all the studies reviewed, the water companies were monopolists.[23] Competition may undermine companies' incentive and ability to adopt IBTs. If one company introduced an IBT with a high price for high water users, a sensible competitive response by rivals would be to charge a relatively low price for high water use. Rather than water conservation the likely end result would be the sorting of households across companies by households' level of consumption. However, empirical evidence from the Texas energy market shows that even with competition, IBTs continued to be used (e.g. Puller and West 2013)[24].

[21] Assessing IBTs is complicated by methodological issues regarding water demand estimation in the presence of multiple pricing blocks, for example, see Arbués et al. (2003) and Sebri (2014).

[22] Estimating residential water demand in Aurora, Colorado between 1997 and 2005 (a drought covered 2000-2005), Kenney et al. (2008) find water consumption was 30% higher in summer, regardless of temperature and rainfall.

[23] In the UK, introducing competition in the residential water sector is being considered, see Ofwat (2016).

[24] For studies on electricity and gas IBTs, see Borenstein (2009) and Ito (2014). The ability to use IBTs in a competitive setting may depend on 'weak' competition, in terms of few consumers being willing to switch suppliers for monetary savings.

Table 1 Information types tested in water conservation experiments

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 point of consumption
General feedback	Feedback on total household water use, sometimes including a breakdown 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's average, and sad faces indicating social disapproval for those whose consumption is above average

3 Behavioural Interventions to Conserve Water

Both the academic literature and policy reports have argued for non-price conservation tools to support water pricing (Renwick and Archibald 1998; EPA 2016; EEA 2017). In many cases where conservation plans successfully reduced water demand (e.g. Renwick and Archibald 1998; Kenney et al. 2008; Kayaga and Smout 2014), the success was achieved by multiple price and non-price interventions working in combination.[25]

3.1 Water Conservation Experiments

Using demand-side behavioural 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. Assessments of these policies increasingly involve natural or constructed 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 particular information types reduce water consumption. Important research questions include the types of information offering the strongest conservation impacts, and whether households' socioeconomic characteristics influence their response. Table 1 lists the information types considered by the existing literature.

There is a surprising paucity of experimental research on water conservation, given the increasing number of environment related behavioural 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; we summarise the studies and their findings in Table 2.

The most comprehensive experimental evidence so far comes from Atlanta in 2007. This research project involved over 100,000 households and avoided sample selection biases[26] by randomly assigning households into three treatment groups and one control group. Compared to the control group, one group received technical advice, another group received norm-based

[25] This makes it difficult to attribute the demand reduction achieved to a particular measure.

[26] If households have actively chosen to be part of a trial, they are likely to have a pro-conservation preference and so evidence from the trial will probably over-estimate the effectiveness of interventions in the general population.

Table 2 Evidence on demand reduction from water conservation experiments[1]

Study	Location	Sample size	Information type					
			Technical advice	Norm-based information	Monitoring device tailored to specific appliances	General feedback	Socially comparative feedback	Emoticon feedback
Kurz et al. (2005)	Western Australia	166 households	No effect	No effect	Significant demand reduction	–	No effect	–
Ferraro and Price (2013)	Atlanta US	More than 100,000 households	Significant demand reduction	Significant demand reduction	–	–	Significant demand reduction	
Ferraro and Miranda (2013)	Atlanta US	More than 100,000 households	–	–	–	–	Significant demand reduction; higher reduction for high water users	–
Fielding et al. (2013)	South East Queensland Australia	221 households	Significant demand reduction	No effect	–	No effect	–	–
Seyranian et al. (2015)	Los Angeles US	374 households	No effect	Significant demand reduction	–	–	Significant demand reduction	–
Schultz et al. (2016)	San Diego US	301 households	No effect	–	–	–	Significant demand reduction; low water users increase consumption	Reduced the effectiveness of other interventions
Otaki et al. (2017)	Tokyo Japan	246 residents	–	–	–	–	Significant demand reduction for low water users	Significant demand reduction for high water users

[1] A dash indicates the information type was not tested in the study. Further details of these studies can be found in Table 3 in the Appendix.

information and technical advice, while the third group received socially comparative feedback, norm-based information and technical advice. Three studies utilise this data, each with a different focus. Ferraro and Price (2013) compare the (treatment) effects of different information types; Ferraro and Miranda (2013) examine heterogeneity in effects across households; while Ferraro et al. (2011) examine the persistence of effects over time.

Ferraro and Price (2013) find that, while average water consumption fell between years for all groups,[27] receiving norm-based information was more effective than receiving technical advice and additionally receiving social comparison reduced consumption still further. The water conservation effect in the treatment groups compared to the control group varied from 7.4% to 53.4%. Ferraro and Price suggest the effect of social comparison could be equivalent to a 12%-15% increase in average price. However, as an IBT was introduced shortly before the trial started, one cannot be sure that the same effects would hold absent the IBT.

Ferraro and Price (2013) find social comparison changed consumption by high and low water users in a "fundamentally" different way, with a 94.1% difference in the relative treatment effect. Ferraro and Miranda (2013) find greater responsiveness to social comparison in households that are wealthier, living in their own properties and with higher water consumption. Heterogeneity in response was absent in the two treatment groups that did not include social comparison. Additionally, Ferraro et al. (2011) suggest only social comparison has a strong long-run effect, as the effects in the other two treatment groups disappeared within a year, but the effect of social comparison persisted for more than two years. Although the size of the social comparison effect fell over time, the result is still striking as letters containing social comparison were sent to households only once.

3.2 Insights from Existing Conservation Experiments

The main insight of our review is that there are insufficient studies to form robust general conclusions and more experimental studies are needed. Some studies suffer from issues with their design and comparing across experiments is difficult as they differ by intervention length, climatic context, and the framing of information.

Nevertheless, the existing evidence suggests some initial conclusions. First, among the information types tested, socially comparative feedback appears most likely to generate significant effects. Second, a one-size-fits-all approach may be ineffective and varying intervention by consumption level may be sensible. Socially comparative feedback appears most promising for high water users, and less effective or even counterproductive for low water users. Third, there may be a complementarity between price and behavioural interventions. In the short-run, information-based interventions may be more effective than price interventions, such as IBTs, because high water users appear responsive to social comparison. In the long-run, the effect of information-based interventions generally declines whereas IBTs can become more effective. Combining the two intervention types may offer an immediate effect and a sustained effect.

Future experimental studies need to address the persistence of information interventions, the heterogeneity of responses across household groups, and their interactions with price incentives, such as IBTs.

[27] The consumption reduction in the control group may have resulted from the introduction of an IBT in early 2006.

4 The Challenges of Applying IBTs in the UK

4.1 UK Water Demand and Water Industry[28]

Residential water supply in England and Wales consists of privately-owned, regulated water companies, which are licensed monopolies in their regions. Most companies 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 companies, with the average being 51.4% (Consumer Council for Water 2015). Even where water bills are based on metered usage, whether households receive bills based on actual or estimated meter readings depends largely on whether households voluntarily submit readings to their water company sufficiently frequently.[29] Metering and billing therefore represent clear obstacles to price signals being effective.

Very little evidence exists on the price responsiveness of water demand in the UK. The few available price elasticity 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).[30] These estimates suggest the scope for water tariffs to reduce demand in the UK is currently less than in some other locations.

For all income levels, water bills account for a small share of household expenditure in the UK, with the richest households spending only slightly more on water than other households (Levell and Oldfield 2011). International experience suggests having a large number of high water users usually creates the opportunity for effective IBTs, but the low variation in water expenditure in the UK may indicate households' water demand incorporates limited discretionary use.[31]

Consumer engagement in the UK also appears low. Survey data suggests a low awareness of tariffs among British water consumers (Consumer Council for Water 2017). Waddams and Clayton (2010) argue UK households have a low understanding of water price, consumption and bills, together with a limited ability to rank household activities by water use. Based on a small survey of Veolia Water South East customers, Gardner (2010) find respondents had a significantly more accurate (though still inaccurate) perception of their water *bills* than their water *price*. This probably reflects 77% of respondents stating they looked at bill totals, while only 15% stated they looked at water prices. Households' better understanding of bill totals implies their demand response will likely be related to the average price of water, suggesting IBTs, where the marginal price changes with consumption, may have reduced effectiveness in the UK.

Also, IBTs require experimentation to develop an effective block pricing schedule, however, the feasibility of experimentation within the UK water sector's political and regulatory regime remains an open question. Despite greater emphasis on sustainable water use in recent years (e.g. Ofwat 2010), development of conservation-oriented tariffs in the UK has been slow. Central to this is a concern about whether water is affordable for all household sizes under IBTs. Both Ofwat (2005) and Defra (2009) have expressed clear views that IBTs must address the affordability/equity issue regarding large households before they can be implemented.

[28] In this sub-section we base our discussion on the current situation in England and Wales. Some arrangements are different in Scotland and Northern Ireland, such as water companies' ownership structure. However the key challenges to using price signals to manage water demand – limited metering and, hence, limited data on water demand – apply across the UK.

[29] Some water companies guarantee their customers one bill per year based on an actual reading.

[30] Gardner (2010) uses quarterly data covering 2007-2010 for 622 metered households. Reynaud (2015) obtains estimates using panel data from 16 water companies between 2002 and 2009.

[31] The result could also reflect a low unit price for water in the UK and/or the relatively low proportion of metered households.

Similarly, Herrington (2007) argues water affordability for larger low-income households appears to be a barrier to metered water charges.

The 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 is likely to be costly and may 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 companies granted "water scarcity status" by Defra – Veolia Water South East and Wessex Water – have trialled IBTs (and seasonal tariffs).[32]

4.2 Do Water Conservation Attitudes Depend on Climatic Experience?

Many of the empirical or experimental papers reviewed utilise data from a pre-existing drought situation. Beyond the natural conditions that define a drought, e.g. a lack of rainfall, the risks of water shortage are likely more prominent within drought-prone communities leading to greater discipline at the individual and collective levels regarding water management (Medd and Chappells 2007).

The UK is currently a temperate "marine west coast" climate, which implies a relatively steady temperature range throughout the year and the absence of a dry season (Peel et al. 2007).[33] 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), and views about the burden of responsibility for conserving water may be significant. For example, 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). A survey of 1200 UK households by Gilg and Barr (2006) on how water-related attitudes are formed finds that individuals who perceive environmental issues as a genuine threat to their own welfare are more likely to conserve resources.

Several southern areas of England were affected by drought from 2004 to 2006. Dessai and Sims (2010) make comparisons between St Edmundsbury and the Sevenoaks District regarding residents' opinions of "the seriousness of the water situation in their locality in 2006". The survey responses suggest the seriousness of the local water situation was perceived to be significantly higher in the Sevenoaks District. This is consistent with the UK Environment Agency finding that Sevenoaks was more negatively affected by drought.[34] However, while significantly more respondents in Sevenoaks stated they had changed their consumption due to the drought, there was little evidence suggesting their willingness to accept price increases or water use restrictions had changed.

The extent of water stress also affects water companies' promotion of water conservation. 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). Also, there are debates over the appropriate

[32] Gardner (2010) suggests the IBT trialled was not successful.

[33] This is in contrast to the areas of 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.

[34] The UK Environment Agency classified St Edmundsbury as under "moderate" water stress and the Sevenoaks District as under "serious" water stress. However, different water companies are responsible for each area and differences in water company actions could also influence the public's perception of water stress.

degree of coordination of water management between different levels of organisation (Medd and Chappells 2007; Taylor et al. 2009); in particular, 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 households show willingness to participate in water conservation trials if given the correct incentives.

5 Conclusion

This paper has reviewed the international evidence on IBTs' and information-based behavioural interventions' ability to manage residential water demand. While IBTs are common in drought-prone areas such as the US, Spain, and Australia, mixed evidence is found regarding their effectiveness, and we highlight the underlying challenges of successfully implementing IBTs. Behavioural interventions appear to offer promise as a water conservation tool, although, the evidence is insufficient to form final conclusions. We suggest further randomised control trials of behavioural interventions are a research priority.

Applying the lessons from the evidence reviewed to the UK highlights several issues. Since water stress in the UK is not an immediate threat to households' living standards, and water bills are typically small relative to household income, UK households have limited awareness of water conservation and are not used to engaging with water costs. In addition to the design complexities associated with all IBTs, in the UK IBTs would need to fit the regulatory, legislative and political context, where affordability and equity for large, low-income households are a major concern. While IBTs could be trialled in particular regions, in contrast to the US, Spain and Australia, regional government is limited in England and historically there has been aversion to 'postcode lotteries', i.e. geographic variations in service provision.

While the current need for, and suitability of, IBTs in the UK appears limited, it seems important to start building a robust evidence base regarding household water demand today, to inform water conservation policies when they are required in the future. This evidence building should cover water consumers, including variations in water demand by socioeconomic characteristics and location, as well as consumers' understanding of their water prices and consumption. That many UK households have an unmetered water supply represents a fundamental obstacle to obtaining reliable data and producing an evidence base regarding price or behavioural interventions.

The improved metering and increased customer communications required for effective IBTs and behavioural interventions will involve costs that will place an upward pressure on water bills. It is essential that IBTs and behavioural interventions in the UK are not only evaluated in terms of their ability to reduce water consumption, but also for their cost-effectiveness compared to other water supply and demand options. Assuming the cost is not excessive, behavioural interventions may prove to be a useful way to 'prime' consumers to the need to conserve water prior to any implementation of IBTs.

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Compliance with Ethical Standards

Conflict of Interest This paper is based on the Centre for Competition Policy report 'Price and Behavioural Signals to Encourage Water Conservation' commissioned and funded by Anglian Water. The views and statements expressed in this paper reflect the authors' own independent views.

Appendix

Table 3 Description of experiments listed in Table 2

Study	Description
Kurz et al. (2005)	An experiment with 166 households from Western Australia, in which the authors compared 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.
Ferraro and Price (2013); Ferraro and Miranda (2013)	(See Section 3.1)
Fielding et al. (2013)	The authors compared the effects of technical advice, norm-based information and feedback on water consumption in 221 households in South East Queensland, Australia. All three treatment groups received technical advice, while two treatment groups additionally received norm-based information and feedback respectively.
Seyranian et al. (2015)	Using a sample of 374 households in Los Angeles covering summer months, the authors compared the effects of technical advice, socially comparative feedback, norm-based information, and norm-based information with an emphasis on personal identity (e.g. the use of "I" and "you" instead of "we"). Households assigned to each treatment group received only one information type.
Schultz et al. (2016)	Using a one-week field experiment in San Diego involving 301 households, the authors compared the effects of technical advice, socially 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.
Otaki et al. (2017)	The authors randomly selected 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. The treatment groups varied according to the feedback they received: feedback with social comparison; feedback with ranking among a group of 100 (hypothetical) households; and feedback with emoticons. The control group received no feedback.

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