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A European project on water sustainability

DEVELOPING NEW DYNAMIC PRICING MECHANISMS

SmartH2O

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SEVENTH FRAMEWORK
PROGRAMME

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Executive Summary

This document is the Deliverable **D5.2, Developing new dynamic pricing mechanisms**, which, according to the DoW has the following goals.

D5.2) Developing new dynamic pricing mechanisms: The deliverable reports on dynamic water pricing, i.e., new water pricing mechanisms for smart meter water supply systems. Short and long term water scarcity are considered as determinants in the pricing structures. Then, it presents the results of the study of the impact of communication via social media of pricing schemes: analysis and evaluation of the most effective ways to publish pricing schemes and integrate them into the communication with and by consumers.

This deliverable aims to report on the motivation for dynamic pricing schemes and their possible benefits. Dynamic pricing would allow for taking into account frequent or even 'real-time' elements of the marginal cost of water consumption and it provides a signal to customers through their bills on the financial impacts of peak hour use and on the environmental cost of water abstraction for public water supply. It is important to note that so far, water utilities have been unwilling to experiment with dynamic pricing, even at the trial stage, because 1) they believe their customer base is not ready yet, and 2) they fear such experiment would increase resistance to smart metering technologies that make dynamic pricing possible. Therefore, this deliverable is forward-looking in the concepts it presents, but cannot corroborate them with field data. This being said, it proposes a tool that would be usable by utilities when they decide to look into dynamic water tariffs. Since that tool cannot be used now, it carries out an ambitious meta-analysis of price elasticity to make up for the lack of data on consumption change due to dynamic water pricing.

Section 1 introduces the work presented in this report.

Section 2 describes the limitations of traditional pricing policies, because they are the baseline against which dynamic pricing schemes can be defined. These include:

- The single-part fixed tariff (fixed charge irrespective of water usage) does not provide customers with incentives to save water.
- Uniform volumetric rates may not effectively influence peak or seasonal demands and if aims covering both fixed and variable costs, may lead consumers to forgo beneficial water uses.
- Within a 'two-part tariff', if fixed charges outweigh the volumetric ones, consumers may not receive the right incentive to reduce consumption
- Increasing block tariffs may not promote social equity, and have often been criticized for discriminating against large families.
- Seasonal water pricing can only be effective if price changes are frequently communicated to customers, with a consequent increase of transaction costs.
- Traditional pricing polices do not require water consumption to be measured with sufficient frequency, and therefore cannot allow incorporating the time-changing marginal economic cost of water supply

The section then continues by discussing the advantages of adopting smart metering enabled dynamic (i.e. time-varying) pricing schemes, and presents evidence from past studies in both the water and energy sector, as listed below:

- Avoidance of manual meter reading and prevention of meter-reading errors.
- Reduced overall consumption levels, and peak consumption.
- Improved customers' experience and engagement.
- Lower consumption implies lower energy costs in pumping and, in the long term, improved investment planning and water resource management decisions.
- Detection and reduction of the amount of water lost in the network (by measuring

continuously the water delivered) and better management of water pressure.

The section then presents past modelling efforts to analyse dynamic pricing schemes. Different methods and techniques are presented together with their advantages and disadvantages, such as:

- Modelling water markets (i.e., allowing for voluntary and mutually beneficial trades). Trading helps equalize the marginal prices faced by various water users, and therefore helps providing information about the value of water in alternative uses and creating compatible. Intersectoral water markets have been slow to develop due to complications of transaction costs and third-party externalities.
- Long-Term marginal costs (LRMCs) are used to reflect the cost of future supply acquisition. If, however, these are greater than short-run average costs, the utility's revenues may exceed current expenses.
- Short-term marginal pricing (SRMCs) match prices, both temporally and spatially, to the marginal costs experienced by the utility and reflect availability of water resources during drought and scarcity. If, however, average costs exceed SRMCs the utility may collect less than its revenue requirement.
- SRMCs that reflect the economic value of water in various uses (scarcity) and promote efficient allocation of scarce water across different sectors (i.e. industry, public water supply, environment, and agriculture).

Then, section 3 presents the proposed dynamic pricing schemes, that are at the heart of this deliverable. They are simple, because when dynamic pricing is implemented, it is likely that the schemes that look the ost straightforward to the public may be implemented first. Three charging schemes are discussed as summarised below:

- Time-of-day tariffs where the volumetric rates increase during peak consumption hours. This pricing scheme is designed to shift water consumption away from peak periods and redistribute it over the remaining hours of the day. This would reduce customer bills as it would lower capacity expansion costs, maintenance and energy costs. Unit volumetric prices would be higher during peak hours than those currently charged but lower over the remaining hours of the day. The variation of the volumetric price over peak and off-peak hours is adjusted so that its value over the day equals the utility's current rate.
- A supply-based dynamic pricing scheme that considers system-level water scarcity (scarcity pricing). Scarcity pricing could address increased dry-season or drought period consumption levels and signal to consumers about the increased value of water under scarcity. Under wet or normal conditions, rates would be decreased below current rates while under dry conditions volumetric rates would increase in order to enable revenue neutrality. The pricing approach allows selecting how the economic cost of water scarcity could be apportioned amongst different water using sectors. Particular emphasis is placed how public water supply consumers could receive a pricing signal reflecting the societal costs of insufficient environmental flows. The approach is extendable to other sectors (e.g. power cooling, irrigated agriculture, etc.).
- A combination of 'time-of-day' tariff and 'scarcity pricing'.

Time-of-day tariffs lead to lower daily peak consumption with consequent reduced energy consumption, maintenance costs, leakage, and lowered and/or deferred investments on pipe capacity expansion. Scarcity pricing leads decreased peak seasonal or drought conditions demands, which will lower or defer investments in expanding capacity for peak summer demands. These economic savings would be estimated by comparing the net present value of capacity expansion programmes with and without the proposed dynamic pricing schemes and would be then reflected within the proposed dynamic tariff schemes through reduced unit volumetric rates.

Next, in section 4, we present the design of the 'SmartH2O pricing tool' meant to allow consumers to explore dynamic tariffs before they are introduced. This tool gives customers a virtual bill that simulates the effect of various pricing schemes, including current tariffs. Utilities can also receive information about customers' reactions towards different pricing schemes. The methods and techniques for social network analysis and influencer detection developed in WP4 (see D4.2) can also be used to support the experimental analysis of customer behaviour in response to the proposed dynamic pricing schemes. Analysis of user interactions on Twitter can allow identifying specific user types and behavioural patterns (e.g. influencers, communities). The identification of most important users and their communities can be achieved in two main ways, as below:

- by tracking users discussions regarding the different pricing schemes (e.g. observing and monitoring the influencer accounts);
- by pro-actively initiating Twitter discussions and channelling them to target users.

These users could be invited to participate in workshops where customer reactions to dynamic pricing schemes are observed and discussed.

Finally, section 5 aims at providing elements concerning the possible price response to dynamic pricing. Actual data on the matter is not expected to be available during the SmartH2O project, and in particular, the tool designed in Section 4 is not expected to be applied by water utilities in the foreseeable future. Therefore, simulating the possible consequences of dynamic pricing on consumption is best achieved through the concept of price elasticity of demand. This is why a meta-analysis of past price responses to the implementation of (non-dynamic) water tariffs is carried out. The section presents the methodology used to estimate the price elasticity of demand for residential households. Since, case-specific datasets are not available, meta-analysis was used to collect price elasticity estimates across 198 studies from 1963 to 2014. Meta-regression helps investigate the extent to which statistical heterogeneity between results of multiple studies can be related to one or more characteristics ('variables') of the studies. Its results are then used to express price elasticity as a function of the characteristics of the sampled studies (i.e. London in UK, Ticino in Switzerland, Valencia in Spain). Three simulations (model evaluations) were performed based on the characteristics of the three case studies. This was done in order to obtain water price elasticity predictions in correspondence of different levels of water scarcity, regulatory frameworks and income as explained below:

- Simulation 'SimWS', i.e. the values of all variables except water scarcity are set at their sample means, while the value for the water stress indicator changes
- Simulation 'SimRF', i.e. with and without an independent water regulator
- Simulation 'SimBLC', i.e. the values of all variables except the location specific-ones are set at their sample means, while regulatory framework, income of inhabitants and water scarcity are assigned case-specific values (London, Ticino and Valencia).

1. Introduction

Typically water supply pricing policies are aimed at meeting costs incurred through system operation and expected infrastructure expansion. Such pricing does not reflect the financial and social marginal costs water consumption has at any particular point in time. This means energy availability, current water demand and water supply (i.e. scarcity) and the environmental damage incurred through water abstraction are not typically represented in water pricing. In most cases water consumption is not measured with sufficient frequency to allow incorporating these realities into water pricing policies. As a consequence, users cannot be provided with pricing signals that incentive their conservation of water in response to the financial and social costs the water system is incurring at any point in time.

Smart metering could change this. After reviewing existing water tariffs (Section 2), this deliverable proposes dynamic pricing schemes (Section 3). Then, this deliverable introduces a simulator that will allow utilities and consumers to evaluate the impacts of dynamic pricing, when this will be considered by regulators, utilities, and water users (Section 4). Yet, in the absence of real-life experimentation from water utilities on dynamic water pricing, it has been necessary to explore alternative solutions to evaluate the behavioural response to dynamic tariffs. This is why Section 5 introduces a price elasticity simulator that relies on past studies on changing water price – with static tariffs. The detailed section-by-section breakdown is as follows.

In Section 2, we first summarise the limitations of traditional pricing schemes to set the stage for introducing new pricing schemes. The single-part fixed tariff does not provide customers with incentives to save water. Uniform volumetric rates are not effective in reducing peak or seasonal demands Increasing block rates or IBR (i.e. when volumetric rates increase stepwise within pre-defined blocks of consumptions) and the seasonal tariffs ('two-part' tariff, where the volumetric rate changes with the season) lead to higher welfare than the single price policy. However since blocks of consumption are designed based on implicit assumptions on customers' water use, such tariff may not promote the objective of social equity; furthermore, IBR has often been criticized as it may not protect families with large size. Finally, for a seasonal water tariff to be effective, the changes in pricing must be frequently communicated to customers, thus increasing utilities' transaction costs. In addition to the above, traditional pricing polices do not require water consumption to be measured with sufficient frequency, and therefore cannot allow incorporating both the 'real-time' social and marginal costs of providing water, nor can reflect the level of water scarcity or environmental damage. The report presents past modelling effort on determining dynamic (i.e. time varying) pricing schemes that take account of water scarcity and intersectoral allocation of scarce resources.

The report then continues with Section 3, with a description of proposed dynamic pricing schemes and how their impacts could be assessed for the case studies. The estimates of price elasticity of demand would be used to evaluate the extent to which increases or decreases in prices could reduce water consumption levels to target levels. The proposed dynamic tariffs target the reduction of both daily and scarcity period peak consumption of public water supply. Their aim is to reduce peak water usage daily and/or during periods of low resource availability to defer or reduce water supply investments and thus reduce long-term financial costs. Three charging schemes are discussed: time-of-day tariffs where unit rates increase during peak consumption hours, a supply-based dynamic pricing scheme that considers system-level water scarcity, and the combination of the two. We propose hydro-economic modelling to evaluate impacts such pricing could have on multiple sectors such as public water supply, environment, agriculture and energy cooling. We use price elasticity of demand to model the effect of proposed pricing policies on water consumption. The economic savings in infrastructure developments, energy requirements and demand management measures, due to the reduced level of consumption, are estimated by comparing the net present value of capacity expansion programmes with and without the proposed dynamic pricing schemes. The financial savings resulting from lower demands during water scarce periods would then reflected within the proposed tariff schemes through reductions in water charges. The three proposed tariffs are relevant to this project as they can only be implemented in presence of smart metering where customers' consumption data is recorded over a short period of time (hourly).

After that, the report discusses the importance, in promoting customers water saving behaviour, of providing consumption feedback to consumers in real-time. Such feedback can help close the gap between perceived and actual water consumption and achieve higher reductions in water use. Also this information coupled with information on up-to-date price changes could enable consumers to make informed choices about their current consumption. This is why we present the design of the 'SmartH2O pricing tool' in Section 4. Using such a tool would allow customers to receive a virtual bill and understand the effect of various pricing schemes, including their current tariff. This is meant to allow consumers to familiarise themselves with new dynamic tariffs before they are introduced in the real world. It also would allow utilities to potentially receive feedback from users about reactions and attitudes towards different pricing schemes. The tool simulates different tariffs based on customers' current consumption and allows customers to visualise virtual savings or additional cost compared to their current tariff and predict how much they would save on a monthly and yearly basis if they reduced their water use. The section then continues with a description of the social network analysis and influencer detection techniques discussed in WP4 (deliverable D4.2). This can be used to support the experimental analysis of customer behaviour in response to the proposed dynamic pricing schemes. Analysis of user interactions on Twitter will be used to identify specific user types (i.e. users that hold crucial roles because likely influential and trusted) and communities that most likely would support diffusion of information about the proposed pricing schemes and favour (positive) customer reactions within the same or other communities.

Finally, since the presentation of dynamic pricing schemes relies on demand curve that rely on the concept of price elasticity of demand, Section 5 estimates the price elasticity of water for the two case studies considered within the present project (London in England and Ticino in Switzerland). The knowledge of price elasticity is of fundamental importance in order to evaluate whether and to what extent raising prices is an effective measure to stimulate water savings by residential consumers, and secondly, to ensure water utilities can calibrate the price to meet revenue requirements. Since case-specific datasets are not available, specific water demand models for London area and Ticino were not yet feasible. We therefore produced a Meta-analysis in order to collect data on a large sample of water demand studies from 1963 to 2014. The resulting meta-analysis goes beyond the existing literature by using a larger sample of studies and by considering additional variables not considered in the literature: water scarcity and regulatory framework. Given the data developed through the meta-analysis we then used meta-regression models in order to simulate price elasticities in the two locations.

2. Existing pricing schemes

Climate change, growing urban population and increased exploitation of available resources represent challenges for water policy makers and motivates the search for efficient and rational use of water resources. Water pricing is a common method to manage consumption, alongside with other demand management measures, such as leakage control, water efficiency and metering [OECD, 1999]. Using pricing schemes to manage water demand can help reducing water consumption levels by a higher extent than non-price conservation programs [Olmstead et al., 2007a, Olmstead and Stavins, 2009, Collinge, 1994, Krause et al., 2003a]. Non-price based water rationing policies, including enforced used restrictions, can be inferior to price policies in terms of both economic efficiency and social equity perspective [Bakker, 2005, Reynaud, 2013, Al-Kahtani et al., 2012]. Furthermore, the literature shows that tariff mechanisms may be necessary to ensure the success of non-pricing policies. For example [Mayer et al., 1998] found that the benefits from using efficient devices, such as showerheads, may be omitted since people may take longer showers in response. In such cases, the combined use of both tariff and non-tariff schemes is suggested in order to maximise their potential.

2.1 Traditional pricing schemes and their limitations

Traditional water tariffs can be classified into ‘single-part’ and a ‘two-part’. The ‘single-part’ tariff consists of a fixed charge, or a water use (volumetric) charge. Under ‘two-part’ tariff, instead, customers are charged a combination of a fixed charge, to recover fixed costs, including administration and billing costs from metering, and a unit volumetric rate, to recover variable costs, including energy supply. All volumetric charges require that customers have a metered connection that is read on a periodic basis.

Single-part fixed tariffs are most often applied in absence of metering. The fixed element is uniform across the customers’ type and may be depending on the value of the residential properties [Thames Water, 2015]. This charging scheme does not provide customers with any incentive to save water since any additional cubic meter results free of charge [Whittington al., 2002]. A ‘single-part’ tariff may alternatively only include volumetric rates, and in this case, the water bill will exclusively depend on the amount of water used. A ‘single-part’ volumetric tariff can be uniform if a rate per unit volume is constant for all levels of consumptions, increasing stepwise within blocks of consumption or, contrarily, decreasing stepwise. The last two tariff types are referred to respectively as increasing block rates (IBR) and decreasing block rates (DBR). IBR and DBR can also be designed as ‘two-part’ tariffs, i.e. include both a fixed charge and a volumetric rate.

The uniform volumetric charge has the advantage that is easy to understand for customers. If it is not associated to a fixed rate (as in the ‘two-part’ tariff), this tariff scheme can ‘*send a signal about the marginal cost of water*’ [Whittington et al., 2002, Spang et al., 2015]. Unit volumetric charges alone may provide incentive to reduce household water consumption [Garcia and Reynaud, 2004, Hoffmann et al., 2006] since these provide consumers with some degree of flexibility in controlling their water bills, based on their usage. Evidence comes from Denmark, where a 54% price water increase from 1993 to 2004 decreased water consumption to one of the lowest level in the OECD countries (i.e. from 155 to 125 litres per person per day), [Dige, 2013]. Contrarily, in a two-part tariff where fixed charges constitute a large portion of the bill, consumers may experience a limited ability to control their bills, and may therefore face lower incentives to save water. Some studies also show that, when the volumetric charge aims to cover both fixed and variable costs, the rate may become too high, and consumers might forgo beneficial water uses and waste money and resources in inefficient water saving [Hoque and Wichelns, 2013]. The balance between fixed and variable charges should be carefully determined, in conjunction with local priorities [Herrington, 2007].

Decreasing blocking rates are often politically unattractive as it assumes that high volume water users end up in paying lower average water prices and thereby they have been rarely used [Whittington et al., 2002].

Increasing block rates (IBRs), have been often adopted in the water sector [Molinos-Senante, 2014, Chen and Yang, 2009, Ma et al., 2014b, Madhoo, 2011, Martins and Fortunato, 2007, Ma et al., 2014a, Strong and Goemans, 2014]. With IBRs, customers are charged different marginal prices for higher quantities consumed. Specifically the marginal price rises within predefined blocks of consumptions. The IBR tariff can be implemented under several variants. The simplest form is a two-block IBR with allowances set on household basis. In some cases the volumetric rate or the range of consumption applied to each block are adjusted to take account of specific customers characteristics [OECD, 2009]. A free allowance can also be allowed though cross-subsidy of the above blocks [Hoque and Wichelns, 2013]. Finally, when it is possible to collect occupancy information, IBR can be adjusted to take into account customer characteristics and can be set on household or person basis as applied in Belgium and Israel [RPS, 2013]. The rationale behind IBRs is that it can encourage water conservation since higher consumption is accompanied by higher charges [Olmstead et al., 2007a, Hewitt and Hanemann, 1995a]. It is also assumed that tariff scheme also allows to achieve affordable supply, and therefore social equity in water use, by providing access to a 'subsidence block' of water: consumers face lower prices for water quantities that are considered to be essential for their biological needs, while higher uses are charged at higher prices [Whittington et al., 2002]. Past studies showed that IBR could reduce annual demand by 5% in average [Herrington, 2007, Rinaudo et al., 2012], however it has been often asserted that IBRs may not promote the objective of social equity, since the consumption blocks are designed based on implicit assumptions concerning each individual's water use and household consumption [Bithas, 2008]. Allowances that do not consider the characteristics of individual households can penalize some customers and can affect customer acceptance of the tariff [Ruijs et al., 2008]. On the other hand, taking account of households size is difficult to accomplish and to keep up to date, and increases the utility's cost of the tariff administration [RPS, 2013].This was also acknowledged by Anna Walker in her review of charging [Walker, 2009].

For an effective IBR tariff, it is important to appropriately determine the range of water consumption where the lowest price applies [Chen and Yang, 2009, Hewitt and Hanemann, 1995a]. The IBRs blocks may be poorly defined if the marginal price for the upper consumption block is not sufficiently high to reduce consumption [Dahan and Nisan, 2007] or if the range of consumption allowed within the first subsidized block is higher than what residential consumers use [Whittington et al., 2002]. The volumetric allowances and the price for each block need therefore to be carefully considered so that water for the basic needs is affordable, while a sufficient incentive is given to discourage excessive use. IBR has often been criticized as it may not protect families with large size. In practice, low-income households tend to be larger on average, and the initial low cost blocks are used sooner, putting the household into the higher price blocks [Mitchell and McDonald, 2015, Zetland, 2011]. In addition, regulators might be reluctant to limit the size of the initial block due to political pressures [Boland and Whittington, 2000]. Winter IBR or water budgets (IBR tailored to take account of the needs of specific customers or customers groups, [Water, 2011] may be used to specify a rule to define the first block – respectively by considering the household's winter consumption or households' characteristics and demand profile. However, the structure where blocks are set on a per household basis may penalise larger households while giving the smaller ones an overly generous allowance. [Herrington, 2007] showed results from modelling IBR with a marginal price for the first block of 60 m3/year. With a two-block IBR, the 45% of large families were charged more than £100/year, which resulted to be higher than for a flat volumetric tariff. This percentage increased when a three-block increasing block tariff was considered. When the first block was free, about the 60% of large families were worse off. On the contrary, the gainers were smaller households, such as pensioners and single adults. [Bithas, 2008] showed through a simple exercise, that a four member households can be charged an average price that is higher than the one changed to a two-member household, and states that this conclusion becomes even stronger if one considers that, most often, household with a higher number of members have lower per capita income and include children and retired seniors.

Seasonal tariff is another case of 'two-part' tariff, often adopted in the water sector, where the volumetric rate changes with the season. Under this tariff scheme, the volumetric rate can be uniform, increasing or decreasing within pre-defined 'blocks' of consumption. Seasonal tariff is usually used in countries where the difference between summer and winter consumption are significant and water shortages become critical during dry seasons [Hoque and Wichelns, 2013]. The rationale behind the adoption of seasonal tariff is the necessity to reduce peak load costs. Literature shows that marginal costs during peak summer months can be double than those observed during off-peak periods, mainly due to higher pumping costs [Pesic et al., 2013]. For a seasonal water tariff to be effective, however, the changes in pricing must be frequently communicated to customers, which increases the transaction costs [RPS, 2013]. Furthermore, in order to effectively reduce seasonal or peak consumption, customers pay with a differential cost that represents the costs of peak supplies (including all environmental externalities) [Hoque and Wichelns, 2013]. Seasonal water tariff was trialled in the UK by Wessex Water under two variants. These included a standard seasonal tariff where the marginal price of water was set 1.5 higher over summer than winter months, and a peak seasonal tariff where low season consumption was used as a benchmark to set a basic allowance for summer season [Wessex Water, 2012]. Results from applying seasonal tariff in the US [Herrington, 2007] show a decrease in daily peak consumption of 12% on average. However, results from application of seasonal tariff in England by South East Water and Affinity Water were inconclusive [EA, 2011, RPS, 2013]. Specifically, seasonal tariff trialled by Wessex Water showed a slight seasonal reduction in demand, while peak seasonal tariff did not result in a significant difference in consumption [Warren and Rickard, 2012]. This could be partly due to local weather conditions, differences in consumption patterns (outdoor water use in England is a lower than in US) or the design of the tariff [RPS, 2013].

Overall, past studies show that both seasonal tariff and increasing block rates may lead to higher welfare rates than the single price policy [Krause et al., 2003b, Rinaudo et al., 2012]. The Independent Pricing and Regulatory Tribunal of New South Wales [IPART, 2014] also stated that a 'two-part' tariff is the most efficient pricing structure for monopoly service providers. This is because the variable price can be set equal to marginal cost of supply while the fixed cost can recover the difference between the average and marginal costs [Cox, 2010]. When a company invests in new assets (such as dams, desalination plants and mains), the marginal cost of supplying water becomes lower than the average cost, as is common with natural monopolies. Therefore, if prices are set to marginal cost the water utility might not fully recover its costs [Ofwat, 1997].

Table 1 below summarises the advantages and disadvantages of traditional pricing schemes.

Table 1: Comparing the performance of alternative tariff structures, from [RPS, 2013].

	Advantages	Disadvantages
Uniform volumetric	- Effective in managing demand if there is a balance between the fixed and volumetric charge is set appropriately. Equitable and fair.	- Not as effective as variable tariff in reducing excessive or seasonal demands.
Simple increasing block	- Can further incentivise efficiency if the size and price of the blocks	- Can penalise larger households if occupancy not

	are well designed.	taken into account. - As with all variable tariffs, likely to meet with initial customer opposition. - Customers can find it difficult to understand particularly if there are more than 2 blocks
Amended increasing block tariff	- Can further incentivise efficiency if the size and price of the blocks are well designed. - Taking into account occupancy/ special needs ensures affordability for all.	- Occupancy data and other differentiating customer information is difficult to obtain and can add to administrative burden and costs. - As with all variable tariffs, likely to meet with initial customer opposition. - Increased complexity can make it difficult for customers to understand and accept.
Seasonal tariff	- Good potential for cost recovery if the seasonal differential is appropriately set. - Can further incentivise efficiency if the summer/winter difference is large enough and appropriately communicated.	- Needs frequent customer communication to ensure it is understood. Seasonal effect may not be pronounced where customers pay by direct debit. - May penalise some households unless allowance is made for basic use. - As with all variable tariffs, likely to meet with initial customer opposition.

In addition to the challenges listed in the table above, traditional pricing policies do not directly reflect water scarcity or environmental damage. These polices do not require water consumption to be measured with sufficient frequency, and therefore cannot allow incorporating the level of scarcity within the calculation of the unit rates [Saglam, 2013, Saglam, 2015]. Smart metering could change this.

2.2 Towards smart metered enabled dynamic pricing schemes.

The description and role of smart metering schemes has been already discussed in a previous deliverable D5.1 titled ‘review of pricing instruments’. This section introduces additional information on the potential benefits of dynamic pricing schemes enabled by smart metering with examples from both the water and energy sectors.

2.2.1 Advantages of smart metering enabled dynamic pricing schemes. Evidence from the water and energy sector

Recently, smart metering technology has been used to overcome the limits of the existing water management measures, since it can enable real-time measurements, communication, analysis and control of consumption data [Lee et al., 2015]. By collecting customers' usage data on a daily or hourly time scale, smart metering allow the implementation of dynamic (i.e. time varying) pricing schemes [Parker and Wilby, 2013, Cole et al., 2012], which can potentially lead to a range of benefits, as described in the sections below.

Avoid errors on meter readings and reducing overall consumption levels

Smart meters allow recording usage data and other information, such as continuous flow, reversing flow, tampering alert information, at a daily or hourly level, and therefore can be used to avoid the complexity on meter readings, often due to the increasing number of customers, and prevent meter-reading errors [Joo et al., 2015].

Smart metering enabled tariffs have been demonstrated to reduce consumption levels [Joo et al., 2015]. Most evidence comes from the energy sector, with reductions in energy use between 5% to 20% [Gans et al., 2013, Houde et al., 2013, Vine et al., 2013, Braithwait, 2000, Taylor et al., 2005]. A variety of pilot studies featuring several dynamic pricing rate designs applied to the energy sector have also been carried out, in the past few years, under different geographical settings, such as in North America, Europe and Australia [Caves et al., 1984, Aubin et al., 1995]. Given the novelty of smart metering in the water domain, there is less research on its effectiveness of reducing water consumption. However, we report below, to the best of our knowledge, results from previous applications.

[Fielding et al., 2013] consulted 221 households in South-East Queensland whose houses were fitted with smart water meters to measure the level of water usage at a 5 seconds intervals. Households were divided into three interventions groups including water saving information alone, social comparison and education, and information and tailored end-user feedback. This was done to test behavioural change and the effectiveness of demand management measures when smart meter technology was adopted. The three intervention groups recorded an average reduction of 11.3 litres per person per day (approximately 7.9%) over the course of the intervention; over the long term, the reduction in water use dissipated, with consumption returning at a pre-intervention level within twelve months.

[Erickson et al., 2012] evaluated the effectiveness of a real time water consumption feedback system for 303 households. Over 15-weeks, smart-meters recorded consumption every 15 minutes, which were communicated to both households and water companies through an online portal. Results showed a 6.6% drop in water consumption in the first nine weeks of the study when the intervention group had access to the portal.

[Petersen et al., 2007] installed a high resolution automated data monitoring system in two college dormitory buildings. Some users received detailed feedback via an online portal, while others were provided with low-resolution, aggregate data readings once a week. Consumption was quantified in terms of electricity and water usage. Results showed an average 3% reduction in water use per person (140 litres), with one dormitory reaching 11% decrease. Recorded electricity savings were higher with an average of 32%. The author justify this difference explaining all dormitories only received aggregated water consumption data (due to technical errors), and contrarily high-resolution feedbacks on energy.

Studies from [Sønderlund et al., 2014] suggest that the conjunctive use of smart metering and household water consumption feedbacks, via different means such as email-based, online portal and IHD (in-home consumption displays), can reduce usage by a maximum of 53.4% [Willis et al., 2010]. Overall, the majority of studies collected by [Sønderlund et al., 2014] showed that smart metering and feedback information were effective in reducing water use, with and average decrease in consumption was 19.6%, with only two studies [Geller et al., 1983, Kurz et al., 2005] showing no effect, and one a 16% increase in water use [Kenney et al., 2008].

[Temmen, 2014] references the 2011 'North West H2ome Smart' programme in Western

Australia, covering 4338 participating households that estimated 6.9% water savings (equivalent to 186,000 kL). The Perth BCP project completed in 2012, included 10,949 household participants and estimated an overall reduction in water use of 6.5%, equivalent to 156,000 kL of water saved. Smart meters have also been used to study potential water savings from using efficient household water devices [Willis et al., 2011, Willis et al., 2013] and to measure householders' perceived and actual water consumptions [Beal et al., 2013].

Reducing leakage levels

Smart meters also allow water companies, by continuously measuring the water delivered within the supply system, to detect and reduce the amount of water lost in the network and better manage water pressure within the system. In addition, [Boyle et al., 2013] cite water pressure management as another potential benefit of smart metering technology. Britton and colleagues [Britton et al., 2008; Britton et al., 2009] used smart meters to identify household water leakage in residential properties located within selected district metered areas in Australia. Research outcomes included a water use profile of the metered households, the entity of leaks encountered and the cost of leak repairs. [Britton et al. 2013] used smart metering to enable a residential leakage communication strategy and achieve reduction in hourly water loss by 89% over a period of three months. [Lourelio et al., 2014] developed a methodology to calculate real losses and apparent losses in distribution networks using data collected from smart metering systems. The methodology proposes a set of algorithms, tested on different district metered areas and used to improve the understanding about the water loss components. Results allowed estimating leakage levels (as well as unreported leaks and bursts), detecting earlier the occurrence of bursts and providing insights about illegal water uses. The Perth Residential Water use study (PRWU), estimated a reduction of post meter leakage by 25% which corresponds to 1% reduction in residential water use and 1.7 GL/year total savings [Water Corporation, 2010]. Finally, the smart metering system implemented in Hervey Bay allowed to detect leakages, identify peak demand and investigate time of use tariff schemes by using low resolution data collection at hourly intervals [Cole et al., 2012, Cole and Stewart, 2012]. In the UK, evidence that smart metering can lead to more effective leakage control comes from Ofwat, the economic regulator, which estimates supply pipe leakage at 42.5 l/property/day versus 19.5 l/property/day for unmetered and metered properties respectively [Ofwat, 2007].

Reducing peak consumption levels, evidence from the water and the energy sector

Smart metering enabling dynamic pricing schemes also have the potential for reducing peak consumption. This implies lower energy costs in pumping and, in the long term, a reduced expenditure to ensure an adequate level of resilience for the network. Water distribution mains and storage facilities are usually designed to provide minimum service standards for peak periods [Gurung et al., 2014, Vine et al., 2013, Lyman, 1992, UKWIR, 2006], thus reductions in peak demand may have potential impact on both capital and operational expenditures. Managing peak demand is essential about reducing the growth of future demand and capping the cost of infrastructure [Brooks, 2006]. [Savenjie and van der Zaag, 2002] sustain that peak demand management should be a primary component of any overall water demand management strategy.

The literature on the effect of smart dynamic pricing schemes in the water sector is limited and more evidence can be found in the energy sector [Newsham and Bowker, 2010, Faruqui et al., 2013, He et al., 2014, Faruqui and Sergici, 2011, Liu et al., 2014]. Past studies in the electricity and gas sector suggest that a reduction in peak consumption is possible.

Results from the Electric Power Research Institute showed that under time-of-day (TOD) and seasonal rate tariffs, customers responded to higher prices during peak periods by reducing peak usage and/or shifting it to less expensive off-peak hours [Caves et al., 1984]. |Faruqui et al., 2010] reviewed twelve utility pilot programs in the United states that focused on the energy conservation impact of in-home consumption displays (IHDs). Results showed that time-of-use (TOU) and critical peak pricing (CPP) in combination with direct feedback IHD, could reduce consumption from 3% to 13%, with an average of 7%. In 2008, the Baltimore Gas and Electric company undertook experiments to test customers' reactions to different dynamic pricing schemes, such as critical peak pricing (CPP) and peak time rebate tariffs (PTR). Under the CPP tariff, the price during 'critical' weeks was set about five time higher than the one during off-peak times while with the PTR tariffs, customers were allowed to earn a rebate during critical peak days if they lowered their water usage. Results showed that participants reduced consumption in a range between 18% and 33% [Faruqui and Sergici, 2011]. Further experiments carried out in Michigan showed that, under the CCP tariff customers reduced their critical peak period usage by 15.2 %, while under the PTR tariffs consumption levels were reduced by 15.9 % [Faruqui et al., 2013]. [Fisher, 2008] also collected evidence from applying smart metering to reduce energy consumption, within 26 projects in ten different countries: three in USA, two in Japan, and twenty-one in Northern and Western European countries. Results showed an average 10% drop in peak demand. Finally the City of Anaheim Public Utilities conducted a dynamic pricing experiment in 2005 [Wolak, 2006] with 123 customers. The experiment did not provide a critical peak pricing rate, but rather a rebate scheme for each kWh reduction in consumption during peak hours. Results showed that customers used 12% less electricity on average during peak hours.

Less evidence comes from applying smart metering enabled dynamic tariffs within the water sector. Studies from the energy sector need to be interpreted with caution, however there is also some evidence that dynamic pricing could also reduce peak water demand level. [Cole et al., 2012] developed and modelled the impact of time-of-use tariffs which imposed an hourly inclining block penalty targeting outdoor consumption. [Brooks, 2006] showed that managing peak demand helps reducing the overall level of consumption and capping the cost of infrastructure. The Wide Bay Water Corporation in Australia is developing a TOU tariff and found out that under certain peak scenarios $230,000 of a $7m investment programme would be saved from reduced capital costs and infrastructure sizing [Turner et al., 2010, Boyle et al., 2013].

In general, time of use and critical period tariffs could impose significant network challenges in the water sector (such as reservoir balancing and pressure management) and therefore it is important to fully understand these challenges and how their costs compare with the potential benefits. The benefits of time-of-use tariffs are not definitive [Walker, 2009], with the possibility that water users are unresponsive to price differences. Present literature on demand response during different times of day is scarce, which rise the need to make this information available through trial implementations [RPS, 2013].

Improving customers experience

Smart tariffs and dynamic tariffs can also help improve customers' experience and engagement. [Boyle et al., 2013] analysed a number of trials on water smart metering. Amongst these 19 out of 49 smart metering installations has 'feedback and customer service' as an outcome, and were demonstrated to improved customers engagement. [Beal and Flynn, 2015] found that a large Australian water companies that implemented smart metering technology generated social benefits of customer satisfaction, community acceptance, improved customers engagement and complaint handling.

Improved investment planning and water resource management decisions

Increased data from smart meters, as well as being able to influence demand through smart tariffs, can also lead to improved investment planning and water resource management decisions. When designing water distribution networks, water utilities use a number of assumptions on how bulk water consumption is redistributed at customer levels and peaking factors. Short-term forecasts are useful in the daily management and network operations, while long-term forecasts are suited for future planning and design [Carragher et al., 2012, Parker and Wilby, 2013]. Traditional methods of developing such profiles and peaking factors, are often based on assumptions on water demand levels that do not necessarily reflect actual consumption trends [Gurung et al., 2014]. This mean that infrastructure expansion plans may be unnecessarily overdesigned. Smart meters allow generating evidence-based water demand curves that can be used to estimate future infrastructure needs. Knowing diurnal patterns and peak demands as well as times of peaks provide useful information on system flow rates, and can be used to calibrate network distribution models and for integrated urban water planning [Cole and Stewart, 2012, Carragher et al., 2012].

While the benefits of accurate network modelling are clear, there are few examples in the literature demonstrating how smart meters can be used for this purpose. Australian water companies that applied smart metering programmes could justify delays in new infrastructure investment decisions and upgrades [Beal and Flynn, 2015]. [Gurung et al., 2014] used high resolution water consumption data from households fitted with smart water meters in South East Queensland and Hervey Bay regions in Australia. Household hourly demand patters revealed from smart meters were used to derive average daily (AD), peak daily (PD) and mean daily maximum month (MDMM) demand curves. Results showed water demand patterns with mornings and evening curves occurring earlier and lower main peaks (by 12% for AD, 20% for OD and 33% for MDMM) than those used by the regions' water utility for infrastructure planning. Smart meters enabled end-use analysis of water consumption, which directly influence water utilities' demand management and investment programmes [Proença and Ghisi, 2010]. Disaggregating water consumption allow determining how frequently and where residents use water in their homes [Beal et al., 2013, Willis et al., 2011] and provide a greater understanding of various end uses, including outdoor, and their likelihood at various times of the day, by allowing a more proactive approach to infrastructure planning.

2.2.2 Modelling dynamic (i.e. time varying) pricing schemes

Traditional water tariffs focus on managing demand through price-mark-up, such the increasing block rates, and rebate schemes to encourage efficient use of water resources [Martin and Kulakowski, 1991, Hewitt and Hanemann, 1995b, Nieswiadomy and Cobb, 1993]. This means that the rate structure does not change with the level of water supply, but is only used to control demand regardless of the level of available water supply. These tariff schemes, where the price paid by the customer only increases as consumption rises, may not be effective in dealing with problems of supply variability. [Brill et al., 1997] argue that using water pricing schemes that are based on average costs only, can lead to economic inefficiency, which increases as the level of water availability declines. They also compared block pricing with water marketing schemes and showed that that markets can lead to more efficient water usage; also tired pricing (i.e. block rates) does not necessarily lead to an efficient outcome. [Brown and McGuire, 1967] examined optimal pricing policies in the Kern County Water District and found that efficient 'allocation' of water prices does not necessarily meet the revenue needs of the water district and suggested that the pricing policy should address both revenue and allocation issues.

This report states the importance of designing a pricing structure that takes account of the level of water scarcity in the analysed water resource system at a specific point in time (dynamic tariff). Water price should reflect the scarcity value of water during drought periods, be sensitive to both 'real-time' variations in water supply and revenue requirements, and efficiently allocate scarce resources amongst different sectors (i.e. industry, public water supply, environment, and agriculture). The following sections fit in this context, by introducing past modelling effort, available from the literature, to determine optimal dynamic (i.e. time varying) pricing schemes that reflect water scarcity (through water markets or short-term marginal costs) and the economic value of water in various uses (e.g. industry, public water supply, environment, and agriculture).

Optimal dynamic pricing and resource allocation through water markets

Water markets (i.e., allowing for voluntary and mutually beneficial trades) can result in scarce water resources moving to its highest-valued uses, maximizing the overall benefits to society as a result. Trading helps equalize the marginal prices faced by various water users, and therefore helps providing information about the value of water in alternative uses and creating compatible incentives [Chong and Sunding, 2006]. The potential gains from water trading and market-based allocation of resources society have attracted the attention of economists for many decades [Vaux and Howitt, 1984, Hartman and Seastone, 1970, Garrido, 2007, Bennett, 2005]. Many studies have demonstrated potential and realized net benefits from trading, in diverse areas such as Texas [Chang and Griffin, 1992], southern Italy and Spain [Pujol et al., 2006], Chile [Hearne and Easter, 1997], Morocco [Diao and Roe, 2003], and Australia [Bjornlund and McKay, 2002, Wheeler et al., 2014] and UK [Erfani et al., 2014].

However, given the potential gains from trade, intersectoral water markets have been slow to develop [Easter et al., 1998, Olmstead, 2010]. Griffin [Griffin, 2006] wrote that in previous studies that aimed at modelling water markets, *'too much is omitted to associate results with potential market results. The behaviours of individual agents are not represented, and the frictional transaction costs of market activity are neglected too'.* Recent studies however [Cheng et al., 2009, Erfani et al., 2013] allow accounting for the relationships between water agents (i.e. market water users or other institutional actors involved) such as sellers and buyers, and track transactions in water resource networks. Putting water markets into practice introduces real-world complications of transaction costs and third-party externalities [Chong and Sunding, 2006]. Transaction costs for water marketing can be quite high, often including: 'the costs of physical infrastructure necessary for transporting water from sellers to buyers, search costs (i.e., identifying willing buyers and sellers), and the legal costs of creating and enforcing contracts and obtaining regulatory permission' [Olmstead, 2010]. Carey et al. [Carey et al., 2002] showed that the gains from trade decrease with transaction costs, especially for smaller networks of farms. Furthermore, for water markets to produce efficient allocation of resources, water rights need to be well defined, and both positive and negative externalities need to be accounted for [Freebairn, 2005]. For example, externalities to non-renewable groundwater abstractions should be considered [Provencher and Burt, 1993], and their consideration become essential when estimating water marketing in regions where groundwater is an important resource [Hanak, 2005]. Return flows present another important externality. Olmstead [Olmstead, 2010] provides some examples of return flow such as: when the irrigation water is not lost to evapotranspiration but rather recharges aquifers levels or surface water flows, or when water transferred to coastal cities is then returned to the ocean through offshore wastewater outfall systems. Impacts on the users of return flows are generally neglected and this raises doubts on the economic efficacy of trade between individual water users and the capacity of water market studies to yield efficient allocations [Vaux and Howitt, 1984]. Therefore, both externalities and return flows are, therefore, an important consideration in water trading. Griffin and Hsu [Griffin and Hsu, 1993] declare that water market outcomes can be Pareto optimal only when '*transferable diversion and consumption rights are established, return flow coefficients are established to identify the location of each diverter's return, and institutional mechanisms are established to create a market presence for instream flow values*'.

Dynamic pricing via short-term and long-term marginal costs

In this section we discuss the issue of efficient water pricing in the absence of markets. Given the difficulites of estimating the value of water through water market studies,in most cases, water is not allocated in a competitive market, and the value of water is referred to as 'marginal value' rather than price [American Water Works Association, 2012]. For water demand, the 'marginal value' value of water can be defined as a monetary value generated by a productive output from using an additional unit of resource (e.g. for agriculture or industry), or the maximum amount the consumer is willing to pay to obtain this unit (e.g. for public water supply), [Mohayidin et al., 2009]. If correctly defined, marginal cost pricing of water services has the potential to assure the optimal allocation of scarce resources [Hanke, 1981, Hanke and Davis, 1973, Renzetti, 1999].

Marginal pricing has often been used in the literature as a mean to ensure efficient allocation of water resources, and has also been widely adopted by Governments, Water Authorities and companies around the world [Bank, 1996, McNeill and Tate, 1991]. In some cases the water price is set using 'peak-load' pricing or long-run marginal costs (LMCs) in order to prodive a guide to infrastructure design [Hanke, 1981, Mann and Schlenger, 1982, Mann, 1987, Chambouleyron, 2004]. LRMCs reflects the full economic cost of water supply, i.e. the cost of treatment and distribution, a portion of the capital costs of current (e.g. reservoirs and treatment systems) and future infrastructure needs, as well as the opportunity cost of both the use and non-use value of water for other potential purposes [Olmstead, 2010].

Some authors, instead, focused upon the determination of 'real-time' pricing, based on short term marginal costs (SRMCs) for producing and transporting the utility service. The reasoning behind adopting daily and hourly price charges is that that utility costs change over time due to demand fluctuations, and various combination of resources with different operating costs can be used to meet these changing demand levels [Russell and Boo-Shig, 1996]. Under spot-market, prices can be matched temporally and spatially to the marginal cost experienced by the utility, rather than based on historical or anticipated cost patterns [American Water Works Association, 2012]. Past studies on 'real-time' water pricing based on short-run marginal costs (SRMCs) can be found in Zarnikau [Zarnikau, 1994] which used 'spot market pricing' to design water rates and provide some guidance in defining strategies to ration water resources during drought and scarcity. The short-run marginal cost of water was determined through the dual-solution of a constrained optimisation model that maximises the utility's welfare and customers' surplus and subject to both water balance and capacity constraints on pipeline, storage and treatment facilities. The level of demand chosen for each customer was expressed as a function of exogenous economic and weather related factors and of the price of water. The optimal spot market price of water for any customer *I* at a sesigned time *t* is sum of the marginal operating costs associated to serving the customer and the shadow price variables associated to any water system constraint related to customer *i*. Such cost was then adjusted to take account of the level of water losses within the analysed supply system. Further work can be found in Schuck and Green [Schuck and Green, 2002] who investigated the effect of water scarcity on irrigation water prices using a dynamic resource constraint, within a conjunctive-use irrigation district (i.e. where surface water supplies are managed jointly with groundwater resources). Specifically, a supply-based water pricing model was developed, where water was allocated based on the price that was allowed to fluctuate with the level of imported water supply. The model was applied to Kern County's Arvin–Edison Water Storage District in California's San Joaquin Valley, which is currently adopting a supply-based water rate structure. The impact of implementing a supply-based water pricing policy was examined together with the effects on acreage and energy use. Schuck and Green [Schuck and Green, 2002] express the price as the sum of three terms, these representing the inverse-elasticity rule, the level of water scarcity and the marginal cost of providing water for irrigation purposes. Results showed that surface water price increases when imported water is scarce, aquifer levels are lower, and groundwater is less substitutable for surface water. Simulation results also showed that benefit of supply-based water pricing extends not only encourage efficient allocation of water but also allow to conserves energy: decreased production during drought leads to less pumping and recharging, generating reductions in energy use.

Both LRMCs and SRMCs may lead to urban water prices that lie well below efficient prices with significant economic costs [Olmstead, 2010]. Since LRMC reflects the cost of future supply acquisition, this may be greater than short-run average cost [Hanemann, 1997]. This means that pricing all units of water at LRMC may cause utility revenues to exceed current expenses, sometimes by a wide margin [Moncur and Pollock, 1988]. At the same way, there is little assurance that marginal cost pricing schemes will yield revenues to the utility exactly equal to the utility's revenue requirement [Zarnikau, 1994], i.e. the utility may collect less than its revenue requirement if its average costs exceed its marginal costs (a situation common in capital intensive industries with sufficient capacity, [Ofwat, 1997]. A way to address this issue would be to rebate net revenues from a uniform volumetric price. A uniform volumetric rate with a rebate has advantages over IBPs which tend to push poor households into the upper tiers of an increasing block tariff [Boland and Whittington, 2000], as also discussed in section 2.1. However, water utilities often adopt increasing block rates, and charge a price that approaches LRMC while meeting rate-of-return constraints through the manipulation of the blocks of consumption [Olmstead, 2010]. Zarnikau [Zarnikau, 1994] lists a variety of revenue reconciliation measures that could be used to ensure prices match the utility's revenue requirements. These include: 1. adding (or subtracting) a fixed charge to customers' bill; 2. multiplying the marginal costs based prices by a fixed factor; 3. Adjust marginal prices in inverse proportion to the customer's price elasticity of demand (Ramsey pricing). Each one of the above reconciliation techniques result in some loss of economic efficiency [Zarnikau, 1994].

Dynamic pricing that reflect scarcity and take account of the inter-sectorial allocation of scarce resources

In presence of droughts, the typical non-price approach often adopted by water utilities is informational campaigns and, if the drought becomes severe, usage restrictions are enforced [Gonzalez, 2011]. However, the impact of informational campaigns can be unpredictable, while usage restrictions may be subject to non-compliance; for example, [Dixon et al., 1996] found that over half customers violated imposed restrictions during a severe drought in South California. Raising prices rather than implementing non-price policies, can decrease the economic cost of achieving water usage reductions [Collinge, 1994, Krause et al., 2003a, Tsuda et al., 2014]. Dynamic pricing schemes that reflect scarcity (i.e. where unit rates are changed in presence of adverse supply and demand conditions, such as scarce water supply linked to dry seasons or drought) can be adopted to give clear signals to customers of scarce availability of resources related to seasons or drought occurrence. Prices must also accurately reflect the economic value of water in various uses, otherwise the allocation of scarce water across sectors may likely be inefficient [Olmstead, 2010]. In the case of water markets, marginal values are different across various types of use and locations of abstractors [Cai, 2008]. This is due to institutional and hydrologic constraints on water trading [Colby et al., 1993, Cai, 2008] such as the transaction costs and system market constraining rules.

Prior efforts on designing optimal dynamic scarcity pricing for water are described by Saglam [Saglam, 2013] who investigated the effect of water scarcity on pricing for different water user groups. The model identifies dynamic prices that targets inter-sectorial efficient distribution of water resources, by maximising the net social welfare of the economy subject to resource and revenue constraints, while balancing the utility's budget through a rebate scheme. The optimal prices reflect the effect of both the shadow price of water, which increases with the level of water scarcity, and the Ramsey pricing rules, which takes into account differences in demand elasticity across users' groups. Results showed that when water supply is scarce and there is no enough water for the considered user groups (residential water users and irrigation), the government increases the price for the relatively more elastic demand. Contrarily, when resources are abundant, the resource constraint dictates prices, and higher prices are 'allocated' to the less elastic demand. Saglam [Saglam, 2015] applied a stochastic dynamic programming model to derive optimal pricing policies for two river basins in southern Turkey. Simulations were carried out to compare the effect of the current and optimal pricing policies on the frequency and severity of shortages. Results showed that, if prices are only set based on the average-cost pricing rules (i.e. to recover the average cost of production and maintenance and water transfer costs), shortages would occur every 8 years. Contrarily, if prices are set to optimality, shortages are considerably reduced and could be non-existent over the next century. As in [Schuck and Green, 2002; Saglam, 2013; Saglam, 2015] express the optimal price as the sum of three terms. Specifically, the first term represents the effect of the revenue constraint, also known as the inverse-elasticity rule, which implies that the less elastic the water demand the higher is its price. The second term reflects the degree of water scarcity (the lower the water supply, the higher the shadow price). Finally, the third term is the marginal cost of production. The novelty of Saglam's work [Saglam, 2013; Saglam, 2015] consists of incorporating both the resource and revenue constraints to distinguish the effects of scarcity and revenue recovery on the prices in a dynamic setup. Previous work from [Brock and Dechert, 1985] implemented a dynamic problem that maximizes the discounted sum of profits subject to a dynamic revenue constraint only. Applications of this approach to water markets could also be found in [Garcia and Reynaud 2004; Diakite et al., 2009; Griffin, 2001] for a single user group in a static environment, and [Nauges and Thomas, 2003], which used a dynamic revenue constraint. It is worth noticing, however, that [Saglam, 2013; Saglam, 2015] does not directly model the water resource system water shortages, but only considers a model that sets prices that ensure, through a water supply function, that forecast demand does not exceed supply.

Finally, [Pulido-Velazquez et al., 2013] designed water dynamic pricing policies that incorporate the marginal resource opportunity cost of water as an indicator of the economic impact of water scarcity. It uses hydro-economic model to ensure a realistic representation of both the spatial and temporal variability of surface and groundwater resources, while incorporating the value of water for the different alternative uses in the basin. The approach is based on the assessment of the basin-wide marginal resource opportunity cost of water (MROC) as an indicator of the economic impact of water scarcity. Two methods were used: simulation and optimization modelling. By defining the objective function as the total net benefit from water allocation, the optimization approach returns the economically optimal water allocation and the marginal resource opportunity cost of water through the shadow prices variables. The simulation approach, instead, assumes that the system is managed according to a set of operating rules and constraints that represents the current operational status of the system. The method was applied to a simplified hypothetical system composed by a reservoir and two demands nodes competing for a scarce resource, with one of the two demand nodes having the highest priority of supply. The average MROC values were computed for different storage intervals and then used to derive the step-pricing curve (i.e. storage versus the marginal price of water). Different pricing policies were also tested, which depend not only on dynamic storage levels but also on previous inflow levels. Pulido-Velazquez [Pulido-Velazquez et al., 2008, Ward and Pulido-Velazquez, 2009, Riegels et al., 2013] uses integrated hydro-economic models to assess opportunity costs of water use amongst the several sectors. Hydro-economic models [Harou et al., 2009] allow reproducing the physical behaviour of the system, i.e. interaction of surface and groundwater resources as well as their spatial and temporal variability, and incorporating the value of water for different users (i.e. urban, agricultural and industrial uses).

3. Proposed dynamic pricing schemes

This is the pivotal section in this deliverable, which goes beyond the existing pricing schemes presented in Section 2 to present innovative dynamic pricing schemes. The implementation of dynamic pricing schemes is first justified (Section 3.1), then economic elements that are important for their definition are introduced (Section 3.2). Following that, the proposed dynamic pricing schemes are introduced: first time-of-day tariffs (Section 3.3) followed by scarcity tariffs (Section 3.4) and combined tariffs (Section 3.5). Finally, potential advantages of these pricing strategies are discussed further in Section 3.6, and Section 3.7 provides concluding remarks.

3.1 Why define new dynamic pricing schemes?

Smart metering allows a two-way information exchange between utilities and consumers. On one hand, smart metering can measure consumption over short periods thus enabling 'dynamic' (i.e., time-varying) tariffs, which could take account peak hour consumption over the day as well as an indicator of system-wide water scarcity.

On the other hand, a well-designed rate structure could give customers a price signal that would reflect that actual societal (economic) cost of their consumption. To maximize the efficacy of pricing as a water conservation measure, timing is important as the societal cost of using water can vary daily (e.g. with energy prices) or over short extended periods (dry seasons, droughts or other supply disruption events). Ideally price signals could be communicated to customers in a timely manner to enable their impact on consumer behaviour. If the billing cycles are monthly, customers' bill lags actual consumption by a month. This would not allow customers to perceive 'real-time' peak from off-peak daily consumption hours, or scarcity events caused by low availability of water resources. With traditional water pricing, customer's ability to quickly respond to the price signals is limited because the pricing signal arrives after the fact.

3.2 Economic elements

3.2.1 Revenue neutrality

The implementation of new water tariffs directly affects the financial flows between water utilities and their customers. Tariffs should sustain utilities' financial flexibility in planning for an uncertain future, yet that should be balanced with the social imperative of protecting customers. Therefore, tariff design should also comprise a revenue target, which the rest of this work assumes to be revenue neutrality, in the sense that neither the utility nor users – taken cumulatively – lose financially from tariff implementation. For instance in the privatised UK water sector, the regulator (Ofwat) imposes a revenue neutrality condition: tariffs must recover the operational and capita costs but not go beyond.

With traditional metering, water bills for residential consumers are in general the sum of a fixed charge and a volumetric fare directly proportional to the quantity of water used. Therefore, water utility revenue R_0 from residential water consumption is expressed as follows:

$$R_0 = F + p_0 D(p_0)$$

where *F* is the sum of its costumers' fixed charges, p_0 is the volumetric rate at which water is charged without dynamic pricing, and $D(p_0)$ is total water demand. Dynamic pricing replaces the single price p_0 by differentiated prices $(p_0, p_1, \ldots, p_n)$. Revenue-neutral pricing then imposes the following condition:

$$p_0 D(p_0) = \sum_{k=0}^{n} p_k D_k(p_k)$$

3.2.2 Price elasticity of demand

The price elasticity of demand is a quotient which compares the relative proportions by which demand varies when price varies. It is generally negative, since demand commonly decreases when prices increase:

$$E(p) = \frac{dD/_D}{dp/_p}$$

The demand change that is the consequence of a price change is obtained by integration from an initial price p_0 to new price p':

$$\frac{D(p')}{D(p_0)} = \exp\left(\int_{p_0}^{p'} E(p)\frac{dp}{p}\right)$$

Residential water demand is price inelastic, i.e., the relative change in water consumption is low compared with the relative change in price. This is a common observation in the residential water pricing literature [Espey et al., 1997; Dalhuisen et al., 2003]. Demand reduction in response to a price increase is dependent on the time elapsed since the tariff change, and often increases as time passes [Dalhuisen et al., 2000; Arbués et al., 2004]. Yet, time dependence is kept implicit in the above equations, because tariff changes are expected to be most effective when included in comprehensive strategies that manage demand through a combination of customer engagement, awareness campaigns, detailed personalized feedback on consumptive behavior, etc, but impacts of such demand management strategies on price elasticity have yet to be investigated.

3.2.3 Deriving the demand curve

Demand curves relate the price with the consumption level [Harou2009]. They are used in this deliverable to describe the price response at the macro level (the utility level, compared with the micro level of the user) in a theoretical sense. This section describes how to obtain a demand curve from price elasticity estimates, which is our motivation for the meta-analysis of Section 4.

For this study, the ‘point expansion’ method is used for extrapolation from a single point on the demand curve. The ‘point expansion, is one of the simplest methods that can be used to determine the demand function, and its application in the water resource contexts dates back to James and Lee [James and Lee, 1971]. This technique is easy to apply since it can be used to obtain an entire demand function estimate from a single value of quantity and price. To use this method, a point on the demand function must be known and the price elasticity of demand (or its slope) must be given or assumed. The first of these inputs is commonly available. For example, we might observe that households in a specific town are paying 3 pence/m3 for tap water, and that the average household is choosing to consume 3000 litres. If there are 5,000 households, then the ordered pair (15 million litres, 3 pence/m3) is a point on the city's demand curve for tap water. Price elasticity is usually exogenously obtained, and for the scope of this report, its estimate was obtained through collection of real-world data and via an econometric model (see section 3 of this report).

Since the elasticity is a single parameter, and the same is true for the contribution of the single demand point, the only viable options for the defining the demand function are two-parameter functions, such as the linear and constant elasticity forms. These can be expressed as q=mp+b and q=kpe, where ‘q’ is the demand, ‘p’ the marginal price, ‘e’ the price elasticity, while ‘k’, ‘m’ and ‘b’ are parameters that define the linear and constant elasticity functions.

The disadvantage of this method is potential oversimplification of the demand curve. The form of the function is either a straight line or a convex curve. Water demand may not exhibits linearity or constant elasticity across the full range of q and p. That is, these two functional forms may not correspond to actual human behaviour in situations far from the point of expansion. The issue arising from this is that a step function may be more representative of actual value-quantity relationship for specific water users [Morris et al., 2003].With these assumptions being clear, the point expansion method can still be a useful technique for estimating demand. Furthermore, this method can be potentially used for all sectors of water demand (e.g., residential, commercial, recreation, hydropower, etc.), [Griffin, 2001].

3.3 Time-of-day tariffs

3.3.1 Demand shifting

Demand shifting divides a daily time frame – or a weekly one if demand is being shifted from weekdays to weekends – into periods of differentiated prices in a way that residential users may be able to reschedule at least some of their water uses. In theory, there can be an arbitrary number of different prices, but then, many users may not be able to come up with efficient scheduling strategies, which would thwart the objective of shifting demand. Besides, simpler tariffs are likely to be tested and implemented before more complex ones can be imagined. Therefore, this section only considers two periods, with the objective of shifting demand from period 1 to period 2 (Figure 1).

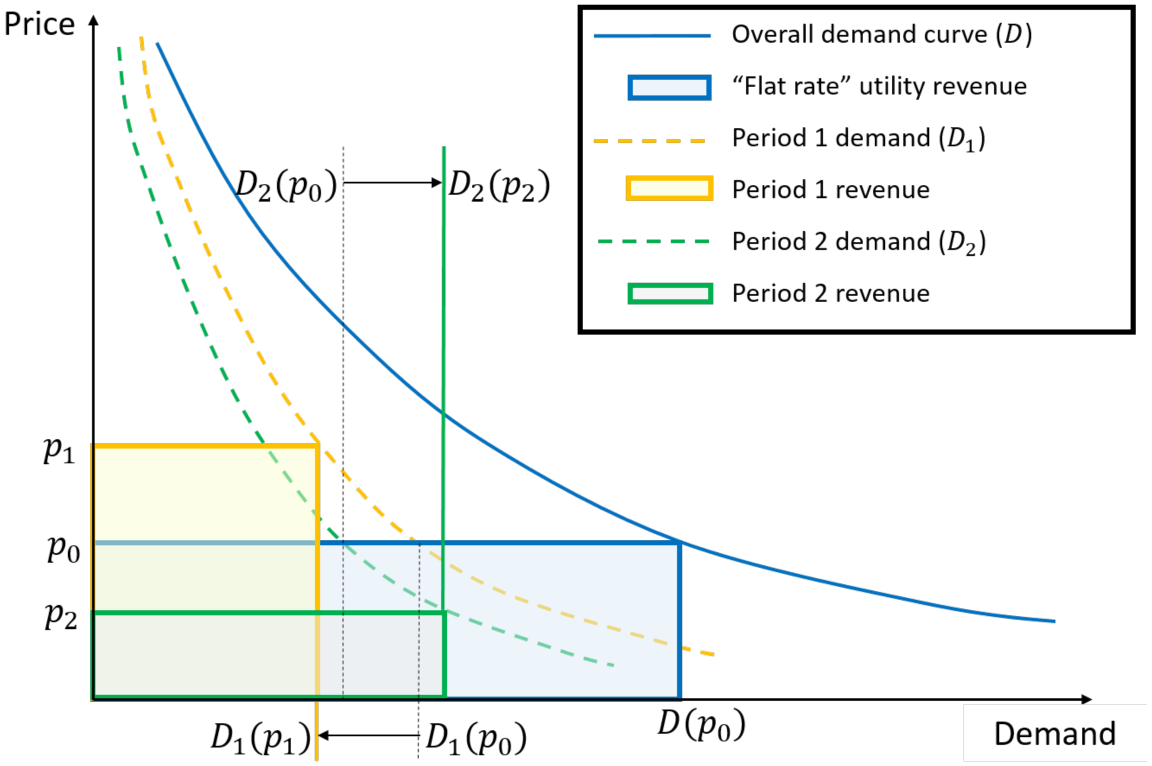


Figure 1. Residential water demand curve disaggregated between two periods, and demand shifting tariff. Rectangles represent utility revenue as the product of demand and volumetric price.

Revenue-neutral pricing means that the sum of revenues from both periods, represented by the combined areas of the yellow and green rectangles on the figure, is equal to the area of the blue rectangle, which represents revenue without dynamic pricing.

3.3.2 Peak and off-peak rates

This charging scheme varies the unit volumetric price according to time of day. The daily change in price is designed to shift water consumption away from peak periods and redistribute it over the remaining hours of the day. Unit volumetric prices would be higher during peak hours than those currently charged but lower over the remaining hours of the day. The variation of the volumetric price over peak and off-peak hours would be adjusted so that its value over the day equals the utility's current rate to ensure revenue neutrality [Ratna et al., 2006]. Water utilities are natural monopolies [American Water Works Association, 2012]. This means that water price cannot be determined by competitive forces. In all situations, the supplier either sets its own prices or establishes water price within a regulated framework. Typically public utilities are the least regulated, since they are assumed to be benevolent, while privately owned utilities are more heavily regulated to control their market monopoly power; left to their own discretion, they can promote prices that exceed efficient ones to increase their own profitability [Griffin, 2001]. In other situations utilities are regulated irrespectively of ownership. In this report we assume that water prices are set to ensure revenue sufficiency and that the same principle will followed when applying the time-of-day pricing policy, i.e., dynamic pricing scheme must generate the same level of revenue as current rates. We assume utilities are either owned by the government or regulated by a Water Authority and that profits are either to zero or some allowed rate of return This condition can be adjusted based on the specific regulatory context. Volumetric rates could be uniform, increasing stepwise within pre-defined blocks of consumptions, or decreasing within block of usage.

The total time-of-use daily charge is the hourly sum, of the recorded level of consumption recorded via smart metering multiplied by dynamic volumetric price. Consumption patterns change from day to day and are generally expected to decrease when smart metering technology is in place and sufficient feedback information is provided to customers [Sønderlund et al., 2014]. In this report we suggest utilities could increase hourly volumetric price using price elasticity of demand estimates to attempt to reduce daily peak demands to target levels. In order to keep the charges equal to previous levels, the volumetric price during off-peak times would be reduced (also using price elasticity of demand estimates) to ensure revenue neutrality. Target levels of demand reduction could be set in various ways, ranging from arbitrary (e.g. 10% lower than current) but ideally in such a way as to maximise total net economic benefits perceived from water use at utility scale, or even at river basin scale. At utility scale economic benefits from water use would be trade-off with long-term discounted capacity expansion savings resulting from lowered peak water use. At basin scale, the same would apply, except reduction in municipal water use would also be set such that the intersectoral allocation (water supply, environment, energy cooling, industrial, irrigation) would be optimised.

Patterns of daily consumption can be estimated based on existing data and literature. A considerable amount of effort has been expended in the literature on water-demand forecasting. In the case of operational control, the interest is restricted to short to medium timescales (hourly, daily and monthly), [Alvisi et al., 2007]. There is a large number of papers detailing methodologies for hourly forecasts [Shvartser et al., 1993, Zhou et al., 2002] and daily or monthly timescales [Shabanov et al., 2015, Maidment et al., 1985, Miaou, 1990]. These papers refer to the recurring patterns and periodicities that exist in water-demand data, at different levels of temporal aggregation. Information from smart metering technology can be used to obtain more detailed information on patterns of daily water consumptions, and obtain more detailed water-demand forecasting.

Since time-of-day would be set in real-time or fixed hourly based on past consumption patterns, the revenue that a utility would accrue from applying such a tariff would only be known at the end of the day. It may happen therefore, depending on the shape of the demand curve that controls hourly price changes, that under the time-of-day tariff the revenue that the company would accrue could exceed the financial target. This situation would occur if the charge obtained from applying the time-of-day tariff were greater than current fixed charge. To eliminate these extra funds one solution is the excess revenue could be returned to customers in the form of lowered end of the month fixed meter charges. Equally, if the dynamic charge turned out to be lower than target costs, the monthly meter charges could be increased accordingly. However, if possible fixed charges are best left alone; ideally over and under-charging would compensate over the medium and long-term and small adjustments could be made annual if necessary.

Time-of-day tariffs could be pre-set of set in real time. With the first one, two different unit rates only are defined: one for peak hours the other one for off-peak consumption. When to apply peak rates and their amount could be estimated based on past maximum peak hourly consumption level and peak-periods. Price elasticity of demand would be used to determine the peak-price, given an estimate current and target demand. The off-peak volumetric price would be set in order to ensure revenue neutrality.

The second method would involve real-time dynamic pricing, where charges would vary by hour in response to real-time or previous hour measurements of actual consumption. Over peak hours, the volumetric price is increased over the utility's current rate using constantly updated price elasticity of demand estimates to try and reduce peak consumption to target rates. Depending on revenues perceived during peak hours, prices would be reduced over off-peak hours. Benefits would involve strong disincentives to consume water during peak hours, disadvantages would be consumers lack of predictability; also consumers would need to be able to consult real-time prices on their phones or home monitors, etc.

3.3.3 Reflecting financial savings within the dynamic tariff scheme

Decreasing consumption in the short-run decreases the operating expenditure such as pumping and treatment costs [Ofwat, 1997). In the long-term increasing consumption requires the provision of new water resources, treatment capacity and the reinforcement of water mains. Water companies usually operate with excess capacity in the short-run for a number of reasons. Seasonal and daily variation in demand means that capacity within the water system must be configured for peak demands [Gurung et al., 2014]. To protect against the risk of unexpectedly high consumption (e.g. during an exceptionally dry summer) a security margin (e.g. referred to in the UK as 'target headroom) is sometimes maintained between capacity and predicted demand, as it is done within the English water supply sector [UKWIR, 2002c]. Also, since it is in most cases cost effective to develop capacity in tranches rather than incrementally, given economies of scale of building for large infrastructure, capacity will tend to increase in steps with the water company having excess capacity in the period after new investment has been completed, while this excess capacity declines over time as demand increases further.

Reducing peak-hour supplies would allow deferring expansion of the conveyance and storage network which would enable lower water charges in the long-term (e.g. no increase in rates beyond inflation or lower than expected increases). Lower peak rates would also imply reduced energy consumption savings and reduced maintenance costs, and reduced leakage.

These savings would motivate the reduction in peak usage and would help set water charges. Specifically, future deferred costs would be first estimated by comparing the net present value (NPV) of a capacity expansion programmes that could be achieved based on the level of consumption recorded with and without the implementation smart metering and the time-of-day tariff. The estimated savings could then be detracted at the end of each month from the fixed charge or from the volumetric rates.

3.3.4 Accounting for discretionary and nondiscretionary use of water

Most residential water use may occur in low-value applications or is discretionary [Rathnayaka et al., 2015]. 'Non-discretionary' use is water consumed for essential purposes that leave the consumer very little discretion regarding timing or volume, such as personal consumption and hygiene. Residential water use in urban areas has traditionally included a significant discretionary outdoor component and various studies have been undertaken to measure and distinguish indoor and outdoor use [DeOreo and Mayer, 2012, Mansur and Olmstead, 2012] and take account of discretionary use when designing water pricing schemes [Ward and Pulido-Velazquez, 2009]. Water end use studies are useful to reveal components of peak demand [Beal and Stewart, 2014, Rathnayaka et al., 2015]. Data collected through smart metering could also be used for this scope [Gurung et al., 2014, Beal and Stewart, 2014].

The time-of-day tariff could be used to target customers which have high discretionary component of peak hour consumption (i.e. high outdoor consumption). Furthermore, outdoor use is considered the most price elastic component of domestic water demand [Cole et al., 2012]. This could be done in order to affect residential consumers who mostly contribute to peak hour demand, especially if discretionary use constitutes a significant proportion of peak hour demand.

3.4 Scarcity tariffs

Demand reduction may take place over any arbitrary period of time. Price must be raised from base price p_0 to demand reduction price p_r in order to achieve a relative change (reduction) X_r in the demand D, e.g., -5% or -10% (Figure 2). Since residential water demand is price inelastic, a higher price would mean a revenue gain for utilities, and therefore a financial loss to customers. One must observe that to ensure revenue neutrality while enforcing demand reduction, it is sufficient for the marginal value of residential water to be at p_r. Revenue neutrality can then be achieved by designing a scheme whereby utilities forsake the excess revenue (black rectangle). For instance, any form of IBR achieves this. IBRs can be designed with multiple objectives, sparking debate regarding matters such as equity among users (as detailed in Section 2). Therefore, there are alternatives to giving back the excess revenue directly through tariff design, as it can be used to promote social or environmental objectives instead – e.g., to implement so-called “social tariffs” designed at guaranteeing access to water to the most vulnerable segments of a population.

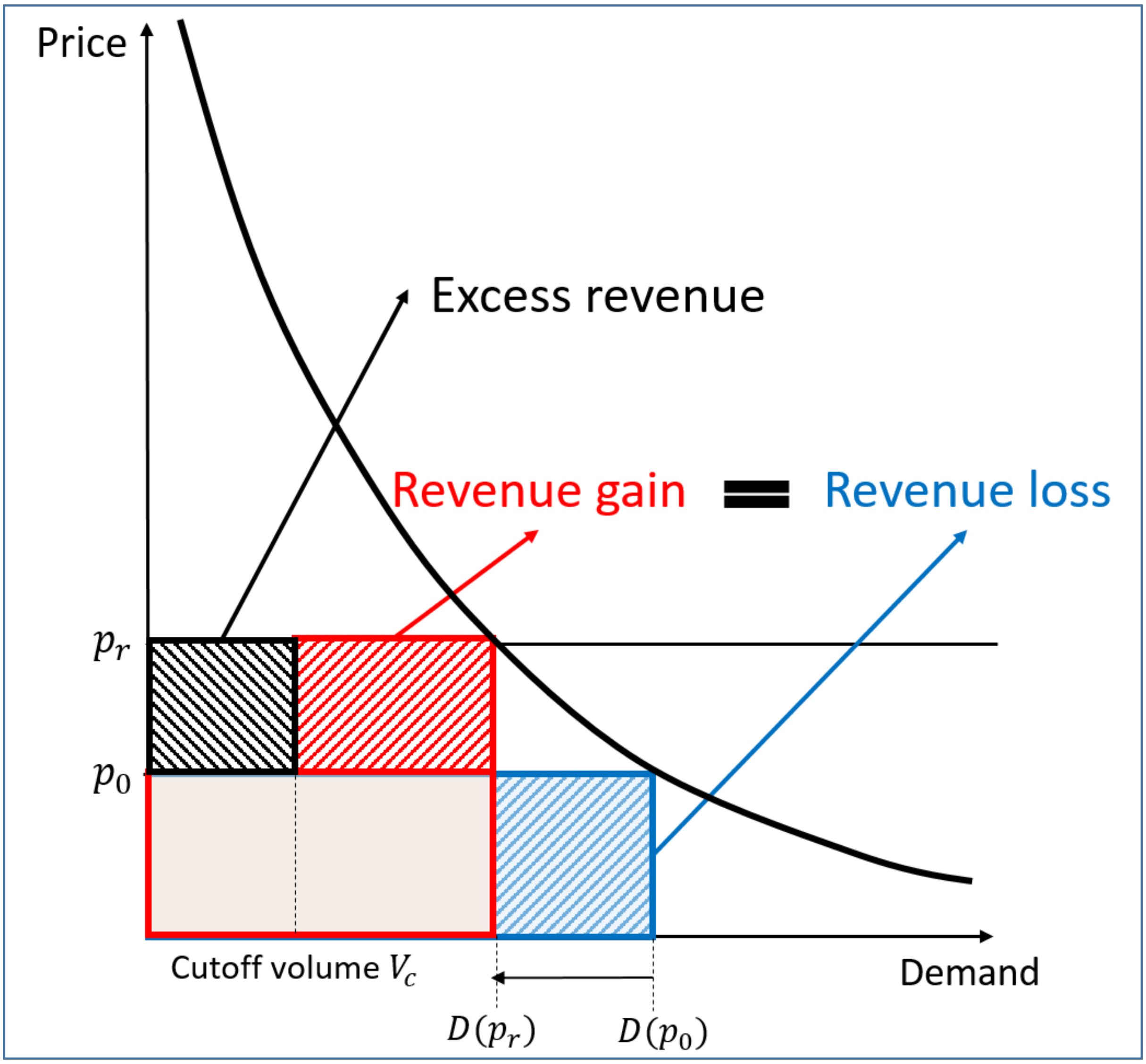


Figure 2. Residential water demand curve aggregated at the utility level, and demand reduction tariff raising volumetric price from p_0 to demand reduction price p_r. Rectangles represent utility revenue as the product of demand and volumetric price.

Scarcity pricing could use temporary demand reduction tariffs to address increased dry season consumption levels and signal to consumers about the increased value of water under conditions scarcity (due to needs from public water supply and/or other sectors). Under wet or normal conditions, rates would be below current rates whilst under dry conditions volumetric rates would increase.

Scarcity price increases could be set in different ways. Prices (volumetric rates) could be solved for with hydro-economic models such that maximum benefits are achieved by the system overall. As with time of day tariffs, scarcity costing could also be fully dynamic, with real-time prices set as a function of scarcity levels (e.g. daily, weekly, monthly, etc.).

For best results at regional scale, public water supply consumer prices would be set such that the overall benefits derived from water use by all sectors would be maximised. This involves trading the off the consumer surplus achieved by public water supply users with the scarcity costs of other sectors (environment, power cooling, irrigated agriculture). One such trade-off would maximise gains to the system overall. An alternative but equal formulation would minimize costs of supplying water. These costs would include both the utility's capital costs of investments, the fixed and variable operating costs, and the scarcity costs. The level of scarcity is difference between deliveries and maximum beneficial water supply [Harou et al., 2009]. Scarcity costs can be defined as the economic value that users would be willing to pay to increase deliveries and eliminate scarcity [Pulido-Velazquez et al., 2008]. These costs can be considered as opportunity costs and have been used in the literature as indicators of system performance [Jenkins et al., 2003], and can be obtained by integrating the area under the demand curves from the quantity demanded to the one actually supplied.

Results from this modelling would return the marginal costs of water at different times and locations of the analysed system [Pulido-Velazquez et al., 2013]. It has often been argued that if the price of water reflects the marginal cost, the optimal allocation could be reached by placing scarce resources to the highest value users [Griffin, 1990, Griffin, 2006, American Water Works Association, 2012]. The marginal cost of water could be revealed through water markets, but since these are usually absent or inefficient [Pulido-Velazquez et al., 2008], most estimates can be based and developing proper method to estimate the value of water for the different users and develop shadow prices reflecting the value of water. [Griffin, 2001] argues that an optimal pricing scheme should include not only the marginal capacity costs (when infrastructure capacity is binding), but also the marginal value of water at sources, the opportunity cost of the user over time, and the marginal capacity cost from limited infrastructure.

Pricing through marginal cost, however, may not necessarily yield to revenue sufficiency: the utility may collect less than its revenue requirement if the average cost exceeds the marginal cost, which is a common situation amongst capital cost-intensive industries with sufficient capacities [Zarnikau, 1994]. Especially in the short term, water utilities operate with surplus of water for the reasons explained above [Ofwat, 1997]. Furthermore, marginal costs do not allow taking account of congestion costs imposed on other customers (e.g. lower pressure and greater risk of interruptions). Congestion costs can be defined as the opportunity cost of a failure of supply. These costs may be greatest at peak times, however, even if supplying water off-peak times may appear to have a low marginal cost, it may have a high opportunity cost if, as a result, the water company cannot meet its summer peak. Therefore, since marginal costs cannot ensure necessarily revenue sufficiency, a variety of revenue reconciliation techniques have often been used in the past in order to re-balance price charged customers the with the revenue requirement. These techniques include: increased fixed charges, multiplication of fixed factors to marginal costs, or Ramsey pricing (Adjusting prices in inverse proportion to the customer's price elasticity of demand), [Zarnikau, 1994].

The scope of the work presented here is to design volumetric rates that increase dynamically, based on real-time supply availability, within the system. The pricing strategy would also need to allow the water company to break-even. In many countries, under drought conditions the first thing that gets sacrificed are environmental flows. These could have potentially high economic value so the water supply-environmental flow trade-off is of particular interest under scarcity. In countries where irrigated agriculture is present, it may make sense for farmers to sell water to cities, but in our case studies, this is not the case. The overall idea then would be to increase prices as environmental flow conditions deteriorate in a responsive way (e.g. weekly or daily, no obvious benefit for real time instantaneous price changes). This would signal to consumers that at that time their consumption is directly harming the environment, and it would likely also, by decreasing demand during peak demand periods, in the long-term, allow delaying some capacity expansion. If prices are set too low they won't affect consumers' behaviour and the environment's value won't be represented, if too high, economic benefits of water will be sacrificed without reason and there is likely to be stakeholder and customer dissatisfaction.

The approach for setting rate increases in response to scarcity is described next. Under conditions of scarcity where water supply is threatened, environmental flows are typically reduced so that PWS can continue as before. We recommend public water supply volumetric price increase during these times to reflect the economic value of foregone environmental flows. During periods of scarcity some environmental flows could still be sacrificed to public water supply, but at a new PWS price reflecting society's loss of ecosystem benefits.

Ecological scarcity costs would be determined from ecological demand curves (Figure 3) and aggregated basin wide as an environmental deficit which could be deducted from PWS abstraction (block on right of Figure 3). In lieu of rationing PWS, prices could be increased such that some or all environmental flows are restored (Figure 4). The likely reductions in PWS abstraction as a result of price increases could be estimated via price elasticity of demand estimates (initially from literature values and/or empirical estimates, then progressively from eventually past experience).

For systems where under scarcity, public water supply would take precedence over a range of other water using economic activities (e.g. irrigation, industrial abstractions), the same approach could be used.

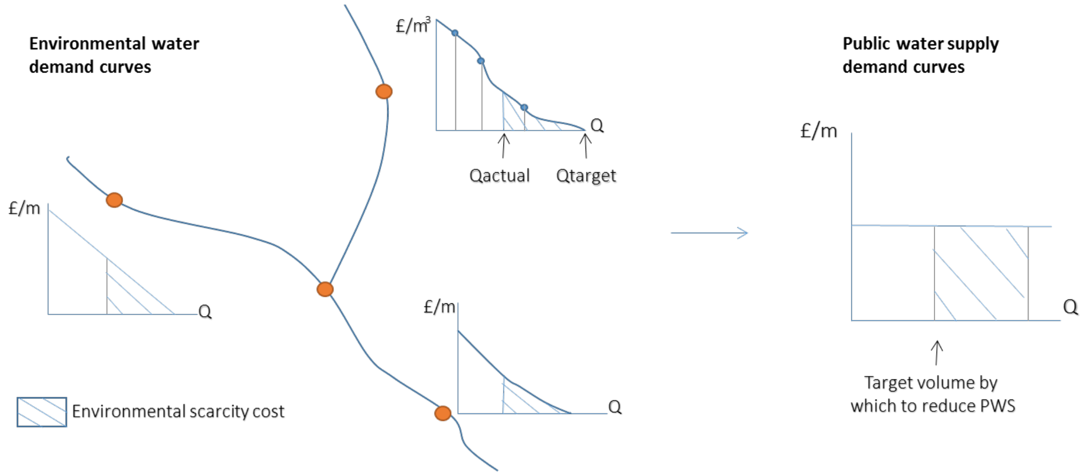


Figure 3: Each ecological economic benefit curve quantifies the economic demand for various levels of environmental flow, Q, in 3 stream reaches of a synthetic river basin. If there is a deficit in environmental flows, e.g. because of higher than normal river abstractions due to a water supply shortfall, the environmental opportunity cost perceived over a certain period of time is the aggregate of the environmental scarcity costs shown. The same approach could be used for other sector benefits (e.g. irrigation, industrial use). The total environmental water deficit coupled with an estimate of price elasticity of demand would allow estimating a new price that could restore environmental flows to some extent (ranging from Qactual to Qtarget in Fig 5).

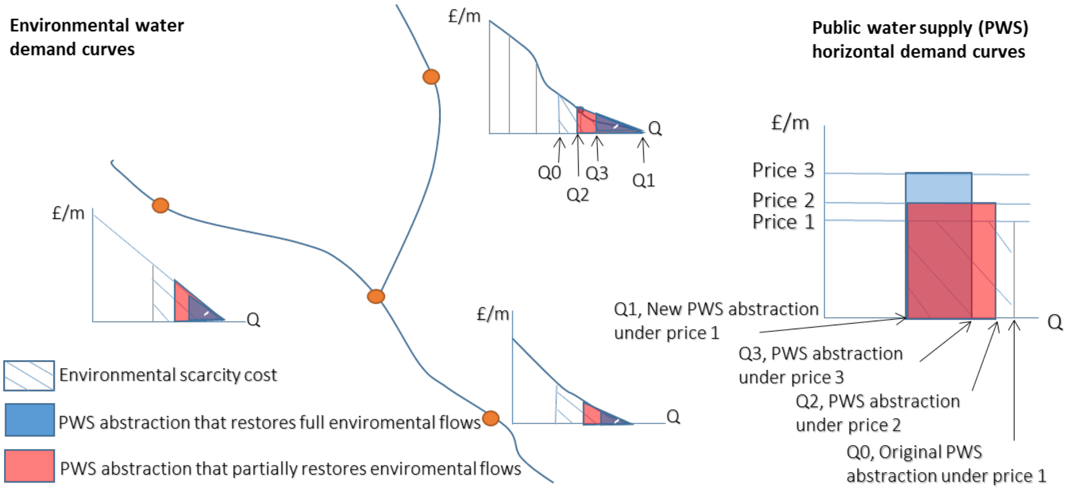


Figure 4: At current rates (Price 1) abstraction rates are at Q0 (PWS achieves target

because of sacrifice of environmental flows). To restore environmental flows to their target levels, Q1, PWS would have to be rationed to Q1. Intermediate options are available where scarcity is shared between the PWS and environmental water sectors; Price 2 would allow restoring some environmental flows and Price 3 would do so further.

Volumetric charges would be reduced during non-scarcity periods (e.g. in wet seasons following droughts) so that utilities remain revenue neutral with regard to scarcity charging. Revenues could alternatively be used for ecological water banks, or for other environmental purposes. Another alternative would be that the monthly or annual fixed charge of customers' bills could be adjusted to ensure revenue sufficiency and neutrality.

In many instances, the entire system is designed to meet peak demand-low supply scarcity conditions as have occurred in historical droughts. A benefit of scarcity charging would be to decrease peak seasonal or drought demands. This lowering of consumption would allow to lower or defer investments in expanding capacity for future peak summer demands. These estimated NPV savings could be used to help set a decreased winter volumetric water price, as explained in the next sections.

3.5 Combined 'time of day' and scarcity pricing

Time-of-day and scarcity pricing could be combined. Economic net present values (NPV) savings deriving from both decreased daily peak water consumptions and during longer seasonal peak periods or drought events, can be accounted for and reflected within prices. This would translate into higher NPV savings compared to those that could be achieved by applying the two tariff schemes separately. Savings would derive from both short-term lowered operating costs on energy and maintenance of the network (e.g. due to reduced leakages), as well as long-term deferred infrastructure investments to expand the capacity of the existing network.

Figure 5 below shows a schematic summarising the three proposed charging schemes and their potential impacts. The red horizontal line represents the utility's constant unit volumetric price, while the blue one is representative time-of-day (panel 'a'), seasonal (panel 'b') and combined daily and seasonal (panel 'c') tariffs. The area below the red line equals the one below the blue line, to ensure the overall level of charge is equivalent to the utility's current one. Lower daily and seasonal peak consumptions, after implementation of the proposed tariffs, are then used to further reduce prices (see dashed blue line in panels 'd', 'e', and 'f').

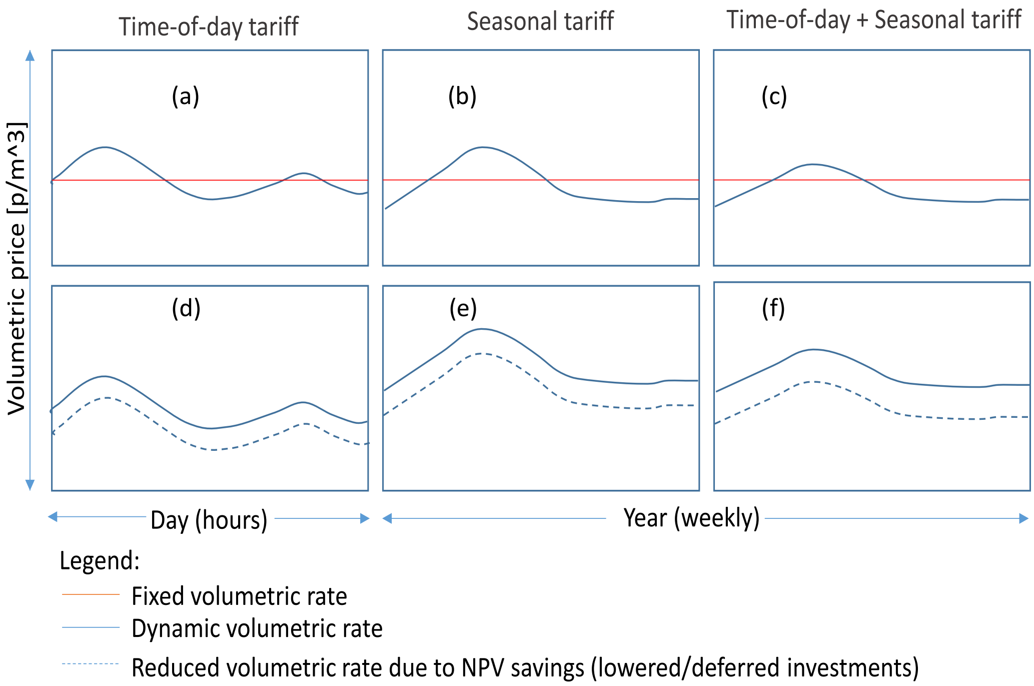


Figure 5: Schematic of the proposed dynamic tariff schemes (time-of-day, seasonal tariff and a combination of the two).

3.6 Applying dynamic tariffs to real water supply systems

In this section we explain how net present value (NPV) saving from application of dynamic tariff schemes can be estimated and reflected within the proposed tariffs.

3.6.1 The time-of-day-tariff

Under the time-of-day pricing scheme, the residential demand curve is used to derive the peak volumetric price set to reduce consumption to a target value, while the off-peak one is set to ensure revenue sufficiency and leave daily prices unchanged compared to the utility's current charges. Optimisation techniques could potentially be used to 'allocate' price amongst peak and off-peak hours.

For estimating the cost reductions resulting from time of day pricing, we would need an estimate of how the dynamic daily pricing impacts utility costs over the long-term. If we have a costed expansion plan for both current practices and consumption spread daily, we could take that difference in NPV and convert it to an overall lowering of prices (dotted line in Figure 5, panel d). Additionally, the saving resulting from lower leakage levels, less maintenance costs, and lower energy costs would also drive a drop in long-term NPV of system operation, which could be passed on to consumers. To arrive at these figures, it will be necessary to work with water companies' operations engineers who could help estimate these savings, or get guidance on how to derive simple order of magnitude numbers.

3.6.2 Scarcity pricing

For scarcity pricing, cost savings would be from deferred investment in supply expansion (as above). Here we can estimate the NPV savings as we can use existing capacity expansion models (such as the Economics of balancing supply and demand, 'EBSD' in the UK). EBSD is planning approach used by the water industry in England to generate socially efficient least economic cost water resources supply plans [UKWIR, 2002a, UKWIR, 2002b].

Within the EBSD framework, supply-demand planning relates to selecting what actions to apply and when to insure that water supply can meet demand over the planning horizon. Typically, the report includes recommendations for the determination of the supply and demand forecasts, and costs (financial, environmental and social). The planning process starts with the choice of the planning period typically 25 years. Then estimates of future demand and supply are considered over the planning period. Demand estimates are done on an annual basis, considering dry year scenarios (periods of low rainfall without demand restrictions), normal weather patterns [EA, 2012] and any other scenarios the company considers relevant to the supply-demand planning problem. Two levels of dry year demands are usually quantified: dry year annual average demand (DYAA) and the dry year critical period (DYCP) demand. The DYCP demand is included in the companies' capacity expansion planning problem only if it drives the need to implement new supply or demand management measures [EA, 2012] and is defined as the average demand over a 'peak demand period', typically a week. The normal year annual average (NYAA) demand represents the average demand over a year with normal weather patterns. Analysis of supply and demand over the planning period may identify supply-demand imbalances. Planners must then identify the widest possible range of available options to re-establish the supply-demand balance. Next costs of each proposed option are estimated. Financial, environmental and social costs must be considered. An algorithm now must be selected to choose the least financial, social and environmental cost solution. Ideally, such an algorithm will recommend an optimal schedule of option implementation dates. Mathematical programming (MP) is used which refers to a class of classical optimisation algorithms developed over the last 60 years. The 'programming' in MP refers to scheduling or selecting rather than to computer programming.

To derive the new dynamic pricing net present value (NPV), EBSD models could be used. We would decrease dry year annual average and critical period consumption rates (DYAA, and DYCP). With scarcity pricing, DYAA would likely reduce, and DYCP potentially would reduce substantially. These reductions in demand would be estimated by using estimates of consumption reduction due to price (using price elasticity of demand numbers).

3.7 Conclusions

Smart meter technology allows to record and store data on water consumption over short periods and will enable 'dynamic' tariffs. In this paper, we propose three dynamic (time varying) tariff schemes that account for both the utilities' expected financial costs for future network capacity expansion, the region's level of water scarcity, as well as peak and off-peak daily water consumption levels. Proposed pricing schemes include a time-of-day tariff, a seasonal tariff scheme and a combination of the two. Under the time-of-day tariff, two unit rates can be set, one for peak, the other for off-peak hours; alternatively, prices can vary dynamically based on real-time above peak consumption. Under seasonal tariff, scarcity prices are set in such a way to trade-off the regional benefits from allocating scarce water resources to multiple sectors (agriculture, urban water supply, industry and environment). In our example we focused on the public water supply – environmental water use trade-off, which is most relevant to the project's case-studies. Off-peak hourly and non-scarcity period prices would be set to maintain the utility's current revenues, i.e., ensure revenue neutrality. Under both tariff schemes, prices would be set using price elasticity of demand estimates (see section 3). Dynamic pricing could, in the short term, lead reduced energy and maintenance costs and lowered investments on pipe capacity expansion, and to deferred or lowered capital investments in the long term. The net present value economic savings are estimated through economic optimisation models and are used to inform decreased volumetric water price.

The separate or conjunctive implementation of both pricing schemes would likely lead to a decreased level of water consumption, although its socio-political feasibility would need to be studied before-hand and would require significant innovation (e.g. next section); also it would require considerable investments in utility billing and customer communication capabilities.

4. A tool for the experimental exploration of innovative pricing schemes

As described in the previous sections (sections 2 and 3), innovative pricing schemes such a dynamic pricing are of interest to water utilities but viewed as risky because of potential negative impacts on customer relations. There are various reasons behind this reluctance to pull the price lever to steer the consumers' behaviour.

During the first phase of the SmartH2O project we held interviews with representatives of the water utilities involved in the test cases, Thames Water Utility Limited in London, and the water utility of the municipality of Terre di Pedemonte, in the Swiss Canton of Ticino. These interviews have also been reported in Deliverable D2.1 (Use cases and early requirements). More recently, we have also discussed with representatives of EMIVASA, the public utility in charge of providing drinking water to the city of Valencia (Spain).

In all these discussions we have learned that pricing is a very sensitive subject for water utilities. This was not a surprise. During the preparation of the proposal of the SmartH2O project we had discussions with several water utilities, and in Italy, France and Germany the issue of water pricing seemed almost taboo. In the UK and in Switzerland the water utilities had a larger ability to use prices as a tool to drive demand, but to a limited extent.

In the UK, utilities face restrictions imposed by the regulatory body (OFWAT) and all tariff changes must have a neutral effect on the utility revenues. Customer complaints on unfair tariff schemes are taken very seriously.

Pricing has a great effect on customer satisfaction, especially if new tariffs threaten to result in higher bills. This is likely to happen for certain customer segments, as traditional pricing schemes don't take into account the actual water volume consumed, but are often estimated fixed rates based on approximate building and flat sizes.

Until a new pricing scheme can be introduced, many aspects need to be considered by utilities, from customer reaction to complex administrative processes and policies on local or even national level.

As anticipated, all these issues were expected, but these considerations also impose restrictions on the type of experiments that can be conducted in the real world with real customers on the impact of tariff schemes on their behaviour. For utilities to be able to experiment with more dynamic pricing schemes before introducing them officially to a large customer segment, test trials will be needed. Such experiments would enable utilities e.g. to explore the overall supply-demand impacts of new pricing schemes, gauge reactions their customers might have to them, and test their ability to communicate and motivate such new schemes and tariffs with customers.

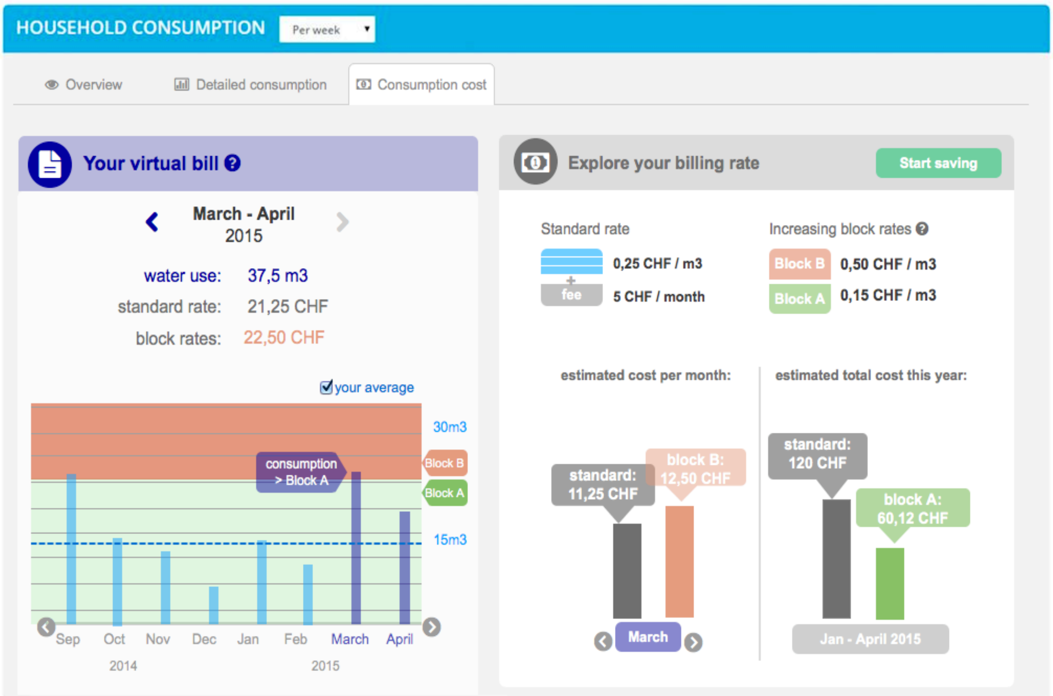
In order to overcome the limitations of real world experimentation with test tariffs and to provide a solution for water utilities to assess the expected impact of tariff changes, we have developed a specific solution, the SmartH2O pricing tool as a component of the SmartH2O platform.

4.1 The SmartH2O pricing tool

The SmartH2O customer portal will provide utilities with a tool which would allow their customers to experiment with a virtual bill (see Figure 6) and explore the potential impact of different pricing schemes, including their current tariff, before they are introduced in the real world. The tool will allow customers to simulate different tariff types based on their current consumption (e.g. block rates) in a visual widget (see Figure 6). They will be able to see virtual savings or additional cost compared to their current tariff and to simulate how much they would save on a monthly and yearly basis if they were to reduce their consumption (see Figure 7).

Actionable tips ("Learn how") on how to reduce water to save money are also provided.

Customers' understanding and perceptions of their monetary saving potential can provide insights to utilities, e.g. if people are supportive and understanding of the reasons for new tariffs and what their implications would be at household level. These simulations with customers would be a valuable complement to the more theoretical studies presented in Section 3. For their specific system utilities want to understand how much they would need to save financially to be motivated to save water. Thus, customers could understand the impact of new pricing schemes and their resulting charges on customers' current consumption (see also requirements in D2.2, use case 8.9 "Learning interactively about innovative pricing schemes"). With this pricing tool, users of the SmartH2O portal will be offered the opportunity to learn how changes in behaviour under dynamic tariffs could lower their bills.



Your virtual bill

March - April 2015

water use: 37,5 m3
standard rate: 21,25 CHF
block rates: 22,50 CHF

Explore your billing rate

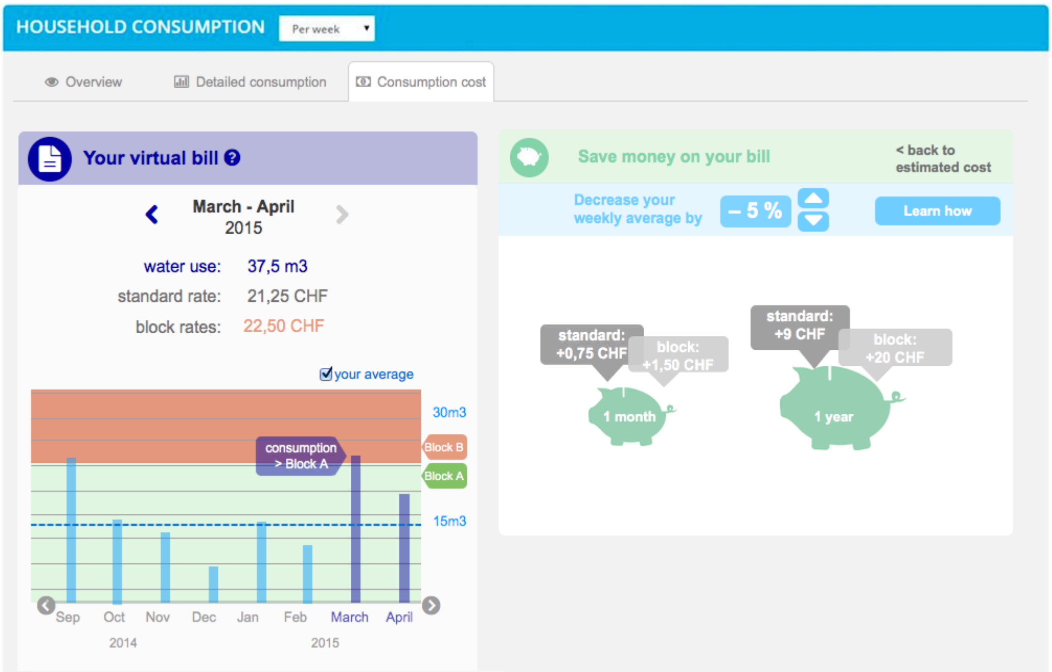
Standard rate
0,25 CHF / m3
fee 5 CHF / month

Increasing block rates
Block B 0,50 CHF / m3
Block A 0,15 CHF / m3

estimated cost per month:
standard: 11,25 CHF
block B: 12,50 CHF

estimated total cost this year:
standard: 120 CHF
block A: 60,12 CHF

Figure 6: Exploration of pricing rates in customer portal (here: standard vs. block rates).



water use: 37,5 m3
standard rate: 21,25 CHF
block rates: 22,50 CHF

Figure 7: Simulation of possible savings for reduced consumption average by tariff type.

However, while such a feature in the SmartH2O portal has the potential to increase customers' understanding of pricing schemes and raise their awareness, it also risks confusing them if not introduced sensibly. The simulative character of such a feature may not be apparent to all users, and could cause confusion about real vs. simulated cost, especially when their real bill is also available online in one way or another. This concern was voiced during our interview with Thames Water.

Thus, the main purpose of the pricing tool is to be used in controlled lab or workshop settings or longitudinal studies with selected customers. This way, a utility can enable the feature only for the selected subset of their customer base, addressing their own concerns and policies, and design the study carefully to gain insights into customer behaviour and reactions, e.g. by applying behavioural economics. With such controlled studies, utilities can much better manage any fear of price increase among customers, and also ensure a confidential setting. Customers can be incentivized to participate in such a controlled study by means of gamification and reputation through the SmartH2O portal, but also through additional rewards or financial benefits.

The tool will be made available at the end of Y2 in accordance with the implementation plan, and its potential regarding customers' awareness of different pricing schemes will be evaluated in a controlled user study as described above with a small subset of utility customers.

4.2 Using social media to support experimental analysis of new pricing schemes

The methods and techniques for social network analysis and influencer detection developed in WP4 (see D4.2) could be used to support the experimental analysis of customer behaviour in response to dynamic pricing schemes. One of the objectives of work in WP4 is to analyse the user interactions on Twitter and identify specific user types and behavioural patterns (e.g. influencers, communities). This information can be used by the utilities to identify especially relevant users for customer panels that could be invited to participate in pricing experiments with the SmartH2O pricing analysis tool. Identifying leading community users can support diffusion of information on new pricing schemes by influential and trusted customers. Potentially both the recruitment of users for the pricing schemes experiments and the social media awareness campaigns for the dissemination of effects and benefits of the new pricing schemes can be supported by social network analysis methods from WP4.

The dissemination of new pricing schemes as well as the effect of different schemes can be facilitated with the help of the users with central roles within communities, e.g. community leaders, and users that are connected to several communities, like brokers (for more information in community roles see D4.2). The water utility could perform targeted communication in Twitter to selected users with high probability of further information spreading of information to their communities. Furthermore, the dissemination through trusted and influential community members is likely to be more effective than a typical promotion strategy by the water utility itself, as the latter naturally entails a subjective dimension through the “voice of the customer”.

Such central users identified through the interactional and behavioural analysis are also more likely to actively contribute feedback in the pricing schemes experiments. In turn, customers that hold important roles in the social media (Twitter) communities are also more likely to disseminate their experiences and feedback from the experiments further to their communities.

Furthermore, the Twitter analysis from WP4 can also be used to track customer reactions to pricing schemes in case a utility decides to introduce a longitudinal pricing pilot in real-world conditions. In that case, the spreading of customer reactions and feedback cannot be controlled as in the laboratory setting but needs to be closely monitored and managed. This is supported by both the social network analysis and influencer detection methods being developed in WP4 that enable the targeted tracking of most important users and their communities. These could be applied by utilities the in two main ways: a) by tracking possible discussions of users regarding the different pricing schemes (e.g. observing and monitoring the influencer accounts), b) pro-actively initiating Twitter discussions and channelling them to target users by using dedicated hashtags that combine pricing and main topical keywords discovered from the influencer analysis. The dedicated hashtags can then be used to both hand track pricing feedback on them and facilitate other users becoming aware of the pricing campaign pushed by the utilities.

For example, Thames Water has embraced social media opportunities for their awareness campaigns, maintaining a very active Twitter account, with a rapidly increasing audience that as of today contains more than 19000[1] followers. Through this account, it informs citizens over potential problems and replies to people’s questions and issues. It could readily benefit from applying methods from WP4 to support the pricing experiments and collect customer feedback to innovative pricing schemes as discussed in the above sections.

4.3 Conclusions

This section discussed why utilities are conservative with regards to pricing trials and communicating freely with customers and the media about pricing changes. We have

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[1] retrieved at 15.07.2015

presented mock-ups of a SmartH20 pricing tool which could allow selected customers in workshop settings to simulate their adoption of various pricing schemes and see their impact on charges over time and in total. This tool could not be implemented and used because of the aforementioned reluctance of water utilities to engage with dynamic pricing at all. Finally, we explore how social media could be used to identify community leaders who would be ideal partners to test pricing options and potentially positively impact other customer’s impressions of innovative pricing schemes such as dynamic pricing.

5. Estimating price elasticities for the three case studies

As explained in previous sections, there is no data available about the user response to dynamic water pricing, because water utilities have been unwilling to engage with an idea demanding such a radical change in their relationship with residential users, even at the trial stage. As a result, we could neither find existing datasets, nor build one by implementing the tool described in Section 4. In order to circumvent this problem, this section carries out a meta-analysis of the price elasticity of water demand, in order to find the determinants of price response. It then uses the results of this analysis to propose an estimate of price response in the three case studies of the SmartH2O project: London, Ticino and Valencia. The moderating role of water scarcity is analysed to get preliminary insights on the potential of dynamic pricing schemes as a demand management strategy (DMS).

Although price measures have been the first and most natural instrument among DMSs, their implementation is still hindered by limited understanding of the extent to which water consumers respond to price signals. In fact, despite an extensive effort exerted by the empirical literature in environmental economics to get consistent estimates of the price elasticity of water demand, a number of issues are still far from having been resolved. In this section we propose an approach based on a meta-analysis that combines results from different studies to produce an estimate of price elasticity of water demand. This is expected to provide insights to government, regulators, and water utilities alike, when they consider dynamic water pricing as part of their demand management strategy.

5.1 Price elasticity of water demand

It must be noted that it remains unclear whether water consumers respond differently across price structures, and whether they react to marginal or average prices [Binet et al., 2014; Nataraj and Hanemann, 2011; Olmstead et al., 2007; Wichman, 2014]. Many authors have even challenged the presumption of elastic water demand [Barrett, 2004; Worthington and Hoffman, 2008].

The price elasticity of water demand is a key variable to evaluate DMSs aimed at achieving long-term sustainable water consumption. In the context of this project, two considerations motivate a good understanding of price elasticity of demand for water. First of all, it is important to *understand whether and to what extent raising prices is an effective measure to stimulate water savings* by residential consumers. Second, accurate knowledge about price elasticity would allow water utilities facing profit constraints to *calibrate price schedules in order to comply with revenue caps imposed by regulatory provisions*.

Moreover, price measures in the water sector have been frequently questioned on the ground of social equity concerns, as raising prices may put low-income households at risk of not being able to afford water supply, failing at the same time in bringing about water savings by water consumers for whom the price increases do not motivate behaviour changes. A correct estimation of water price elasticity across households' and location characteristics would make it possible to devise pricing schedules able to take into account variations in the willingness to pay over different groups of consumers (e.g. increasing block rates…).

Finally, in order to implement integrated DMSs, it is important to assess the relative effect played by different measures – i.e. restrictions, retrofitting, innovative price mechanisms directed at stimulating water conservation. To this aim, a meta-analysis that tries to model in a more comprehensive way the context in which the demand is located, can provide policy makers and utility managers with useful information to help evaluate the potential impact of pricing policies.

The high heterogeneity of price elasticity estimates across studies has prompted past systematic reviews to try to identify and assess sensitivity of price elasticity to a number of factors including demand specification, data characteristics, price specification, tariff structure, functional form, estimation technique and location of demand [Espey et al., 1997; Dalhuisen et al., 2003]. However, none of these analyses has made an attempt to model the local contexts in which the primary studies have been conducted in order to investigate the role played by factors that may have a moderating effect on consumers' response to water price increases.

In this section, we conduct a meta-analysis of water price elasticity by controlling a few location-specific factors and in particular: 1) the presence and nature of an independent regulatory authority; 2) an estimate of regional water scarcity; 3) the households' average income. Water scarcity is expected to strengthen households' motivations to consume less water, an attitude that may interact with price incentives and accordingly lead to differentiated responses in terms of water use. The presence of an independent sector regulator means that the relationship between water utilities and consumers takes place in a formal institutional setting. In turn, this confers credibility to price policies, which are less likely to undergo discretionary changes over time. We believe that both aspects impact consumer behaviour and providing empirical evidence on these issues would be the first step towards more targeted policy interventions.

5.2 The meta-analysis

A meta-analysis combines results from different studies to get summary statistics for an effect size of interest, e.g. price elasticity, to identify causes of heterogeneity among empirical results, and to test hypotheses about relationships between results coming from each study and some factors that can explain their variability.

In this case, we use meta-analysis as a tool to obtain price elasticity measures related to the three case studies: London, UK, Ticino, CH and Valencia, ES. To do so, we estimate a meta-regression model, and express the price elasticity as a function of the characteristics of the sampled studies and location-specific variables. Thereafter, we perform simulations (model evaluations) based on characteristics of the two case studies.

5.2.1 Sampled studies

The meta-regression analysis (MRA) described in the following pages makes use of price elasticity estimates across 198 studies from 1963 to 2014. The sample is constructed by starting from the dataset used in [Dalhuisen et al., 2003], which includes 51 studies. To get the full sample, we used two complementary search strategies. First, we consulted prior narrative review articles in residential water demand [Worthington and Hoffman, 2008] and did a hand search of cited papers in these reviews. Second, we searched the following online databases:

1) Scopus,
2) ISI Web,
3) RepEc,
4) ScienceDirect,
5) Springer,
6) Wiley,
7) Social Science Research Network (SSRN),
8) NBER,
9) CEPR.

We compiled the simplest list of keywords, including: (1) water; (2) demand; (3) price elasticity and used a Boolean search.

We read all article abstracts and eliminated those not relevant to the topic (e.g. not focusing on residential consumers). We developed a coding protocol and arrived at a short list of 352 articles, of which 147 were demand studies added to the 51 used in the meta-analysis conducted by [Dalhuisen et al., 2003].

Table 2: Sampled studies.

Sample					
Studies in the sample = 125 **Observations = 635**		**Studies**		**Observations**	
Location	***United States***	64	51.2%	414	65.2%
	Europe	26	20.8%	111	17.5%
	Other locations	35	28.0%	110	17.3%
Publication status	***Published***	113	90.4%	570	89.8%
	Unpublished	12	9.6%	65	10.2%

After having dropped studies for which we are not able to measure one or more variables included in the meta-regression analysis, we are left with 125 studies, whose distribution in terms of location and publication status is summarized in Table 2. The final number of elasticity estimates, i.e. available observations, amounts to 635. More than half of sampled studies uses US data, European studies represent 20%. Most of the studies considered were published in international journals.

The following histogram depicts the distribution of sampled studies overtime; the last two decades show a proliferation of water demand studies.

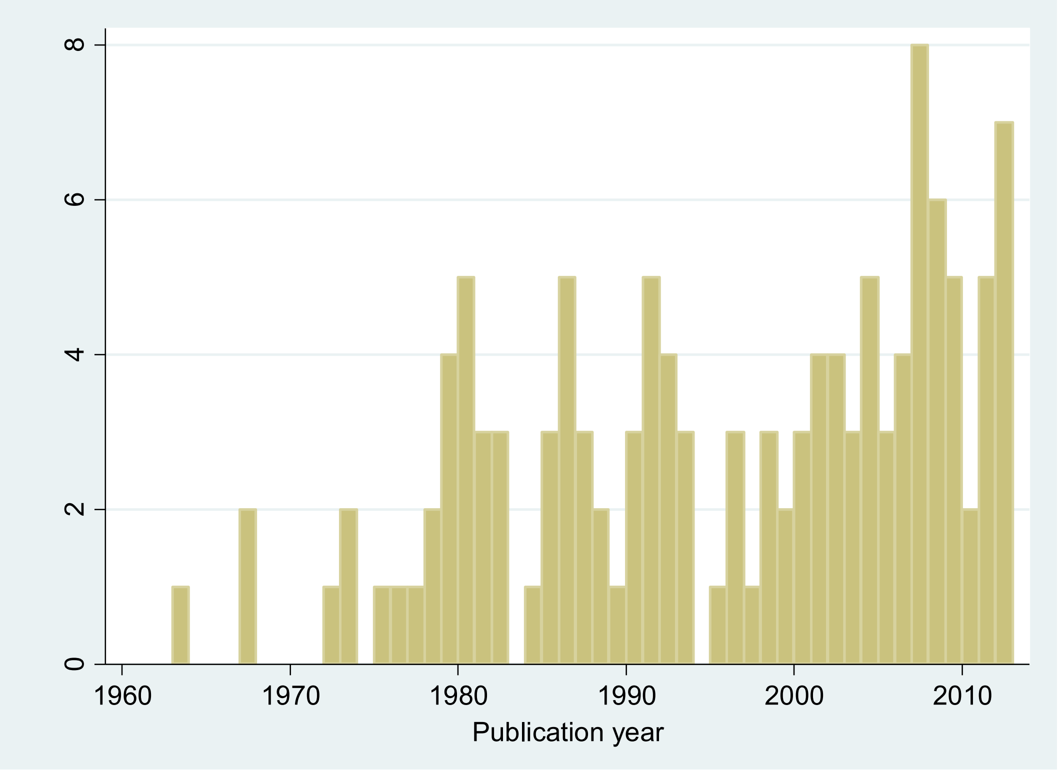


Figure 8: Distribution of water demand studies over time.

5.2.2 Variables

Like previous meta-analyses, we look for a number of studies' characteristics identified as relevant in explaining estimates variations, including:

1) *demand specification;*
2) *data characteristics;*
3) *methodology*

On the water demand specification side, we take into account: the *type of price elasticity* estimated (long run, segment) vs. the short run elasticity assumed as baseline; the *price measure* employed (marginal price, Shin price) vs. average price assumed as baseline; the *conditioning variables* included in the specification (lagged water consumption; evaporation rate; season; household size; population density; income level; commercial use; temperature; rainfall; difference variable); the functional form (semi-logarithm; double-logarithm; flexible) vs. linear assumed as baseline.

The data used in the studies varies greatly. We control for the longitudinal disaggregation level (daily; monthly data) vs. annual data assumed as baseline; the cross-sectional disaggregation level (household data) vs. aggregate data as baseline; the season during which data have been collected (summer; winter); the data structure, which can be a time series or a panel vs. cross-section assumed as baseline.

The methodology employed to get the estimates of the water demand is a crucial aspect to be considered when evaluating the price elasticity. In the meta-analysis we control for the estimator used (instrumental variables; two stage least squares; three stage least squares) vs. ordinary least squares (OLS) assumed as baseline. Moreover, we introduce a variable that allows to differentiate between a discrete-continuous choice approach to get an unbiased estimate of price elasticity for non-linear tariff structures (e.g. increasing block rates (IBR) and decreasing block rates (DBR)).

Some controls at study-level are also added to the meta-regression model. These are: the publication status of the paper (published) vs. unpublished assumed as baseline; the publication year; the number of observations used to run the model for each estimate performed in each study. Published and recent studies that are based on larger samples are expected on average to yield more robust results.

Table 3: List of variables.

List of variables		
Variable category	**Variable type**	**Variable description**
Demand specification	Type of price elasticity	Long run elasticity°
		Segment elasticity°
	Price measure	Marginal price as exp. var.°
		Shin price as exp. var.°
	Conditioning variables	No. of conditioning var.
		Lagged dep var in specification°
		Evaporation rate in specification°
		Season in specification°
		Household size in specification°
		Population density in specification°
		Income level in specification°

		Commercial use included°
		Temperature in specification°
		Rainfall in specification°
		Difference variable in specification°
	Functional form	Specification is semi-logarithmic (x is logarithmic)°
		Specification is semi-logarithmic (y is logarithmic)°
		Specification is double logarithmic°
		Specification is flexible°
Data	Disaggregation overtime	Daily data°
		Monthly data°
	Disaggregation over-users	Household data°
	Data period	Summer data°
		Winter data°
	Data structure	Time series data°
		Panel data°
Methodology	Estimator	Instrumental Variables (IV)°
		Two Stage Least Squares (2SLS)°
		Three Stage Least Squares (3SLS)°
	Innovative method	Regression based on discrete/continuous choice°
Controls		Published study*
		Publication year
		Number of observations
Location-specific variables	Socio-economic factors	Gross domestic product per capita
	Weather conditions	Temperature
		Rainfall
	Tariff structure	Increasing block rate°
		Decreasing block rate°
	Location	Europe*

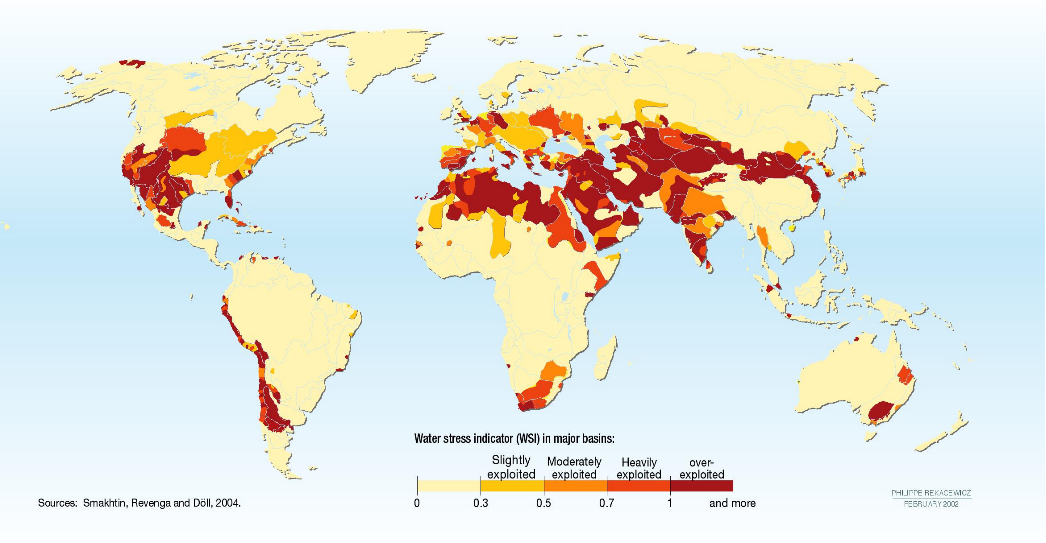
° dummy variable

Some location-specific variables have been added to take into account local characteristics that can have influence on the households' responses to water prices. Gross domestic product per capita is meant to control for the average socio-economic status of people living in the location where the study has been conducted. It is measured in 2005 US dollars and has been sourced by the Centre for International Comparisons at University of Pennsylvania [Heston et al., 2012]. Temperature and rainfall measure two dimensions of natural condition considered as highly responsible of residential water consumption and as a consequence expected to have an impact on price elasticity. Information has been gathered at state level from the World Bank. The tariff structure in place when the study has been conducted is controlled for through two dummy variables which take value 1 or 0 if in the study location water customers face an increasing block rate and a decreasing block rate, respectively. Finally, a dummy variable is introduced to discriminate between studies conducted with European data and the remaining ones.

5.2.3 Introducing additional variables

We consider two additional variables: water scarcity and regulatory framework. Water scarcity is measured at basin level by relying on a regional “water stress indicator” (WSI) published by the United Nations Environment Programme (UNEP). Regulatory framework documents the presence of an independent regulatory agency at national level.

Level of water scarcity



Sources: Smakhtin, Revenga and Döll, 2004.

Figure 9: Water Stress Indicator in major basins.

The Water Stress Indicator (WSI) was developed by [SMAK2005] and recognizes environmental water requirements as an important parameter of available freshwater. Mean annual runoff (MAR) is used as a proxy for total water availability, and estimated environmental water requirements (EWR) are expressed as a percentage of long-term mean annual river runoff that should be reserved for environmental purposes. Using global annual water withdrawal data from the FAO and the IWMI for industrial, agricultural, and domestic sectors, global water resources incorporating environmental water requirements were evaluated.

The Table 4 shows the descriptive statistics of the water stress indicator.

Table 4: Water scarcity: descriptive statistics.

Level of water scarcity				
Water Stress Indicator	**Mean**	**Sd**	**Min**	**Max**
	3.2204	1.4967	1	5

Regulatory framework

Regulatory frameworks shape interactions between water suppliers and consumers through various means. An independent nationwide water regulator is habitually associated with the promotion of transparency and information disclosure towards consumers and/or the introduction of customer service performance indicators. In that respect, bill information has been found to affect the intensity with which consumers respond to price signals [Shin, 1985;

Gaudin, 2006]. Moreover, since water conservation may be a goal to be pursued at local level, a national regulator is in a better position to support price measures combining them with complementary policies and accordingly making them more effective.

To collect information about the presence of an independent water regulator in each location where a water demand estimation has been performed, we have used different sources. For the United States, we have relied on State-level information provided by the National Association of Regulatory Utility Commissioners (NARUC). For other locations, we used [OECD, 2015] and in few cases not covered by the previous sources we did ad-hoc web browsing to learn about local water governance. **Table 5** shows the sample distribution of the variable.

Table 5: Regulatory framework: descriptive statistics.

The regulatory framework			
Studies in the sample = 125		**Studies**	
Independent Water Regulator	***Yes***	79	63.2%
	No	44	35.2%
	Impossible to measure	2	1.6%

5.3 The econometric model

After having collected data on estimated price elasticities reported in the selected sample of previous water demand studies, along with information on study-specific and context-specific factors, a meta-regression has been run, where the dependent variable is represented by the price elasticity (PE) and the independent ones are the above mentioned explanatory factors.

The econometric model is the following:

$$PE_{is} = \alpha + \beta X_{is} + \gamma Z_{is} + \varepsilon_{is} \qquad (1)$$

where PE_{is} is the price elasticity i coming from study s, X_{is} and Z_{is} are two vectors of study-specific and context-specific characteristics respectively, β and γ are two vectors of coefficients to be estimated and ε_{is} is an idiosyncratic error term.

5.3.1 Data analysis and results

The price elasticity estimates available for the purpose of performing the meta-analysis amount to 635. Their distribution is shown in **Figure 10**. The sample mean is -0.40, practically analogous to -0.41, which is the sample mean obtained by [Dalhuisen et al., 2003], who had 296 available estimates (all of them are included in our database). The sample mean obtained by excluding observations in the dataset used by [Dalhuisen et al., 2003] is -0.39. The standard deviation is 0.71, whereas the minimum and maximum values in the sample are -7.47 and 7.90, respectively (both values come from estimates gathered by [Dalhuisen et al., 2003]. Only 54 price elasticity estimates are lower than -1, whereas 548 range from -1 to 0, providing substantial evidence for water demand being price inelastic.

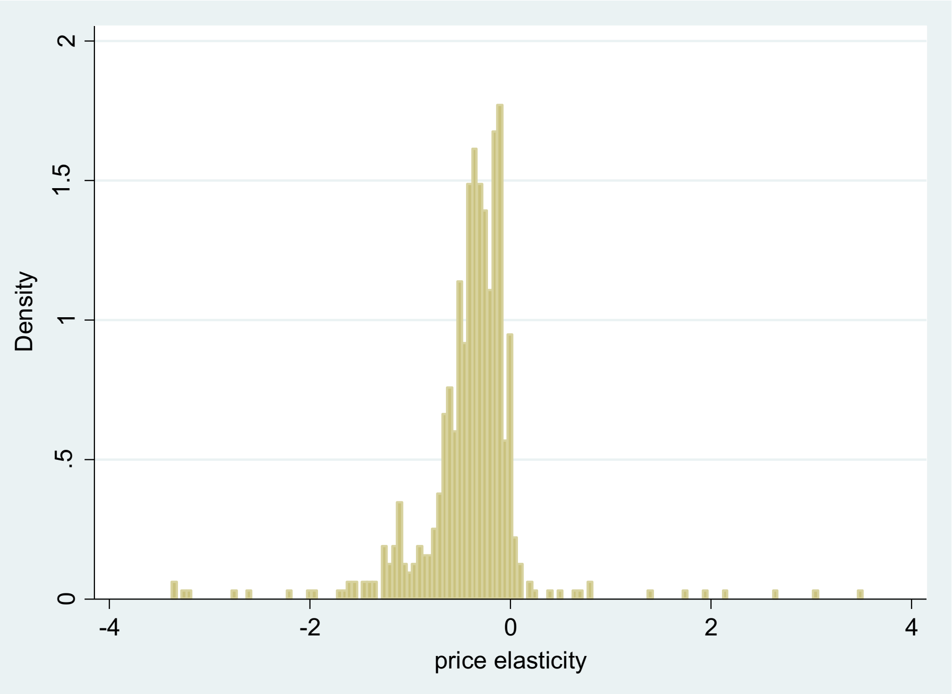


Figure 10: Distribution of price elasticities.

Table 6 reports descriptive statistics related to the variables used in the model reported in Equation (1).

Table 6: Descriptive statistics.

Descriptive statistics					
Variable	**Yes**	**Mean**	**Sd**	**Min**	**Max**
Long run elasticity°	63	.0992	.2992	0	1
Segment elasticity°	27	.0425	.2019	0	1
Marginal price as exp. var.°	331	.5213	.4999	0	1
Shin price as exp. var.°	15	.0236	.1520	0	1
No. of conditioning var.	-	8.169	13.67	0	206
Lagged dep var in specification°	94	.1497	.3570	0	1
Evaporation rate in specification°	65	.1035	.3049	0	1
Season in specification°	68	.1083	.3110	0	1
Household size in specification°	261	.4189	.4938	0	1
Population density in specification°	33	.0525	.2233	0	1
Income level in specification°	496	.7898	.4078	0	1

Commercial use included°	22	.0350	.1840	0	1
Temperature in specification°	271	.4350	.4962	0	1
Rainfall in specification°	376	.6035	.4896	0	1
Difference variable in specification°	146	.2299	.4211	0	1
Specification is semi-logarithmic (x is logarithmic)°	16	.0252	.1568	0	1
Specification is semi-logarithmic (y is logarithmic)°	11	.0173	.1306	0	1
Specification is double logarithmic°	340	.5423	.4986	0	1
Specification is flexible°	53	.0835	.2768	0	1
Daily data°	53	.0835	.2768	0	1
Monthly data°	334	.5260	.4997	0	1
Household data°	233	.3669	.4823	0	1
Summer data°	60	.0945	.2927	0	1
Winter data°	43	.0677	.2515	0	1
Time series data°	94	.1480	.3554	0	1
Panel data°	403	.6346	.4819	0	1
Instrumental Variables (IV)°	29	.0457	.2089	0	1
Two Stage Least Squares (2SLS)°	48	.0756	.2646	0	1
Three Stage Least Squares (3SLS)°	6	.0094	.0968	0	1
Regression based on discrete/continuous choice°	13	.0205	.1417	0	1
Published study°	570	.8976	.3034	0	1
Publication year	-	1996	11.85	1963	2014
Number of observations	-	38213	169754	1	1654037
Gross domestic product per capita	-	25086	9929	762.1	59065
Temperature	-	15.68	6.329	-7.144	27.8
Rainfall	-	601.5	442.1	0	2702
Increasing block rate	256	.4031	.4909	0	1
Decreasing block rate	36	.0567	.2314	0	1

Europe°	111	.1748	.3801	0	1

° dummy variable

We estimate two meta-regression models: Model 1 and Model 2. Model 1 entails a specification including only study-specific factors, i.e. factors capturing the way in which the primary study has been designed and conducted. Study-specific factors include data characteristics, empirical methodologies, variables taken into account in the water demand estimation and so on. Model 2 is augmented with location-specific factors, which include gross domestic product per capita, tariff structures, location, water scarcity and regulatory framework.

Table 7 reports OLS estimates of a meta-regression which does not include location-specific variables (Model 1). Both coefficients and standard errors are shown. In order to get robust standard errors, they are clustered at study level.

The meta-regression makes use of 574 price elasticity estimates drawn from 122 studies. This happens for three reasons: (i) we use only negative price elasticity estimates, because positive ones do not make sense in economic terms; (ii) outliers (price elasticities lower than -2) have been dropped; (iii) there are some observations for which we are not able to measure all the variables included in the model.

Table 7: Meta-regression results (OLS estimate with robust standard errors) – Model 1.

Meta-regression - Model 1				
Variable category	**Variable type**	**Variable description**	**Coefficient**	**Standard error**
Specification	Type of price elasticity	Long run elasticity°	-.0465	.1066
		Segment elasticity°	-.3427***	.1277
	Price measure	Marginal price as exp. var.°	-.0041	.0807
		Shin price as exp. var.°	-.0231	.0808
	Conditioning variables	No. of conditioning var.	-.0008	.0016
		Lagged dep var in specification°	-.0362	.0765
		Evaporation rate in specification°	-.0671	.0634
		Season in specification°	-.1344*	.0803
		Household size in specification°	.0587	.0642
		Population density in specification°	.1206	.0961
		Income level in specification°	-.0257	.0716
		Commercial use included°	.1926	.1482
		Temperature in specification°	-.0024	.0780
		Rainfall in specification°	-.0144	.0878
		Difference variable in specification°	-.0536	.0846
	Functional form	Specification is semi-logarithmic (x is logarithmic)°	-.1058	.1080
		Specification is semi-logarithmic (y is logarithmic)°	.1788	.1281
		Specification is double logarithmic°	-.0664	.0595
		Specification is flexible°	-.0124	.0889
Data	Disaggregation overtime	Daily data°	.1875**	.0938
		Monthly data°	.0540	.0881
	Disaggregation over-users	Household data°	-.1018*	.0567
	Data period	Summer data°	-.0444	.0709
		Winter data°	.1233**	.0525
	Data structure	Time series data°	.0786	.1233
		Panel data°	.0403	.1039
Methodology	Estimator	Instrumental Variables (IV)°	.1282	.1011

		Two Stage Least Squares (2SLS)°	.0924*	.0545
		Three Stage Least Squares (3SLS)°	.1597**	.0726
	Innovative method	Regression based on discrete/continuous choice°	-.3782*	.1981
Controls		Published study°	-.0392	.1238
		Publication year	.0002	.0024
		Number of observations	.0002*	.0001
Observations (clustered at study level)		*574*		
Studies		*122*		
F(33,121)		*4.00*	*Prob>F=0.0000*	

° dummy variable

*,**,*** denote significance at 10%, 5%, 1% respectively.

The discussion of estimated coefficients for individual variables is interesting in itself, but results from meta-analyses are better exploited through simulations of realistic exogenous shocks or methodological advances that may involve more than one variable, as Sections 3.5 and 3.6 will show. Individual coefficients may not be significantly different from 0, but a variation in corresponding variables may still play a significant role when implemented jointly with other variables. In order to depict realistic changes in either methodology or context-specific variables, Sections 3.5 and 3.6 simulations vary jointly a set of variables; the final overall effect may be significantly different from 0 due to the joint action of different factors.

According to the results of Model 1, segment elasticities are significantly larger (in absolute value) than point elasticities. The inclusion of variables controlling for the season t is associated with larger price elasticity estimates (in absolute value). Larger price elasticities are also estimated when household level data are used in the water demand studies. Winter and daily data, on the other hand, are more likely to produce lower price elasticities (in absolute value).

As far as the estimators are concerned, both two stage least squares (2SLS) and three stage least squares (3SLS) are associated with more inelastic water demand, whereas the use of the discrete/continuous choice approach, used in more recent studies, produces larger price elasticity estimates.

Table 8 reports OLS estimates of a meta-regression which also includes location-specific variables (Model 2). Again standard errors are clustered at study level. Since other variables are added to the meta-regression specification, and they are not observable for all studies, the number of observations further decreases. Model 2 is run on 531 observations drawn from 112 studies.

Table 8: Meta-regression results (OLS estimate with robust standard errors) – Model 2.

Meta-regression - Model 2				
Variable category	**Variable type**	**Variable description**	**Coefficient**	**Standard error**
Specification	Type of price elasticity	Long run elasticity°	-.0250	.1135
		Segment elasticity°	-.2888***	.1096
	Price measure	Marginal price as exp. var.°	-.0094	.0790
		Shin price as exp. var.°	-.0340	.0819
	Conditioning variables	No. of conditioning var.	-.0012	.0018
		Lagged dep var in specification°	-.0428	.0747
		Evaporation rate in specification°	-.1153	.0915
		Season in specification°	-.1489*	.0765
		Household size in specification°	.0534	.0559

		Population density in specification°	.1593	.1041
		Income level in specification°	-.0685	.0646
		Commercial use included°	.1506	.1397
		Temperature in specification°	.0884	.0765
		Rainfall in specification°	-.0960	.0654
		Difference variable in specification°	.0530	.0997
	Functional form	Specification is semi-logarithmic (x is logarithmic)°	-.0164	.1002
		Specification is semi-logarithmic (y is logarithmic)°	.1986	.1468
		Specification is double logarithmic°	-.0135	.0590
		Specification is flexible°	.0940	.0797
Data	Disaggregation overtime	Daily data°	.1312	.0987
		Monthly data°	.0890	.0786
	Disaggregation over-users	Household data°	-.0589	.0595
	Data period	Summer data°	-.0613	.0629
		Winter data°	.1212**	.0481
	Data structure	Time series data°	.1741*	.1044
		Panel data°	.0066	.1137
Methodology	Estimator	Instrumental Variables (IV)°	.1678	.1251
		Two Stage Least Squares (2SLS)°	.1053*	.0571
		Three Stage Least Squares (3SLS)°	.0629	.1014
	Innovative method	Regression based on discrete/continuous choice°	-.5751***	.1601
Controls		Published study°	-.0444	.1154
		Publication year	.0006	.0029
		Number of observations	.0001	.0001
Location-specific variables	Socio-economic factors	Gross Domestic Product per capita	.0030	.0028
	Tariff structure	Increasing block rate°	-.1420*	.0768
		Decreasing block rate°	.0285	.0663
	Location	Europe°	.0446	.0861
	Additional variables	Water scarcity	.0252	.0216
		Regulatory framework°	-.0214	.0743
Observations (clustered at study level)		*531*		
Studies		*112*		
F(37,111)		*8.87*	*Prob>F=0.0000*	

° dummy variable

*,**,*** denote significance at 10%, 5%, 1% respectively.

If we compare the results of Model 2 with the ones obtained running the Model 1, we note that segment elasticities keep being larger, in absolute value, than point elasticities. The presence of a variable accounting for the season the data belong to in the water demand specification still plays a statistically significant role in making price elasticity estimates larger. Like in Model 1, winter data produce more price-inelastic water demand, whereas daily and household level data lose their statistical significance in explaining the magnitude of water price elasticity.

The statistical significance of discrete/continuous choice approach is even greater than in Model 1 and implies larger price elasticity estimates. 2SLS keeps being statistically significant, while water demands estimated using time series produce lower price elasticities.

5.4 Simulations: effects of innovative pricing policies

SmartH2O aims to explore the water saving potential of various pricing schemes including block-rates tariffs and different forms of dynamic pricing. In this section, we explore results of simulations based on Model 2 and compare estimated price elasticities with and without increasing block rates (IBR). We run two separate simulations: the first one predicts price elasticities obtained by adopting the discrete/continuous choice approach, a statistical method that helps properly estimate water demands characterized by non-linear prices; the second one is based on the same methods as the baseline. Dynamic pricing is still under debate in the water industry and has not been implemented yet and so cannot be explored in this modelling. We can study the effect of block rates though.

Results are reported in **Table 9**.

Table 9: Price elasticity simulation with and without IBR.

Simulation by tariff scheme						
	Tariff structure	**Statistical Method**	**Mean**	**Se**	**95% confidence interval**	
Price elasticity	**IBR=1**	**Discrete/ Continuous Choice**	-1.059	.1463	-1.3495	-.7689
		Baseline	-.4935	.0554	-.6033	-.3836
	IBR=0	**Baseline**	-.3514	.0337	-.4182	-.2847

Results show that adoption of increasing block rate schemes make the demand for water more elastic. The simulation based on the adoption of same statistical methods shows that introducing IBR would increase the absolute value of price elasticity by approximately 40.4% (from -0.3514 to -0.4935). If increasing block rates are in force, other things being equal, a 10% price increase implies a reduction in water consumption equal to 4.93%. The predicted price elasticity reaches the value of -1.059 if we run a simulation based on the adoption of IBR and discrete/continuous choice approach.

5.5 Simulations: effects of water scarcity, regulatory framework and adopted methodology

In this Section we run simulations based on coefficients estimated by Model 2 (Section 5.3), to obtain water price elasticity predictions corresponding to different levels of water scarcity, different regulatory frameworks, and different methodologies.

We examine two model evaluations. The first one (SimWS) is performed by setting the values of all variables except water scarcity at their sample means and by varying the value of the water stress indicator. The second simulation (SimRF) is performed by setting the values of all variables except the regulatory framework at their sample means and by setting the value of regulatory framework indicator at 0 (absence of an independent sector authority) or 1 (presence of an independent sector authority). Results are reported in Tables 10 and 11.

Table 10: Price elasticity simulation by water scarcity (SimWS) - setting the values of all variables except water scarcity at their sample means and by varying the value of the water stress indicator.

Simulation by water scarcity (SimWS)

	Water stress indicator	Mean	Se	95% confidence interval	
Price elasticity	**Min=1**	-.4675	.0621	-.5905	-.3444
	Med=3	-.4171	.0255	-.4675	-.3666
	Max=5	-.3667	.0342	-.4344	-.2990

As expected, since the Model 2 water scarcity coefficient is positive, when the water scarcity level is increased from its minimum value to its maximum, the simulated water price elasticity goes down in absolute value. A 10% price increase, other things being equal, implies a reduction in water consumption equal to 4.68% and 3.67% in, respectively, the least and most water-stressed locations. In other words, locations characterized by more severe water scarcity issues are found to be less responsive to price increases.

The result could be counterintuitive, but it should be emphasised that the Model 2 coefficient of water scarcity (Section 5.3) does not measure the effect of increasing water scarcity on consumption, which is expected to be negative. In fact, it captures the impact of water scarcity on price elasticity, i.e., the moderating role exerted by water scarcity on the response of water consumption to price increases. The smaller response of residents to price increases in more water-stressed locations could be due to different reasons. Water scarcity may imply an already heightened awareness of the importance of water conservation. Water scarce regions may also have higher water tariffs. For both reasons, further tariff increases may be less likely to produce water saving, because households have already reduced discretionary water uses.

Table 11: Price elasticity simulation by regulatory framework (SimRF).

Simulation by regulatory framework (SimRF)					
	Independent regulator indicator	Mean	Se	95% confidence interval	
Price elasticity	**Present=1**	-.4170	.0300	-.4765	-.3576
	Absent=0	-.3956	.0590	-.5124	-.2787

Table 11 reports results of simulations with and without an independent water regulator. The impossibility to distinguish statistically price elasticity when an independent regulator is present from price elasticity when it is not is not surprising, because the regulatory framework coefficient in Model 2 is slightly negative yet the coefficient standard error is very large. If the sector is reformed and an independent sector regulator is established, price elasticity is not found to vary to a significant degree. Indeed the perceived credibility of regulators in setting prices goes beyond the presence of a sector authority that is institutionally separated by the regulated utilities; it may entail institutional, social and political traits of the country as the fragmentation of politics, independence of judiciary or third-party pressures (see [SPIL2013]).

5.6 Simulations: application to the case studies

In this section, we use the estimates obtained by Section 5.3 to get statistics of price elasticity estimates for our three case studies: London, UK, Ticino, CH, and Valencia, ES.

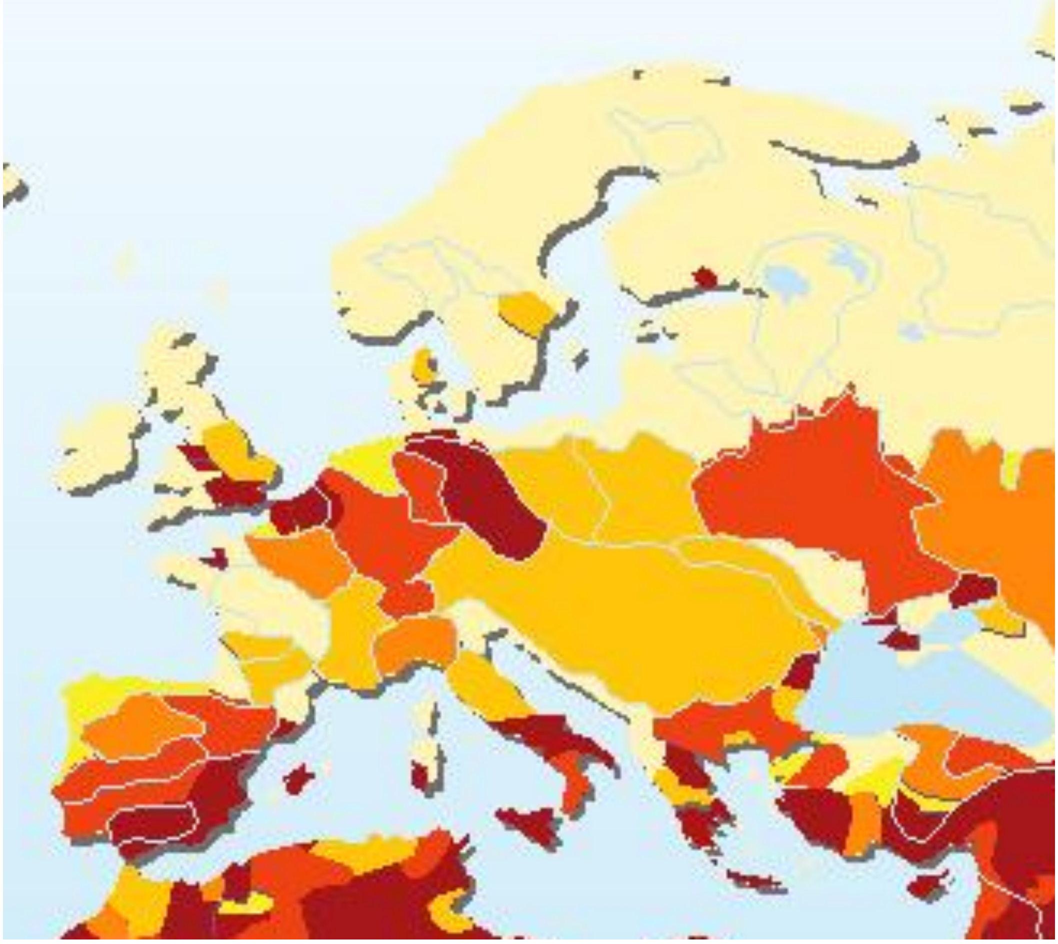


Figure 11: Water Stress Indicator in the case study areas.

A baseline simulation of cases (SimBLC) is performed by using Model 2 and setting all variables but location-specific ones at their sample means, i.e. regulatory framework, income of inhabitants and water scarcity are assigned case-specific values. This offers estimates for London, Ticino and Valencia price elasticities.

Figure 11 is a zoom of Figure 9 focusing on Europe, in order to clearly identify the case studies locations for the validation of SmartH2O. The London and the Valencia areas are over-exploited and accordingly exhibits the maximum level of water stress (i.d. Water Scarcity=5), while the Ticino Canton is classified as heavily exploited (i.d. Water Scarcity=4).

An independent national water regulator is present in United Kingdom (i.d. Regulator=1), whereas it is absent in Switzerland and Spain (i.d. Regulator=0). The three case studies are located in Europe (i.d. Europe=1). The most recent figures of GDP per capita provided by the Penn World Table (reported in 2005 US dollars for uniformity over the time series) are 32.260 USD for United Kingdom, 28.741 USD for Spain and 44.823 USD for Switzerland. Results are reported in Table 12.

Table 12: Price elasticity simulation by case study – baseline methodology (SimBLC).

Simulation by case study (SimBLC)

	Case study	Mean	Se	95% confidence interval	
Price elasticity	**London**	-.3171	.0888	-.4931	-.1411
	Ticino	-.3195	.0991	-.5158	-.1232
	Valencia	-.3421	.0685	-.4779	-.2064

The price elasticity simulations for the three case studies are by far lower, in absolute values, than the sample mean provided in section 5.3.1. In the London area, a water price increase by 10% would produce an estimated of 3.17% reduction in consumption. Likewise a tariff increase of 10% would produce water savings of 3.20% in Ticino and 3.42% in Valencia. Most of the reduction is explained by the European location of the three cases. Our estimates seem to suggest that in Europe water price elasticities are lower in absolute value than in other parts of the world.

Using the baseline methodology, we have tried to estimate by an ad-hoc simulation the price elasticities of the water demand in the three case studies if an IBR was introduced as tariff structure. Results are reported in Table 13. The absolute values of water price elasticities go up, as it could be expected after having shown meta-regression estimates in section 5.4. With an IBR put in place, price elasticities would increase from -0.317 to -0.399 in London, from -0.319 to -0.402 in Ticino and from -0.342 to -0.425 in Valencia.

Table 13: Price elasticity simulation by case study – effect of IBR.

Simulation by case study (effect of IBR)					
	Case study	**Mean**	**Se**	**95% confidence interval**	
Price elasticity	**London**	-.3997	.0966	-.5911	-.2084
	Ticino	-.4021	.1188	-.6376	-.1667
	Valencia	-.4248	.0873	-.5977	-.2519

5.7 Discussion and conclusion

Section 5 is aimed at offering meaningful estimates of water price elasticity estimates in the three case studies. Since case-specific datasets are not available, ad-hoc estimates of water demand models for London area, Ticino and Valencia were not feasible. Therefore, we decided to rely on a meta-analysis conducted on a fairly large sample of water demand studies performed in the past. The meta-regression models estimated have been used, as a second step, to simulate price elasticities in the three locations.

Three meta-analyses have been conducted in the past in order to investigate systematic variations in price elasticity across water demand studies [Dalhuisen et al., 2003; Espey et al., 1997; Sebri, 2014]. We believe that the current meta-analysis goes beyond the existing literature in two respects: first, it uses a larger sample of recent studies up to and including 2014; second, this analysis allows for a more detailed modelling of contexts in which the water demand is located, i.e. it considers information on water scarcity and regulatory framework.

Water demand under traditional pricing schemes is confirmed to be price inelastic. The sample mean of price elasticities is equal to -0.40.

Location-specific characteristics are source of variation in price elasticity. Firstly, our analysis shows that, perhaps counter-intuitively, water scarcity tends to decrease price responsiveness. Indeed, water scarcity can by itself generate an intrinsic motivation to water conservation. However, to the best of our knowledge, there are no analyses trying to disentangle the effect played by water scarcity on price elasticity. We find that, aside from its direct impact, water scarcity moderates the relationship between water price and water consumption to a slight yet statistically significant degree (SimWS of Section 5.5). If water scarcity indicator moves from a minimum level (value equal to 1) to the maximum level (value equal to 5), the consumption response to a 10% increase in price levels changes from 4.68% to 3.67%. We believe further field trials or the use of field data are necessary to reject in a robust way the intuitive hypothesis that economic incentives to save water are strengthened in areas of water stress. Possible explanations for this finding could be that price measures might crowd-out intrinsic motivations stemming from water stress. Alternatively, residents of more water scarce locations might have already exhausted the potential of water saving practices and, thus, are less sensitive to price measures. The interaction between water scarcity and DSMs in households' water consumption decisions is matter for further research.

Secondly, our results reveal that the adoption of more sophisticated (albeit non-dynamic) pricing schemes, such as increasing block rates (IBRs) significantly makes pricing policies more effective. IBR introduction is found to increase the absolute value of price elasticity by approximately 40% (from -0.3514 to -0.4935). The equity concerns related to IBRs can be addressed through redistribution of additional revenues through rebates on the low-income households' fixed fee (similarly to the approach described in Section 3.4 for scarcity tariffs).

A final set of core findings deals with the two SmartH2O case studies, i.e. the London area, Canton Ticino and Valencia. Compared with the sample mean value estimated for water price elasticity, which is equal to -0.40, the simulated price elasticities for our case studies under a baseline scenario are lower, i.e. they are equal to -0.32, -0.32 and -0.34 for London area, Canton Ticino and Valencia respectively. Under the baseline scenario (SimBLC), a 10% price increase causes, other things being equal, a reduction in water consumption that is equal to 3.20% in London area and Ticino and 3.40% in Valencia. Motives for a reduced effectiveness of price policies may be traced back partially to European location: our estimates show less price-elastic water demand in Europe than in other places in the world.

Alternatively, if innovation in price schemes toward IBRs is a realistic scenario, price elasticities can be assigned values from -0.40 for London area to -0.42 for Valencia.

Our results suggest that price measures have some potential in inducing households to save water. Under the optimistic scenarios that are revealed by the use of advanced methodologies, utilities and policy makers can expect residents to reduce water consumption. Innovative pricing schemes such as increasing block rates are confirmed to have a water-saving impact and hence their adoption is recommended.

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