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A systems approach for assessing water conservation potential through demand-based water tariffs

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ABSTRACT

Sustainable and responsive water management policies are essential to provide high-quality, reasonably priced drinking water to consumers at any time, while simultaneously ensuring a profit for the water utility. Such goal can be typically achieved through two different types of policy, namely increasing water supply, or managing water demand; the latter can be performed, among others, through water pricing. Pricing, especially when demand-based, can lead to a behavioural change in customer water use, but it is arduous to introduce for a number of political and social reasons; it is essential to engage with relevant stakeholders to clearly recognize pros and cons of implementing a new water tariff. As a consequence, in this paper, economic and social implications of demand-based tariff structures, and their potential for greater water conservation, are assessed through a participatory approach. The variation of residential water demand and revenue outcomes were simulated through an integrated participatory systems approach by assuming that an inclining block tariff was introduced on the Gold Coast region, Australia. Such connection between price, demand, and revenue is highly complex and the choice of System Dynamics for this modelling exercise is considered ideal as it can explicitly handle the non-linearity, feedbacks and interconnections of such system. The simulation model was developed by collaborating with relevant stakeholders, thus ensuring the logical inclusion of all the relevant inputs and connections. Such model integrates three components, namely revenue forecasting; water billing; and demand feedback sub-model. The results show that: a) the inclining block tariff can effectively lead to behavioural change and water consumption reduction, especially within the high water users group, although the predicted water savings would be lower than when adopting water restrictions; b) customers' feedback to an increased cost can be used to achieve revenue neutrality; c) based on customer feedback and modelling simulations, the ideal proportion of customers to be charged with the second block tariff is 20%, however this can be recalculated and varied during wet seasons or dry seasons to optimise water availability. The developed model allows water planners to explore a wide range of policy alternatives (e.g. alternative pricing scenarios to influence demand) over medium to long-term periods and to optimise best-practice decision making for urban water conservation and management.

1. Introduction

The sustainable and responsive management of water resources has become over time an increasingly delicate issue, as it is influenced by continuously increasing population, as well as by climate extremes and decreasing water availability. In particular, during the Australian Millennium Drought (1997–2009), the worst drought in recorded history (CSIRO, 2010), local institutions inevitably increased their efforts towards reducing water scarcity risks, with most of the state governments committing to increase their water availability through the construction of large-scale desalination plants and other infrastructure investments, as well as the introduction of a range of demand management measures such as, for example, restrictions on water use (Porter et al., 2015), water-efficient technologies, and water recycling options both in residential and industrial sectors (Beal et al., 2012; Giurco et al., 2011). Especially in an urban context, a proportion of the water supplied is dedicated to end-uses that would not require high-quality drinking

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water, such as toilet flushing or irrigation (Beal and Stewart, 2011), hence attention has been given to the use of water of different qualities, including recycled water and rain water, with several studies trying to optimise and integrate these systems in the same water supply network (Bertone and Stewart, 2011; Gao et al., 2014). In general, there are two distinct types of policy that can be deployed by water utilities: management of water demand (such as through water restrictions or pricing) and augmentation of water supply. These are interconnected, since better demand management (e.g. optimised water pricing) can lead to a reduced need for supply augmentation (Grafton et al., 2015). This strategy in turn can enhance the resilience against the effects that climate change, extreme events and increased human activity may have on a number of water sources, both in terms of quantity and quality (Bertone et al., 2014, 2016a; Haddeland et al., 2014; Schewe et al., 2014). Numerous studies have recently been undertaken, especially in the Australian context such as Grafton et al. (2015), in order to optimise water tariffs, and in turn water demand and water supply augmentation. Although urban water consumption accounts for only about 10% of the total water use in Australia (ABS, 2016), it is generally recognised that better planning and regulation, through instruments including pricing, can help optimise water use and create climate-resilient water suppliers in an urban context.

A water tariff (i.e. pricing) provides a potential management solution to deal with the delicate challenge of supplying affordable water to all consumers while at the same time conserving water resources. Water tariffs can be estimated in a way to keep supply and demand into balance; it has been asserted that if water use is allocated based on such price, several issues associated with climate and socio-economic scarcity could be overcome (WB, 2016). However, pricing water services is controversial. The main challenge when setting a water tariff is to make sure householders pay a reasonable price based on the available water that can be supplied, but additionally the price should be high enough to guarantee a realistic profit for the water utility and to optimally postpone water supply augmentation. Crucially, water pricing should also have the goal of promoting efficient water-use behaviour, in order to help achieve the sustainability of the water resources over the medium to long term. The process of water and sewage pricing involves several stakeholders at different political and regulatory levels, but also within water utilities, bulk water suppliers, and, of course, customers. Each of these stakeholders would have different aims and views on water pricing, thus reaching unanimous agreement on water pricing-related issues is often a challenge. In fact, there is typically disagreement over the water pricing objectives in the first place, as well as on the actual effects of the introduction of such water tariff (Whittington, 2003).

In Australia, typically the implementation of urban water prices lasts three to five years and the actual price is set by independent pricing authorities which differ from state to state. Such period is called ‘price determination period’, during which water tariffs are usually fixed, and thus cannot vary in case of drastic changes in water availability such as during drought periods (Grafton et al., 2015). As a consequence of such limitation, in recent time there has been a shift towards urban two-part water tariffs consisting of a fixed access charge and a water consumption-related charge, with the aim of leading to more efficient water consumption (NWC, 2011). In 2012, the Independent Pricing and Regulatory Tribunal (IPART) predicted that in 2015–16 the volumetric charges would account for a large part (80%) of a total water bill, with only 20% related to fixed charges. However, in this case such as in many others, there is no inclusion of a “scarcity price” thus, in situations such as during a drought, the price (and thus consumption behaviour) does not change; this implies unaltered water demand despite decreased water supply, leading to potential water scarcity and likelihood of anticipated water supply augmentation projects (Grafton et al., 2014, 2015; Sahin et al., 2016; Sahin et al., 2015b).

Inclining block tariffs (IBT) have been now adopted by all the main Australian cities. An IBT scheme applies an increase in the volumetric charge when a predetermined water consumption threshold is exceeded; thus, consumers using a lower amount of water pay proportionally less, while householders in the high-consuming block have to deal with a higher marginal cost for using much larger quantities of water (Crase et al., 2007). IBTs can be set up with two steps only (such as in NSW and South Australia), or with multiple steps such as in all other Australian jurisdictions; the extreme case is given by Busselton Water in Western Australia with an IBT incorporating eight steps (Frontier Economics, 2008). In general, at least in developed countries, IBT are considered a fair pricing method, since they target only consumers using an excessive amount of water, but at the same time they help achieve a target urban water consumption (Sibly and Tooth, 2014). Despite the growing acceptance and deployment of IBT for urban water pricing, certain IBT features such as thresholds and thus pricing blocks seem to be often poorly designed, without the use of a robust, rigorous scientific approach; as a consequence, the effectiveness of such tariffs is limited as the wasteful use of water is not fully discouraged (Crase et al., 2007).

The link between a water tariff, water demand fluctuations and change in revenue is highly intricate and defined by a number of interconnected factors. The deployment of an integrated modelling approach allows the integration of empirical data with qualitative expert inputs, as well as combining a number of different methods under the same framework. System Dynamics Modelling (SDM) was selected for this modelling framework to assess the water tariff-demand-revenue nexus given its ability of accounting for the feedbacks, interdependencies, and non-linear correlations characterising such system. SD is a powerful computer-aided modelling approach, initially developed and applied in the fields of engineering and management (Forrester, 1961). Gradually, the improvements and evolution of such SD approach lead to its application in other fields (e.g. chemical, biological, social, ecological, physical) to represent the behaviour of complex systems (Bertone et al., 2016b; Fiddaman, 2002; Ford, 1999; Sahin and Mohamed, 2013; Sahin et al., 2015b; Scarborough et al., 2015; Sterman, 2000, 2008). In the specific field of water resources, SDM has been used in relation to irrigation systems and water quality (Gharib, 2008; Zhang, 2008), as well as in the climate-energy-water nexus context (Newell et al., 2011). Also, Dawadi and Ahmad (2013) utilised SDM to investigate the influence of growing population and climatic conditions on the water resources. Rehan et al. (2013) used SDM to examine the distinctive features and feedback loops for financially self-sustaining water distribution networks interactions among system variables over time.

Environmental systems in particular, are characterised by highly non-linear behaviours, feedbacks and interdependencies (Patten and Sven, 1995); similarly, several interconnected components pertaining to different specific fields (e.g. economic, social, environmental, ecological) also define water resources systems (Loucks et al., 2005). As a result, traditional modelling approaches seem to be inadequate in representing such a wide category of systems, including the assessment of urban water policy options (Barker, 2010); this is due to a rigid supply side modelling approach (Hughes et al., 2009), in contrast to more appropriate dynamic approaches incorporating the response of the demand side given a change in price. SDM is therefore an appropriate modelling technique for such complex, nonlinear system. It also has the benefit of being considered a hybrid methodology able to combine the advantages of both continuous and discrete concepts of time.

SDM was therefore applied to estimate the effects of the