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The paradox of water pricing: dichotomies, dilemmas, and decisions

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Abstract We deliver a public policy perspective on the dichotomies, dilemmas, and decisions of water pricing. First, the dichotomies between price and value, and costs, are defined to explain the paradox of water pricing: the price of water almost never equals its value and rarely covers its cost. Second, the dilemmas of water pricing are highlighted across efficiency and equity, objectives for water pricing, and the instruments available to decision-makers. Third, the challenges of decision-making are evaluated and illustrated in relation to water pricing. Fourth, an adaptive process is provided that includes participatory assessment of risks and options to guide water-pricing decision-making.

Keywords: water tariff, costs, equity, efficiency, regulation

JEL classification: Q21, Q25, Q28, Q58

> *The price of water almost never equals its value and rarely covers its costs.*
> The authors

I. Introduction

In many countries, policy-makers face the dilemma of how to respond to increasing physical water scarcity—the decline in water supply *per capita* (Falkenmark *et al.*, 1989; Jaeger *et al.*, 2013). The traditional focus on supply-based 'solutions' to water scarcity and investing only in water supply infrastructure is an insufficient response to the demand- and supply-side causes of water scarcity (Grafton, 2017). To cost-effectively manage spatial and intertemporal trade-offs across alternative uses, policy-makers must consider a wide range of options beyond maintaining or investing in water supplies. These policy options include, but are not limited to, demand-based water conservation measures, such as water pricing, and the evaluation of water values across alternative uses to identify and resolve water misallocations (Grafton *et al.*, 2017).

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Despite a huge literature on water pricing (see reviews by Hirshleifer *et al.*, 1960; Hanemann, 1997; Olmstead and Stavins, 2009; OECD, 2010; and Grafton *et al.*, 2014) going back decades, and also water valuation (see reviews by Hanemann, 2006; UNDESA, 2006; and Garrick *et al.*, 2017), many water utilities, regulators, and governments do not effectively integrate water pricing into a portfolio of measures to deliver water supply services (Convery, 2013). Here, we use case studies to illustrate how decision-makers might resolve the 'paradox of water pricing': water almost never equals its value and rarely covers its costs.

Our case studies include water pricing for cities in a poor country (Phnom Penh) and a rich country (Canberra); water pricing for irrigation (Vietnam); and water pricing for multi-purpose water infrastructure (Tasmania). Each case study was selected to illustrate key insights of water pricing and, with the exception on Phnom Penh, has been the subject of previous study by the authors. Our review of both the theory and applications of water pricing provides three key contributions: (i) an overview of the economics of water pricing; (ii) a demonstration of the key dimensions and challenges of water pricing; and (iii) a decision-making process to navigate the risks and options associated with water tariff design.

Section II provides an overview of the dichotomies between water values, prices, and costs. Section III highlights the dilemmas of how to choose among competing options for water pricing. Section IV surveys the range of possible decisions in relation to water pricing. Section V presents a process that enables water-pricing decisions to be integrated into water governance. We conclude by summarizing the key steps for policy-makers who seek effective and efficient water pricing.

II. Water dichotomies

Adam Smith famously described the diamond-water paradox[1]: water, which is essential for life, has a high value in use but commands a low market price; jewellery diamonds, which are luxury goods, have a low use value but command a high market price. The difference in price is explained by dichotomies between economic value, price, and cost. This 'paradox' holds just as true today, more than 200 years after it was popularized by Smith.

(i) Economics of water value, price, and cost

The *economic value* (EV) of a given level of water consumption is the benefits derived from its use. The EV of water can be measured by the value of other goods and services, or monetary units, that an individual is prepared to trade off for the amount of water consumed (Hanemann, 2006, pp. 78–80).[2] The *economic price* (EP) is what an individual pays per unit for any good or service, typically defined in monetary units. In the

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[1] Smith (1776; 2007, p. 26) did not offer the example of diamonds and water so much as a paradox, but rather as a device to present his understanding of value. White (2002) describes the paradox as a fable and claims that Smith was, in fact, able to explain the apparent contradiction between price and value.

[2] Young and Loomis (2014) provide a detailed exposition of how to value water in different circumstances.

case of water, the price paid by most water consumers is not a market price, but rather a regulated price determined by a water utility, regulator, or by government. The *economic cost* (EC) of a given supply of water is the explicit trade-off in other goods and services (or in monetary units) required to provide this quantity and quality of water. In the context of water supply, EC includes directly incurred *private costs* from capital investment, such as building a dam to store water, and operational costs, such as water treatment and distribution costs. EC also includes *external costs*[3] that are not directly incurred by the water supplier, but nevertheless impose costs on others. For instance, *external costs* from building a dam could include reduced ecosystem services that may arise from changing the timing, temperature, and volume of a downstream river's flow.

The reason why water, typically, has a low price is because the *average private cost* (APC) is low in many circumstances. The APC is the total *private cost* of water supply divided by the amount of water supplied. While the capital costs of supplying water are often very large for centralized distributed water supply systems, these costs are typically allocated over a large volume of water supplied which, in turn, makes the average cost[4] relatively low. If this low average cost also results in a low price, which is typically the case when water is supplied or regulated by a public agency on behalf of consumers, then many individuals can also ensure that all their high-value uses of water (drinking, cleaning and cooking) are satisfied within a reasonable budget constraint. Indeed, the low price for urban water services in many high-income cities means that water bills are, typically, a small proportion (less than 2 per cent) of most households' total expenditures.

The concepts of value and price are illustrated in Figure 1(*a*). The horizontal axis is the water consumed by an individual and the vertical axis is the *marginal value* of water for each unit of water consumed. The value of an extra or incremental amount of water to an individual is its *marginal value* (MV). The MV of water is very high for low levels of consumption because the water that is consumed is only for high-value uses, such as drinking. The MV declines as more water is consumed. Thus, additional water is used for less valuable uses. For example, drinking water is more highly valued than water for food preparation that is more highly valued than washing a car, and so on, until the extra water consumed may only have a low MV.

The *total value*[5] of water to the consumer is the entire area under the individual's MV curve in Figure 1(*a*), up to and including the last unit of water consumed. The total value of water to the consumer less the total amount paid for water is called the *consumer surplus* (CS),[6] the area marked with horizontal lines. Consumer surplus represents the net value or benefit from consumption and, all else equal, the lower is the price the higher will be the consumer surplus. In other words, raising the water price in

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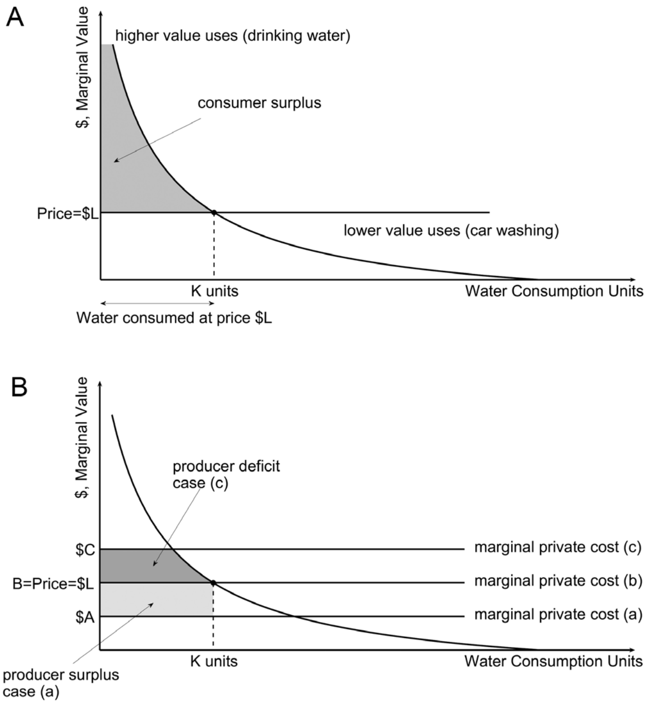
[3] External costs are costs incurred in production, or in an activity or a service, that are not directly incurred by the person(s) undertaking the activity but rather imposed on others external to those undertaking the activity.

[4] Average cost (or average total cost) is total economic costs (fixed and variable) in producing a good or service divided by the number of units produced of the good or service.

[5] Total value represents the entire benefits derived from a given quantity or quality of a good or service which can be measured by how much of other goods and services, or in monetary units, an individual is prepared to trade off for this quantity and quality of the good or service.

[6] Consumer surplus is the difference between the total value a consumer is prepared to pay for a certain quantity or quality of a good or service and what the consumer actually pays.

Figure 1: (*a*) Marginal value, the water price, and consumer surplus. **(*b*)** Marginal private costs, the water price ($L), and producer surplus (deficit)



the absence of any other change, such as an improvement in water quality or reliability, reduces consumer surplus.

Figure 1(*b*) shows the relationship between *economic value*, *economic price*, and *economic cost*. Three cases are illustrated that represent three different *economic costs* for delivering water to the consumer. In each case the *marginal private cost* (MPC), or the extra cost of delivering an incremental volume of water, is constant, but this marginal cost differs across the three cases. For simplicity, we assume the extra costs imposed on others from an incremental increase in the water supply, defined as the *marginal external cost* (MEC), is zero.

Case (*a*) shows that the marginal cost (that equals MPC because MEC = 0) equals A and is less than the price ($L); in case (*b*) the marginal cost is B and equals the price ($L); and in case (*c*) the marginal cost is C and exceeds the price ($L). In case (*a*), the water supplier receives a *producer surplus* (PS)[7] on all the water sold. The PS is the sum of the difference between the price received by the water supplier and its marginal cost of supply for all units of water; it is represented in Figure 1(*b*) by the area shaded in horizontal lines. In case (*b*), price equals marginal cost and there is no producer surplus. If there were no fixed costs associated with the supply of water services, then the level of consumption (K units) associated with this price ($L) would maximize the

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[7] Producer surplus is the economic returns to a producer of a good or service that are in excess of the minimum necessary to elicit the supply of the good or service.

consumer surplus while simultaneously ensuring that all costs of water services were fully recovered. In case (*c*), there is a producer deficit or loss, represented by the area shaded by vertical lines, as it costs more to supply the water than the revenues received from the water consumer. A producer deficit can only continue in the long run if the water supplier receives a subsidy or transfer to cover this loss.

A first-best goal of water pricing, from a societal perspective, is to supply water services at the lowest feasible cost (including *private* and *external costs*), charge the lowest possible price (while ensuring all costs are paid), and, thereby, deliver the largest possible consumer surplus over time.[8] Key challenges to achieving this 'first-best' water pricing outcome include:

(i) accounting for all the costs of water supply, including the *external costs*, such as the non-market value[9] of reduced ecosystem services, and the future supply costs if water storage is exhausted today;
(ii) delivering universal basic human water needs to all that are of high value (drinking, washing and sanitation, cleaning, and cooking);
(iii) charging water prices that allow the water supplier to cover both fixed costs (that do not change with the amount supplied) and variable costs (that vary with the amount supplied); and
(iv) measuring and accounting for within water decision-making the many market and non-market values of water across different uses.

(ii) Water pricing paradox

The water pricing paradox, its price almost never equals its value and rarely covers its costs, is explained by the special characteristics of water and how it is governed. Price almost never equals its value because water, typically, cannot be transferred across competing uses where there are different marginal values. This can arise from regulatory restrictions, such as prohibitions on the transfer of water from agriculture to urban uses (e.g. Grafton *et al.*, 2012; O' Donnell *et al.*, 2019), and by bio-physical constraints because water is heavy (1 cubic metre = 1 metric tonne) and costly to transport (Hanemann, 2006, p. 74).

The dichotomy between water values and the water price can arise for different users engaged in ostensibly the same water use. This may arise when there is rationing on the overall amount of water that can be consumed by a household, or if there are restrictions on given uses, such as a ban on outdoor water uses (Grafton and Ward, 2008). Under rationing, a water consumer may have a very high value for a particular outdoor use, such as watering a favourite tree, that greatly exceeds the value of some permitted indoor water uses, and also the water price. This would be a case of water misallocation within a household because the consumer could have a higher consumer surplus (for a

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[8] Hanemann (2006, p. 87) similarly expressed the problem of water, from an economic perspective, as being 'one of matching demand with supply, of ensuring that there is water of a suitable quality at the right location and the right time, and at a cost that people can afford and are willing to pay'.

[9] A non-market value is the economic value of public or environmental goods (e.g. wildlife) that is not directly traded or accounted for within markets.

fixed level of overall water use) if she used more water outdoors and less indoors, even if she paid a higher water price for her outdoor use.

The second part of the paradox (price rarely covers its cost) arises from two factors. First, the *external cost* imposed on others from water extraction, supply, and treatment is, at best, only partially accounted for in the calculation of water supply costs. In relation to water, these *external costs* could include a deterioration of any one of the following types of ecosystem services: (i) provisioning services, e.g. water directly used for drinking or irrigation; (ii) regulating services, e.g. water that reduces temperature extremes; (iii) habitat services, e.g. water that enables fish migration and spawning; and (iv) cultural services, e.g. water associated with ancestral practices, spiritual significance, or language and aesthetic appreciation.

Another reason why the water price rarely covers its costs is because the fixed costs, such as the capital cost of water infrastructure, are, at best, only partially included in the water price charged in many countries (Hanemann, 2006, pp. 76–7; OECD, 2012). The difference is made up by transfers or subsidies to water suppliers that are, typically, paid from general revenues or taxes of local, state, or national governments. A failure to cover all costs of supplying water services can reduce the incentives for utilities and other water providers to supply any additional water, or even maintain existing water infrastructure. These unintended consequences, in turn, exacerbate water scarcity over time, particularly when water demand is increasing.

While there may be valid reasons why the water price is set at less than its marginal cost of supply, such as safeguarding basic human water needs of the poor (United Nations, 2015), it also arises because of 'rent seeking' behaviour by water consumers and decision-makers (Huppert, 2013; Grafton, 2019). Such rent-seekers will generally have their basic water needs already met, but still wish to pay a lower price and have others pay for the difference between what the water service costs and what they pay.

To illustrate how the water pricing paradox arises, we consider two examples. First, in Kenya girls and women in rural communities can travel up to several hours per day to extract water from a common well or stream and carry water back to the community (Graham *et al.*, 2016). Such water has high value because it is required for basic household water needs yet its *economic price* is zero because there is no charge for the water they extract. The *economic cost* of the water is high because the water carriers are unable to undertake any other productive or leisure activity while collecting the water. Second, in well-developed water markets with a cap on overall extractions, such as those in Australia's Murray-Darling Basin (Grafton and Horne, 2014), the *economic price* for water can be high, especially during droughts. Nevertheless, the market water price may be less than its *economic cost* because the *external costs* associated with water use, such as the environmental consequences of reduced stream flows (Akter *et al.*, 2014), are not fully accounted for in the cap or the regulations about how water can be used.

III. Water dilemmas

When choosing among alternative options about how to allocate water across users, uses, locations, and over time, decision-makers face multiple, and frequently conflicting, objectives. A common assumption is that the objectives of decision-makers are aligned with societal or public interest objectives. In reality, some decision-makers ignore inconvenient scientific evidence (Chindarkar and Grafton, 2019) and may choose to favour one sector or group of water users at the expense of another because it is in their personal interest. Indeed, there are many types of adverse behaviours undertaken by both water users and decision-makers that occur in both rich and poor countries (Transparency International, 2008; Grafton and Williams, 2019). Here, we focus only on what we consider to be legitimate societal objectives in relation to water pricing.

(i) Efficiency versus equity

Efficiency in freshwater allocation can be partitioned into two different but related concepts: (i) *allocative efficiency*, an outcome where it is *not* possible to reallocate water across different uses and increase overall consumer surplus for the given water supply and existing level of cost recovery, including full compensation for water users with a reduced allocation; and, (ii) *dynamic efficiency*, an outcome where it is *not* possible to reallocate water nor infrastructure investment across different uses, locations, and time to increase the *present value*[10] of the sum of consumer and producer surplus, including full compensation for users with a reduced allocation of water. Note that dynamic efficiency incorporates water-supply infrastructure because of the need to optimally time water-supply investments and avoid customers paying for the costs of, but not receiving benefits from, premature infrastructure investments. By comparison, an equitable, fair, or just water allocation is one that conforms to locally established norms of distributive justice, including perceptions of fairness about both processes and outcomes (Raymond, 2003).

To capture the notion that efficiency *and* equity are important objectives, Grafton *et al.* (2017) defined a 'just, allocative, and dynamically efficient' (JADE) water allocation as a suitable goal. The challenge of implementing a JADE water allocation is to increase overall consumer surplus from water consumption while simultaneously: (i) protecting the welfare of the poor and vulnerable; (ii) considering all water values (including *non-market values*), and (iii) ensuring the costs of water supply are fully recovered.

A common assumption is that there is always an efficiency versus equity trade-off and that an increase in the water price always disadvantages the most vulnerable.[11] As Rogers *et al.* (2002) show, this is not necessarily true. For example, in the city of Phnom Penh, Cambodia, in 1986 its publicly owned water authority had only 27,000 customers out of a total population at that time of over 400,000. Of those residents with a main water supply connection, less than half paid their water bills. Those without water supply connections accessed water from private suppliers who charged a much higher per unit price than the water authority. Beginning in 1997, the water authority increased water tariffs to cover maintenance and operating costs under a

[10] The present value is the value of future benefits (or costs) measured in current dollars.

[11] Feldstein (1972, p. 34) presented a way to regulate public prices, subject to a budget constraint by the producer. He found that, if distributional equity is a key consideration in terms of pricing, then, 'the more consumption of the good is concentrated in low income families, the lower should be the relative price of the good'.

structured plan (Chan, 2009, p. 602; Biswas and Tortajada, 2010, p. 165) that included the installation of water meters for all customers and a process to respond to non-payers (Chan, 2009, p. 599; Biswas and Tortajada, 2010, p. 165). The number of customers with access to the city water supply has increased dramatically because higher prices and a lower rate of non-payment has incentivized the expansion of the water distribution system. Despite the higher water price paid by city water customers, those connected to the water supply pay, on average, less than the prices charged by private water suppliers.

Not pricing water has unintended consequences. For example, until the 2000s, the Vietnamese government set a price for irrigation water equal to a fee set at between 4 and 6.5 per cent of the value of farm production. This fee covered depreciation and repairs, inputs (electricity and fuel), and personnel costs for state-owned irrigation systems (Davidson *et al.*, 2005). In 2008, the Vietnamese government placed a moratorium on further payments of the irrigation fee on all land irrigated by state-owned irrigation water suppliers (115/2008/NĐ-CP, article 1.5).

The plus side of the 2008 Vietnamese pricing reform has been that farmers increased production on previously idle land while administrative costs fell because the irrigation fee was no longer collected. But, a zero marginal price incentivized higher irrigation water demand and led to unintended consequences and negative environmental effects (Ho and McPherson, 2010, p. 33), such as increased groundwater pumping and aquifer depletion. State-owned and operated irrigation water operators also became reluctant to expand, and in some cases maintain, their water supply systems. Consequently, and over time, state-owned irrigation infrastructure seriously degraded owing to a lack of maintenance, and there was a general deterioration in water supply services to irrigators. In response to these unintended consequences of not pricing irrigation water, the Vietnamese government legislated reforms in 2017–18 to enable the direct recovery of costs from farmers.

(ii) Water-pricing objectives

Hanemann (1997) provides an important guide for decision-makers who wish to undertake water pricing. He proposed four key normative criteria (with sub-criteria) in relation to decision-making that we summarize as the following objectives:

(i) *revenue covers costs* so that water supply is self-sustaining and also sufficiently stable for planning and investment purposes;
(ii) *costs of water supply are based on actual costs* rather than arbitrary assumptions, and supply costs include both *private* and *external costs*;
(iii) *appropriate price signals* exist for consumers so that the volume of water they use affects how much they pay; and
(iv) *the marginal costs of water supply are transparent*, including the impact of current consumption on the future water supply (that is described by economists as *user cost*).[12]

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[12] User costs are costs that might be incurred in the future that arise from using up an incremental unit today of a scarce resource (such as water in a dam).

As Hanemann (1997) highlights, these objectives are difficult to meet. Key challenges we identify include:

(i) *effective implementation* (e.g. difficulty of calculating a marginal cost that includes *marginal external cost* and *user cost*);
(ii) *conflicting goals* (e.g. need for appropriate incentives for conservation versus a desire to keep water prices as low as possible);
(iii) *agency conflicts* (e.g. the business goals of the public water utility versus the political goals of elected leaders); and
(iv) *inter-temporal trade-offs* (e.g. maintaining current water prices versus providing price signals of increasing water scarcity).

Resolution of these challenges, and the speed at which water regulation and pricing can be reformed to deliver particular goals, is context specific because of diversity in the priority of different goals and the capacity of regulators to practically implement chosen methods of water pricing and regulation. For example, what the City of Sydney, Australia (Grafton *et al.*, 2014) is able to achieve in water pricing, water regulation, and water infrastructure investments will be different to, say, Makhanda (formerly Grahamstown), South Africa (Nowicki, 2019) by virtue of history, social norms, financial and administrative capacities, sizes of the respective cities, and the willingness and ability of consumers to pay for water.

(iii) Water-pricing choices

The tariff design choices available to decision-makers revolve around two instruments. First, miscellaneous charges or subsidies imposed on or rebated to water customers that are independent of the water used. Second, a water tariff that consists of two parts:[13] (i) a *flat charge* independent of the water used, and (ii) a *volumetric price* that can vary with the level of water use. These pricing instruments and the multiple options available are illustrated in Figure 2.

Miscellaneous charges and subsidies are not directly part of water pricing but can be used to deliver particular socio-economic goals. For instance, a one-time water connection charge allocates the fixed costs of delivering water to previously unsupplied customers. A subsidy in the form of a low-income rebate for households can help to offset a permanent or temporary increase in water charges, or to defray the costs of water conservation devices.

A *water tariff* refers to both the fixed and variable components of a water bill. The fixed component or flat charge is, typically, levied to ensure the high capital costs of providing water services are fully covered; if consumers only paid a volumetric price equal to the marginal cost of water services, there would be insufficient revenues to recover the fixed costs of supplying water, such as maintenance and debt repayments for previous infrastructure investments. As the flat charge does not vary with the amount used, it also provides a stable revenue stream for water service providers because water demand often varies over a year. The volumetric price is a per unit price (such as $ per kilolitre (kl)) for the water used by the consumer.

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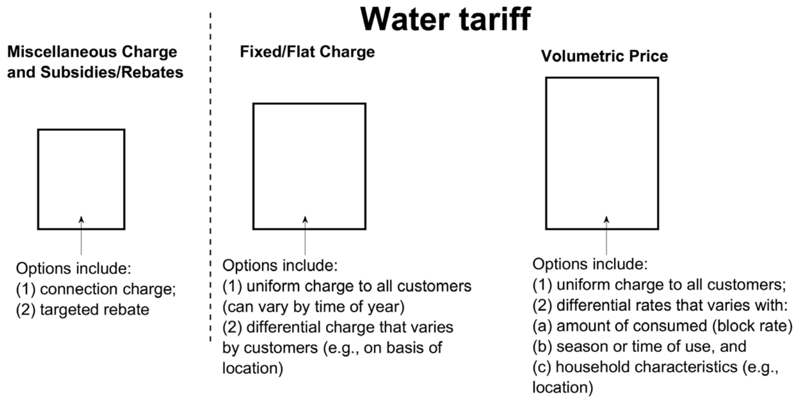
[13] Hirshleifer *et al.* (1960, pp. 90–3) proposed four possible solutions to ensure full recovery of supply costs in the presence of a falling average cost of water supply, including a two-part tariff.

Figure 2: Water pricing options



A uniform volumetric price is the same for all consumers at all times of the year, all levels of water scarcity, and all levels of consumption. A variable volumetric price is a per-unit water price that changes because of any of the factors highlighted in Figure 2. The most common variable volumetric price is a price that changes with the amount of water consumed. An increasing (decreasing) block price is one where customers are charged a higher (lower) price per unit of water consumed beyond a given 'block' or volume of water consumed. The stated intention of an increasing block pricing structure is to provide incentives for households to conserve or wisely use water. An unintended consequence of such pricing is that larger water-consuming households may end up paying a higher volumetric price than smaller water-consuming households, even if their per person level of water consumption is at or below the *per capita* level of water use in the community. A block rate pricing structure also has the downside that the *marginal values* of water differ because water customers face a different price. Thus, block rate pricing, as currently implemented by water utilities, results in water not being allocated efficiently across users (Chu and Grafton, 2018).

IV. Water decisions

Water pricing needs to be integrated into the entire portfolio of water supply and conservation decisions because tariff structures determine the revenues of the water supplier and also influence water consumption, investment decisions, and future supply levels (Grafton *et al.*, 2014). This requires a systematic process to respond to three key questions: (i) how do alternative water tariff designs affect current and future water consumption and supply? (ii) which water tariff structure is most consistent with regulatory objectives? and (iii) what complementary (non-price) measures are needed to fully deliver public interest goals?

Generally, the water supplier is a fully/partly publicly owned enterprise or privately owned company and, typically, subject to some form of regulation in relation to its water pricing. Large-scale private water suppliers are often also subject to some form of regulatory control because the delivery of water services is a *natural monopoly* which arises whenever average costs are declining in the amount of water supplied.[14] The economic advantage of a natural monopoly, if properly regulated, is that it lowers the price paid for water even when all costs are recovered and provided by a single water supplier (Hanemann, 2006, pp. 74–6).

To ensure a single water supplier does not abuse its market power and charge a water price that more than covers all its costs, regulatory oversight of price-setting is required; water treatment and service-level requirements are also necessary to ensure appropriate service standards. Typically, water supply regulations include a maximum price that can be charged to customers and this price must be justified by the costs of production.

Figure 3 provides a heuristic of the almost endless permutations of water tariff design. The vertical dimension represents the degree to which the water tariff is variable or fixed. At the bottom of the vertical axis the tariff consists of only one component, a flat charge, while at the top of the vertical axis the tariff only consists of a volumetric price. The horizontal dimension represents the degree to which individual water consumers are differentiated in relation to the water tariff they respectively face. At the far left all consumers face an identical tariff; at the far right the possibility exists that each consumer could be charged a different tariff.

Four end points (A, B, C, and D) in Figure 3 represent the possible boundaries of water pricing. Point A is the case where the water tariff consists only of a volumetric price (flat charge = 0) that is uniform for all water customers; point B is where there is only a volumetric price that is potentially different for each water consumer; point C is where there is only a flat charge (volumetric price = 0) that is potentially different for each water consumer; and point D is where there is only a flat charge (volumetric price = 0) that is the same for all water consumers. Almost all water tariffs that are currently operational around the world are in between these four possible boundary points.

A first step towards evaluating potential reforms is ascertaining where the current water tariff sits within Figure 3. Next, it is possible to decide what movement (if any) is required to meet objectives, e.g. revenue self-sufficiency, meeting basic water needs, and efficiency goals. For instance, a shift vertically upwards in Figure 3 towards greater prominence of volumetric pricing will likely increase allocative efficiency and the incentives for consumers to conserve water. However, such a change in the water tariff may also reduce the predictability of revenues for the water supplier as water consumption varies across different times of the year.

In relation to the vertical axis in Figure 3, how much the water tariff influences water use is determined by how responsive water consumption is to a change in price. Typically, the proportional reduction in household water use from a price increase is less than the proportional increase in price such that household water use is *price inelastic* (Dalhuisen, *et al.* 2003; Olmstead and Stavins, 2009; and Grafton *et al.*, 2011). From the perspective of the water supplier, this means that an increase in the volumetric price will increase total revenue as the higher price will more than offset reductions in water use. Indeed, this is one of the reasons water prices are regulated, so as to avoid a monopoly water supplier raising the price to earn a return in excess of its economic costs.

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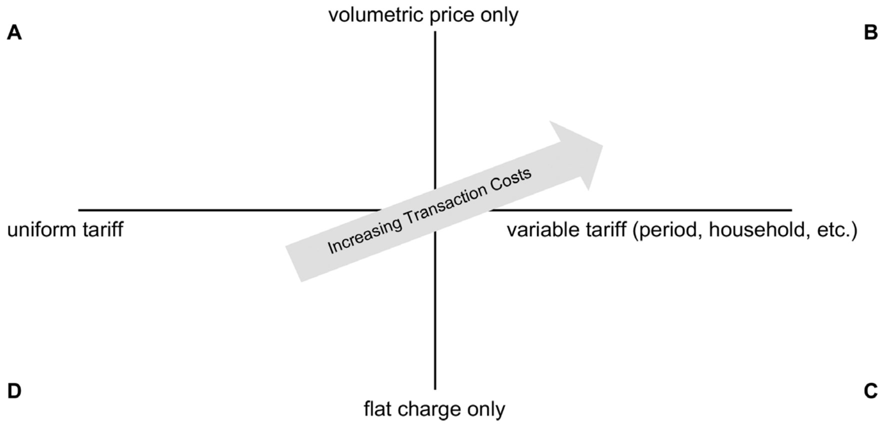
[14] A natural monopoly arises when the average cost of providing a good or service continually declines (which also means that marginal private cost is less than average cost) in the amount produced by the supplier. This phenomenon, typically, arises when there are very large capital costs that must be incurred prior to any production (such as with a municipal water distribution).

Figure 3: Dimensions of water pricing



A shift horizontally to the right in Figure 3 allows for greater flexibility in the water tariff charged to customers and, thus, offers the possibility of incorporating equity considerations into water pricing. A different water price based on when water is consumed, such as charging a higher volumetric price when there is less water available (Grafton and Kompas, 2007), may also promote dynamic efficiency. The trade-off is that the greater the differentiation of water tariffs across consumers, the higher the *transaction costs*[15] (Garrick and Aylward, 2012) that, in this case, include those costs associated with determining and collecting the water tariff. For instance, a variable volumetric price could include installing a smart meter in each customer's residence that records real-time water use and allows for a customized water price that varies across different segments of a billing period (O'Keeffe, 2018). Such pricing is likely to be much more costly to implement than charging every consumer a uniform flat charge. As a result, in many locations where there is currently a limited capacity to measure water use or even to set an appropriate volumetric price. Thus, a water tariff at, or near, point B is, in many locations, currently infeasible.

The decisions water suppliers or water price regulators face vary depending on both the bio-physical and socio-economic contexts. In general, decision-making on tariff design will be more challenging when: (i) household income is lower; (ii) water supply variability is higher; (iii) adverse, or even corrupt, behaviour is more pervasive; (iv) there is a longer history of water tariffs not covering water supply costs; (v) the administrative and financial capacity of water suppliers is less; (vi) there is a lower incidence of water metering; and (vii) environmental costs from water diversions and lack of waste water treatment are high.

(i) Water tariff design

To illustrate the determinants of water tariff design, we review urban water tariffs. Typically, a flat charge without a volumetric price is implemented where the water

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[15] Transaction costs are the ancillary costs incurred in relation to transactions around the exchange or use of an asset or consumption of a good or service.

resource is relatively abundant compared to the existing water demand. In Scotland, for example, fixed charges are the norm and households pay them through municipal taxes that are based on property prices rather than their level of water consumption. A similar approach to pricing water is employed in most of New Zealand, including the capital city of Wellington.[16]

Effective volumetric pricing requires that water consumers have a water meter that accurately measures their water use. In poorer countries, the costs of metering represent a substantial capital cost and, thus, may limit the cost effectiveness of volumetric pricing. In most OECD countries, households pay a water price that includes both a flat charge and a volumetric price that depends on the level of water used. Uniform volumetric prices are the most common approach in France, but in Spain the use of increasing block pricing is more common. In general, and noting there are exceptions, in cities where water is relatively scarce, and/or water demand is more variable across seasons, variable volumetric pricing is more likely to be used. This is because the local water supply authorities are typically obliged, especially in summer months or in times of drought, to impose water restrictions and have a greater reliance on a volumetric water price to manage water demand.

The pricing of water in the Australian Capital Territory (ACT) is illustrative of the decision-making context for urban water pricing. As in most Australian towns and cities, the water price in the ACT is set every few years by an independent pricing regulator: the Independent Competition and Regulatory Commission (ICRC). The water price is inflation-indexed and is expected to recover all the necessary fixed and variable costs[17] of the sole water supplier, Icon Water, an unlisted public company owned by the ACT government. The water price determination by the price regulator is made following public submissions to assess what costs can be 'recovered' and, thus, passed on to consumers in the form of a higher water price.

The ICRC has established that the water tariff for ACT water customers includes a flat charge and an increasing block tariff (IBT) for the volumetric price. The volumetric price has two tiers such that water consumers that use more than 200 kl per year pay a much higher volumetric charge for their water. The higher block tariff is intended to provide an incentive for households to conserve their use of water. The fixed supply charge is set much lower than what is necessary to recover the fixed cost of the water supplier, while the first tier of the volumetric price is set substantially above the marginal cost of supplying water.[18]

An unusual feature of the ACT water price is the Water Abstraction Charge (WAC) which was first applied in 1999–2000. The WAC is set by the ACT government independently of the ICRC water tariff, and paid directly to the ACT government. It includes three components: (i) a fixed supply cost that represents the expenditures associated with catchment management; (ii) an environmental cost that accounts for lower

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[16] Wellington City Council only has 1,200 customers with water meters. All other water users pay a charge that depends on the value of their properties.

[17] This is a common goal for pricing regulators. The EU Water Framework Directive, Article 9, states that 'Water prices must allow for the (adequate) cost recovery of water services, including environmental and resource costs' (Gawel, 2015).

[18] Icon Water recovers only about 10 per cent of its water supply costs from the fixed supply charge and the remaining 90 per cent from volumetric charges.

downstream flows and is proxied by the cost of purchasing water in perpetuity; and (iii) the opportunity cost borne by downstream users of reduced downstream flows that is calculated by the seasonal price of downstream water for irrigation purposes.

A possible risk with the current ACT water tariff is the under-recovery of all supply costs if actual water consumption is less than the demand forecast by the ICRC in the price determination period. This may arise in times of severe water restrictions as a result of a drought or contamination of the main water supplies, both of which have occurred within the past 20 years. Indeed, despite the fact that the ACT has water storage capacity equal to over 5 years of current annual water use, the territory is vulnerable to welfare-reducing water restrictions because of: highly variable inflows, an increasing variation in precipitation, a rising annual maximum daily temperature, and a growing population.

An alternative to setting in advance (with automatic adjustments for inflation) a water tariff that is independent of water inflows, is a dynamic price (Grafton and Kompas, 2007) that increases in a step-wise fashion as the volume of water storage decreases. The key benefit of dynamic pricing is that it greatly reduces the need for water restrictions or rationing[19] and can also provide the revenues needs to fully recover all supply costs when water demand declines (Chu and Grafton, 2018).

Despite the advantages of a dynamic water tariff, the ACT government has eschewed its use so far. A key reason for this reluctance is the possible resistance by households. Australian water consumers are concerned that, in the absence of rebates or concessions to poorer or large households, higher water prices allow wealthy households to 'buy' their way out of water shortages (Randolph and Troy, 2008). By comparison, water rationing for outdoor use has substantial support because it is perceived to affect all households equally, even if *marginal values* of water for outdoor use can be substantial and the willingness to pay to avoid severe water restrictions is high (Cooper *et al.*, 2011). In sum, in the ACT, and many other places, water is not viewed by either governments or consumers as a regular economic good and a sense of 'fairness' in how water is delivered, priced, and rationed is an important factor determining tariff structures.

A further insight into water pricing is that many jurisdictions have a 'water supply and reliability' priority in that they would much rather have a supply solution to water scarcity than a water demand and pricing approach. For instance, following almost 8 years of water restrictions that ended in 2011, the ACT government almost doubled the capacity of its water storages by 2013 at a cost of AU$410m (ACT Audit Office, 2015) or about AU$1,000 per resident. This large infrastructure cost has been incorporated into the water price charged to water consumers, making the ACT volumetric price in excess of 200kl/year ($5.38/kl), the highest in Australia and one of the highest in the world.

A similar 'supply-first' approach was also implemented in other Australian cities during the Millennium Drought that ended in 2010. In response to unpopular water restrictions, Sydney and Melbourne built billion-dollar plus desalination plants that became operational only after the drought ended and were not used (beyond testing) for several years thereafter. Such supply augmentation decisions were taken by state

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[19] In 2004–5 welfare losses due to water restrictions were estimated to be about $150 per household in Sydney relative to applying a volumetric price that varied with the level of water storage (Grafton and Ward, 2008).

governments independently of the pricing regulator and were a ‘political fix’ to growing anger over water restrictions. These water supply augmentation decisions resulted in the construction of desalination plants long before they were required and when alternative demand-based approaches, such as dynamic water pricing, would have generated much higher consumer surplus for water consumers (Grafton *et al.*, 2015).

V. Risks and options for water pricing

There is no one-size-fits-all model for water pricing. The applicability of a particular tariff design, and complementary policies, depend on the specific context and regulatory objectives. Here, we provide a process for regulators and water suppliers to think through the risks associated with tariff design, decide on the options that address those risks, and, hence, meet policy objectives.

We consider a risk as ‘an event with uncertain consequences’. For water pricing, risks could include: failing to meet a specific objective, such as revenues covering costs; a particular tariff causing an inequitable or inefficient water allocation; the transaction costs of a pricing regime overwhelming the capacity of the regulatory agency; or, an external change, such as population growth, undermining the capacity of an existing tariff structure to continue to meet specific objectives. To address such risks, a range of options are possible that may include tariff reforms and, also, complementary non-price measures, such as free water allocations or cash transfers to low-income households.

Here, we outline a process for examining water pricing risks and options that adapts a causal approach to risk assessment for food-energy-environment-water systems (Grafton *et al.*, 2016; FE2W Network, 2019) that has previously been applied in water management (Wyrwoll *et al.*, 2018). A key feature of the underlying process, and our adaptation of it below, is a participatory approach to policy development and implementation. This means that stakeholders are meaningfully involved in the process of tariff design, implementation, and reform; not consulted as an afterthought or to verify pre-determined decisions.

Participatory policy design enables regulatory agencies and water suppliers to better understand the potential trade-offs and unintended consequences of decisions. Water users will generally have better advance knowledge than a theoretical model of how their water use might respond to, say, seasonal water pricing. In the case of regulated pricing, water suppliers understand how variable supply costs or rising demand will affect their capacity to maintain and augment infrastructure. This type of stakeholder knowledge is a key input to technical analysis, such as hydro-economic modelling, of water tariff design. Eliciting stakeholder knowledge is not a costless exercise, but it is a valuable one if, as in most cases, it mitigates the social and *economic costs* of poor decision-making.

Table 1 presents a three-stage risks and options process for implementing or reforming water pricing. We illustrate this process below by adapting a real-world arrangement for pricing irrigation water extractions from multi-purpose reservoirs in Tasmania, Australia (Wyrwoll, 2019). The state-owned electricity enterprise, Hydro Tasmania, operates 30 hydropower stations through a network of 54 major dams and reservoirs. Water pricing is used to charge irrigation schemes that extract water

Table 1: A risks and options process for water tariff design

Stage	Action	Description
(1) Scoping	*(I) Identify stakeholders*	Who are the water price payers and payees? Who else is indirectly affected by water use decisions?
	(II) Identify objectives	What are the priority objectives of water pricing?
	(III) Estimate economic variables	What are the ranges of values for key variables under the existing tariff, e.g. MPC, MEC, MV, CS?
	(IV) Understand existing water pricing regime	Classify the current regime in relation to Figure 3. Using economic variables as a guide, are there any inconsistencies between existing regime and objectives?
	(V) Identify risks, causes, and consequences	What are the risks of the existing tariff? What are the causes? And consequences? Where possible, define consequences in terms of objectives. Using a causal risk diagram, show how risk(s), causes, and consequences are linked.
	(VI) Develop options	Identify options that address the linkages between causes and risks, and risks and consequences. Consider tariff reforms and non-price policies.
(2) Risks and options assessment	*(VII) Assess options*	What are the potential unintended consequences of reforms? Which options are compatible? Which are contradictory? How do economic variables change under different options? Are objectives met? Classify pricing reforms in relation to Figure 3. Use quantitative modelling
	(VIII) Stress test options	Conduct a secondary risk assessment of priority options. How will stakeholders respond to options? What actions manage the risks of options failing to achieve objectives? What are the potential implementation costs?
	(IX) Make decisions	Select a portfolio of options using pre-defined criteria and/or decision tools, e.g. maximizing consumer surplus. Does the institutional capacity exist to implement options?
(3) Monitoring and implementation	*(X) Consult and revise*	Consult stakeholders on implementation of options. Identify alternative approaches to implementation.
	(XI) Phased implementation	Conduct policy experiments of selected options. Integrate lessons from pilots in subsequent phases. Scale-up implementation.
	(XII) Monitor and evaluate	Monitor and evaluate outcomes across objectives. Enable stakeholders to play a central role in monitoring and evaluation. Document outcomes to inform subsequent risks and options assessments.

from reservoirs and rivers on which its power plants are located (see Hydro Tasmania, 2017). The volumetric water price they pay includes a water scarcity premium that represents the risk that, during low levels of water storage, Hydro Tasmania incurs costs by importing electricity from the mainland (via an undersea cable) and/or forgoing revenues from reduced exports during peak price periods in the mainland electricity market.

In our illustrative example of the three-stage decision-making process, we consider a hypothetical multi-purpose reservoir operated by a hydropower company. Irrigators extract water directly from the reservoir, creating a direct trade-off with hydroelectricity generation and revenues. We suppose the economic regulator is considering reforming a current water-pricing regime where irrigators pay a flat charge for an uncapped volume of water. Such reform is motivated by rising irrigation water demand, high electricity prices (and higher electricity generation), and recurring droughts that are causing reservoir levels to regularly fall to low levels.

In this example, we suppose the regulator identifies the following stakeholders: 20 irrigators each paying a fixed charge to access water from the reservoir; the hydropower company that supplies water; and recreational fishers who are indirectly affected by water use decisions because fish habitat declines with lower reservoir levels (Action I). The regulator's objectives include: the hydropower company receives sufficient revenues to compensate forgone generation; irrigators retain water access during periods of low inflows (in line with social norms); irrigators receive appropriate price signals to adjust their water use to scarcity (Action II).

The regulator uses surveys and stakeholder workshops as the basis for estimating economic variables. The *marginal private cost* is the historical and projected electricity price; the *marginal value* of water is estimated for different farm activities and converted into a water demand function (see Figure 1(*a*)); the *marginal external cost* of low water levels is estimated in terms of the non-market value of lost recreational fishing days; the *economic price* of water is estimated by dividing the hydropower company's revenue from the fixed charge by the estimated volume of water extractions; farmer consumer surplus and hydropower company producer surplus (from irrigation water supply) are estimated, showing that the producer surplus is negative (Action III). The flat, uniform tariff for irrigators to extract water locates the current regime at Point D in Figure 3 (Action IV).

The regulator identifies the key risk as allocative and dynamic inefficiency in water allocation. This risk encompasses: the hydropower company's water supply revenues not covering costs; the costs of water supply not being based on actual costs; lack of appropriate price signals for irrigators; and lack of transparency over marginal cost of water supply. A workshop involving all stakeholders is used to collectively identify the causes, consequences, and linkages in a causal risk diagram (Action V); feasible options are collectively identified through a facilitated process led by the regulator (Action VI). These possible options and associated risks are illustrated in Figure 4. It shows there are multiple long-term and immediate causes for the identified risk; water is misallocated inter-temporally and between irrigation and hydroelectric generation.

One of the primary causes of the risk is that irrigation extractions are not capped while the flat charge does not provide incentives to manage water use. The regulator uses participatory hydro-economic modelling to estimate the changes in economic variables and welfare outcomes from alternative tariff reforms and the impacts of non-price measures. Importantly, this modelling includes a range of scenarios for key variables in relation to climate change, electricity markets, and agricultural systems. A cost–benefit analysis is used to assess options; this analysis includes the non-market value of recreational fishing and the values of electricity generation and agricultural production to the broader economy (Action VII).

The regulator identifies several priority options. One of them is the introduction of a volumetric water price and a fixed charge to gradually pay off the installation of water meters. This reform would involve a shift along the vertical axis in Figure 3 (towards point A). A participatory workshop with irrigators is used to identify complementary actions that manage the risk that this option does not achieve regulator objectives (Action VIII).

Figure 4: Water pricing risks and options for a multipurpose hydropower reservoir

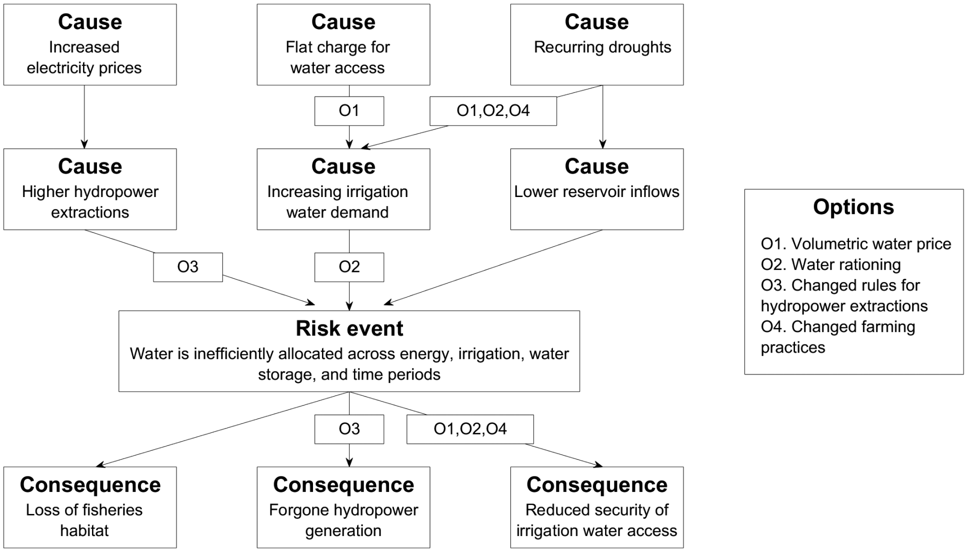
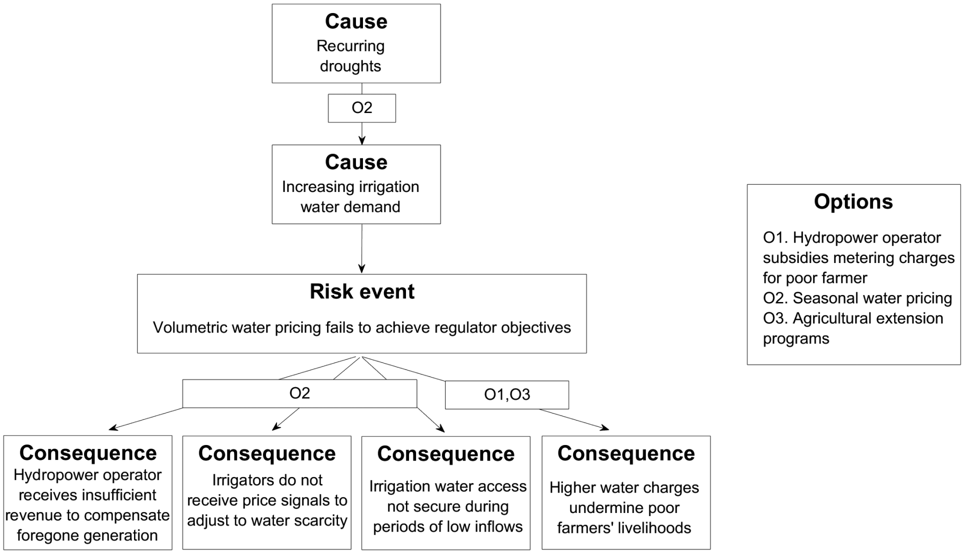


Figure 5 shows the possible complementary actions: (i) the hydropower operator partially subsidizes the fixed cost of the water meter installation and meter reading for poorer farmers; (ii) farmers pay a seasonal water price that increases in the dry season; and (iii) the regulatory agency funds agricultural extension programmes for farmers. The regulator decides to proceed with a policy portfolio comprising a two-part tariff and complementary actions on the basis that, compared to alternatives, it maximizes the sum of consumer surplus and producer surplus (from water supply), accounts for the marginal external cost of water extractions, and is most likely to meet the regulator's objectives (Action IX). An evaluation determines that sufficient institutional capacity exists to implement this portfolio of options and the transaction costs of water pricing are manageable with existing resources.

As part of the participatory process, irrigators, fishers, and the hydropower company are consulted on how the new water-pricing regime should be introduced (Action X). Based on these consultations, the reform is implemented over 4 years (Action XI). As part of its adaptive management process, the regulator conducts an annual review of the water pricing reform and updates the causal risk model as required (Action XII). A comprehensive review of the reform and reservoir management is conducted with stakeholders in Year 10, leading to a new risks and options process considering the potential access of an urban water utility to the reservoir.

Figures 4 and 5 and Table 1 summarize our illustrative case of water pricing reform. Unquestionably, the real world of water pricing is more complicated and challenging. Nevertheless, the principles of water pricing reform are consistent and a structured reform process that (i) considers risks; (ii) considers unintended consequences of decisions; and (iii) engages with water users, will likely produce better water outcomes than top-down decisions based on invalid assumptions. The key point is that an iterative, systematic process, such as the one we have outlined here, helps decision-makers

Figure 5: Adaptive assessment of water pricing reform



understand risks, evaluate a range of options, and helps to avoid water pricing that fails to deliver on reform objectives.

VI. Conclusions

Decision-makers around the world face the dilemma of how to deliver a reliable supply, now and into the future, of water services that safeguards basic human needs and maximizes the consumer surplus of water users. This requires not only engineering decisions about maintaining and augmenting water supply, but also economic decision-making about how to price water in ways that incorporate sustainability, efficiency, and equity.

Key to effective and efficient water pricing is a systematic process to understand: (i) the value of water in alternative uses; (ii) the *private* and *external costs* of supplying water services; and (iii) the multiple options to determine an appropriate water tariff. Within the four dimensions of water pricing (uniform versus variable tariff and flat charge versus volumetric price), there is an almost infinite number of possible pricing combinations. Within this choice set, the preferred water tariff depends on multiple factors including: the goals of water pricing; the capacity of a water services supplier to allocate its costs, to price water, and to collect revenues from its customers; the price responsiveness of water consumers; and what is considered to be a fair or just water tariff.

To guide water pricing reform and decision-making about water tariffs, we provide a systematic process for water pricing. We contend that this process, at a minimum, requires: (i) *scoping* (identify stakeholders, understand *status quo*, identify possible risks, consequences, and options); (ii) *risks and options assessment* (assessment of options, stress testing of options and decisions); and (iii) *monitoring and implementation* (monitor, consult, and revise). Failure to implement such a process will increase the likelihood of unintended consequences and will likely perpetuate the paradox of water pricing; its price almost never equals its value and rarely covers its costs.

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