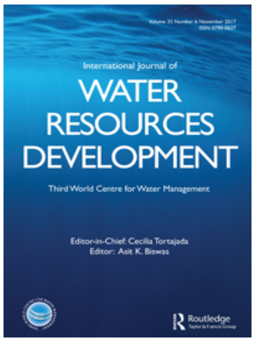

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Desalination and the commons: tragedy or triumph?

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ABSTRACT

A policy is more likely to be economically efficient when its costs and benefits fall on the same group, but politicians can allocate costs and benefits to different groups within their jurisdictional commons. This article examines the distribution of costs and benefits from desalination projects using examples from San Diego, Almería and Riyadh. The examples illustrate how mismatches between costs and benefits can persist or change as politicians adjust the policy portfolio to balance inefficiency and political risk.

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Common-pool resources are notoriously difficult to manage due to their non-excludable, yet rival nature (Dietz, Ostrom, & Stern, 2003; Gordon, 1954; Hardin, 1968). The management of common-pool *water* resources is even more difficult, because allocation decisions affect water as well as the costs of sourcing, moving and treating that water. Water projects are often subject to common-pool resource dynamics because water flows and infrastructure scale invite or require involvement from government bodies that have the power to allocate benefits and costs (Ostrom, 1965; Zetland, 2008). The existence of such a situation in which benefits and costs are shared need not lead to a dilemma in which the common-pool resource is mismanaged. It depends on how local political institutions manage the commons (Ostrom, Gardner, & Walker, 1994).

This article uses three case studies to illustrate how politicians allocate the non-excludable, rival common-pool costs and benefits of desalination in ways that can subsidize one group at the expense of another. Mismatches between costs and benefits matter to policy makers as they grow in magnitude and burden because less efficient, less fair outcomes attract more attention and controversy (Biswas, 2005; Braga, Strauss, & Paiva, 2005). This political-economic perspective on allocation adds to basic economic discussions of efficiency by highlighting why interest groups might lobby politicians to change allocations and why politicians might choose one policy over another that seems more efficient (Krueger, 1974; Tullock, 1967).

It will be useful to begin with a brief overview of the case studies, their cost–benefit mismatch, and their political conditions. In San Diego (USA), local politicians have told existing water customers that their payments for desalinated supplies would improve reliability, but reliability will actually fall (and political risk rise) if politicians allow developers to divert

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additional water to new homes (Zetland, 2009). The situation in Almería (Spain) is simultaneously worse and better with new desalinated supplies. On the one hand, farmers have not reduced their unsustainable depletion of groundwater. On the other, the loss of that common-pool resource has increased the likelihood that farmers will buy more water from the desalination plants politicians have built for them (García-Rubio & Guardiola, 2012). The final case, Riyadh, illustrates how a royal decree can shield households from 99% of costs, until a newer decree lifts prices near to the full cost of service. These cases illustrate how politicians can allocate costs and benefits to different groups, but they also show that the resulting inefficiencies and subsidy burdens can make it hard for 'unsustainable' policies to continue.

The article proceeds as follows. The next sections explain how desalination can address scarcity and how politicians distribute the costs and benefits of scarcity. Three brief case studies then illustrate how desalination's costs and benefits reflect local institutions. Those are followed by a short discussion of the impacts of desalination on the world's climate (a global common-pool resource) and a concluding section on lessons learnt.

The political economy of water scarcity

Water is an important input to many activities that directly and indirectly benefit humans, but increasing water scarcity (or stress) makes it difficult to meet all demands (Zetland, 2014). Potential reforms must address this perceived excess of demand over supply, but they must also consider existing management norms. Most discussions of economic water use for direct human benefit treat water as an excludable good. Urban water supplies, for example, are sold to any member of the public (hence, a 'public' utility) in a system that is managed as an excludable, non-rival club good. Agricultural water rights, likewise, are treated as excludable, rival private goods. The next section will discuss management of non-excludable water such as common-pool water, but this section examines how exclusion makes it easier to expose users to price signals and other tools for balancing demand and supply.

In conditions of scarcity, economists reduce demand by shifting in or sliding up the demand curve. The demand curve of an individual or group shows how the value of each unit of water falls as more water is consumed. These values show priorities, i.e., for drinking over irrigation. Taking values as given, actual consumption – or quantity demanded – only occurs for units whose values are greater than the price of water. The demand curve can shift in with a change in tastes or technology that assigns lower values to water, meaning that less is consumed at the same price. One might, for example, decide not to have a lawn or use drip irrigation to produce the same greenery with less water. An increase in price, in contrast, reduces quantity demanded by choking off lower-valued uses, e.g., the tenth minute in the shower.

Supply can be increased in symmetric ways. Supply can shift out (delivering more water at the same cost) with a change in tastes or technical innovation, e.g., deciding to use recycled wastewater or implementing better desalination technology. Quantity supplied can increase by spending more money to use existing sources more intensively, i.e., sliding up the supply curve.

Each of these options treats water as an excludable good, but the process of choosing which option to pursue depends on a non-excludable political process that affects everyone. Leaders play a critical role in making policies that affect scarcity (Ostrom et al., 1994). In some cases, they may tighten exclusion so costs and benefits fall on the same people and efficiency increases (Baumol & Oates, 1971; Hoque & Wichelns, 2013). Or they might loosen or abandon exclusion such that costs and benefits fall on different groups (McEvoy, 2014; Zetland, 2009).

This article will argue that leaders may manipulate the distribution of benefits and costs from desalination to promote their interests. The size of the resulting cost–benefit mismatch indicates the policy's inefficiency and inequity, but the existence of a mismatch does not mean the policy is mistaken. Some policies may be inefficient compared to theoretical alternatives but more politically attractive.

Allocating costs and benefits in the commons

Most economic discussions of inefficient water use focus on negative externalities from private consumption or overuse of common-pool resources. These examples are similar in theory since the negative externality cost of one person's action falls on another who cannot exclude or protect themselves from it, just as one person's use of water in a commons leaves less for others who are helpless to prevent that use. In these cases, inefficiency can be blamed on inaccurate price signals and missing rights, respectively. Policies can change those outcomes, and this article focuses on how politicians affect outcomes by allocating the costs and benefits of desalination projects. Although costs and benefits could be matched to treat the water as a private, excludable good, they are often mismatched, such that costs fall on one group while benefits go to another. This problem of mismanaging the 'common-pooled' costs and benefits of major infrastructure projects is well known (Eckstein, 1958; Flyvbjerg, Bruzelius, & Rothengatter, 2003; Hirschman, 1967), but it is not inevitable. It is therefore important to define inefficient allocations and explain why leaders might allow or prevent them.

Conventional cost–benefit analysis collapses time, space and risk into a net present value (NPV) that is misleading when temporal, spatial and informational impacts are unevenly distributed. Why would impacts be uneven? Citizens prefer benefits that are known, local and current but costs that are unknown, distant and future. Those biases would explain why citizens support low-NPV projects that deliver sooner over high-NPV projects that deliver later (Kahneman, 2011). Or perhaps politicians emphasize local and current benefits while obscuring distant costs. This presentation *may* reflect the median citizen's preferences if the resulting NPV is positive *and* losers are compensated, but – as Scitovszky (1941) pointed out in his criticism of this Kaldor-Hicks criterion for efficiency – losers are not always compensated. It is thus common for special interests to benefit when policies skew the allocation of common-pooled costs and benefits (Acemoglu & Verdier, 2000; Kaufmann, 2005; Transparency International, 2008; Wallis, 2004; Zetland, 2010). Taking such a mismatch as given, it is likely to be problematic for politicians if citizens believe that excess costs are falling on them (Thorndike, 2006). Thus, choices or policies might be defined as 'sustainable' when benefits and costs fall on the same group but 'unsustainable' when benefits go to one group and costs fall on another. Although a politician might argue that such distortions serve the greater good – e.g. by helping citizens accept useful but complex ideas they may not have the time or ability to understand – one might just as easily argue that the distortions serve politicians' selfish interests (Hall, 2000; Zetland, 2010).

Principal–agent theory explains why and how citizens use politicians as their agents. Public-choice theory explains why and how selfish politicians may betray citizens to serve their own or special interests. Combined, these theories give a simple model in which the average voter (principal) trusts their politician (agent) to represent their interest but where the politician may actually serve a special interest (public choice). In the case of desalination projects, the agent serves the principal by implementing solutions that maximize expected net benefits to the principal. Betrayal of the principal occurs when the agent unfairly allocates pooled costs and benefits to principals as a means of helping themselves or special interests. The above definition of an unsustainable policy can thus be expanded from its economic base of costs exceeding benefits to a political dimension, i.e. 'unsustainable' if principals think their agents have given them the worse share of pooled costs and benefits.

These definitions will make it easier to discuss how desalination might come with a 'surprising' distribution of benefits and costs. They also suggest how to reduce inefficient and unfair outcomes, i.e. reporting the size and distribution of a policy's fiscal, environmental and social impacts to citizens who have some way of expressing their (dis)approval of the policy. Such a process could enhance efficiency, social cohesion and political stability.

Reliability or growth in San Diego?

The city of San Diego and neighbouring municipalities share approximately one year of surface storage capacity and possess virtually no groundwater reserves (SDCWA, 2015). The region ('San Diego', for convenience) receives most of its water from a complex aqueduct system that extends hundreds of kilometres to the north and east from its location at the south-west corner of the United States. That system is owned and operated by the Metropolitan Water District of Southern California (Met), a cooperative of 26 member agencies whose payments cover Met's costs of importing water to the region. San Diego's County Water Authority (the Authority) is Met's largest member agency in terms of payments and water deliveries. The Authority and Met have a complex relationship that has survived over 70 years of disputes (Zetland, 2008).

These basic facts mean that San Diegans face two costs for their water supply. The first is the cash cost of using energy and infrastructure to bring in water. The second is the expected cost of risk, i.e. losing access to imported water. Although some of this risk is physical (losses due to canal leaks, pipe breaks, weather variation and so on), its largest share is political, i.e. Met deciding – as it has on occasion – to reduce San Diego's supply (Zetland, 2008). San Diego wants to reduce this risk by increasing local supply from wastewater or seawater. Although San Diego has recently expanded its recycled-wastewater programme, politicians convinced the citizens a decade ago to commit to a desalination plant (Flannery, 2008). Poseidon LLC opened the $900 million Claude 'Bud' Lewis Carlsbad Desalination Plant in December 2015. (Lewis, Carlsbad's mayor until 2010, negotiated the original project for his city. The Authority took over the contract when financing costs and legal troubles rose.) The plant's production capacity of 190 ML per day will provide roughly 7% of the region's total water supply (Fikes, 2015).

Why have San Diego's leaders pursued desalination when there are cheaper paths to reliability? The Authority has tried to reduce demand. Efficiency improvements and awareness have reduced water consumption from roughly 760 litres per capita per day a decade ago to current levels of about 570 litres per capita per day (SDCWA, 2016). Although residents use 40% of their drinking water outdoors, the Authority has not tried to complement the inward shift of demand by raising prices to reduce the quantity demanded (SDCWA, 2016). Why not? The first answer is simple. The utility's price increases based on rising costs are controversial enough without adding scarcity surcharges that attract lawsuits (Stevens, 2014). The second is cynical. Politicians and developers want to sell more houses to new arrivals, and higher water prices would discourage growth (Zetland, 2009). The third is psychological. Higher prices may cause a discrete change in tastes that results in dead lawns and – more important – an elastic response that lowers revenues. The fourth is tactical. Higher prices will reduce demand without increasing San Diego's water security because lower purchases from Met would decrease San Diego's 'right' to Met water, which it might want to exercise in a drier, future year (Zetland, 2008). These overlapping reasons explain why leaders might present a biased picture of the costs and benefits of desalination.

Allocating costs and benefits

The shift from living within current supplies to getting new supplies worries locals, who have paid for decades of growth benefitting land developers (Jennewein, 2015; Keatts, 2013; Larson, 2013; Yerardi, 2014). In the current case, politicians have minimized perceived financial burdens by spreading the plant's $900 million cost across *all* customer bills. The magnitude of this obfuscation can be calculated using Authority figures projecting that an "average household's water bill would increase approximately $6 a month by 2016 to pay for" a 7% increase in supply (SDCWA, 2012). These two numbers allow us to compare the current, average-cost plan, in which all customers pay $6 per month, to a marginal-cost plan in which 7% of customers pay the full cost of marginal demand, i.e. an additional $6/0.07, which is $86 per month ($1032 per year). Those additional charges would panic current residents by signalling an end to business as usual, and frighten potential migrants by signalling the true cost of their presence. Note that this average-cost policy also weakens downward pressure on intensive and extensive demand(consumption and growth, respectively), by hiding marginal costs within a single price for the entire area (Zetland, 2008).

In a stylized representation of these differences, Figure 1 shows how demand (solid) interacts with two different prices aimed at covering the costs of supply: the dashed line, with S_b representing baseline supply (roughly $815/ML) and S_d representing the roughly doubled marginal cost of desalinated supplies (SDCWA, 2012, 2013). This supply curve interacts with demand according to the way prices are set at P_1 or P_2. A price based on average cost results in a quantity demanded (P_1, Q_1) that necessitates the desalination plant. A price

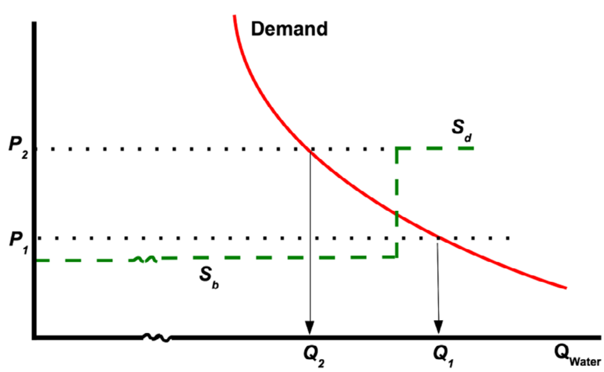

Figure 1. San Diego charges a low, average-cost price (P_1) on water, such that quantity demanded (Q_1) justifies the more expensive desalinated supply (S_d). Prices at P_2 (representing the marginal cost of desalinated water) would result in a lower quantity demanded (Q_2) and thus no need for additional, desalinated supplies. Source: Author elaboration.

based on the marginal cost of additional water from desalination results in a drop to a quantity demanded (P_2, Q_2) that renders the desalinated supply redundant (Vedachalam & Riha, 2012). The important difference between these scenarios can be seen if consumption is limited to S_b. Will additional supply (S_d) raise the quantity demanded by charging P_1 or lower it with prices at P_2? A reduction in use would be a tough sell in a region whose population has grown at more than double the national rate since World War II and has no plans to slow down (RWMG, 2013).

What about reliability and risk? An increase in price that reduces consumption *when supplies are available* leaves less room for cutting demand when supplies are scarce. More intriguingly, a reduction in water purchases from Met lowers the Authority's 'average draw' on Met water, a reference point for allocating scarce water among Met's member agencies that San Diego wants to preserve for future emergencies (a 20% cut from Q_1 is less painful than a 20% cut from Q_2). Desalination, in contrast, allows current behaviour and growth to continue at a small cost to the average customer. It also gives local leaders greater security in their interdependent relations with Met (Yousef, 2004).

What about the plant's climate change impact? The plant will emit 61,000 tons of CO_2e annually (Voutchkov, 2008). The estimated damage from those emissions varies, but let's assume a social cost of $50 per ton, or roughly $3 million per year, which works out to less than $0.005 per human. Going local, an offset of emissions under California's cap and trade system, based on current prices of $12/ton CO_2e, probably adds about $750,000 per year to costs, or $0.25 per San Diegan.

The only relevant fact from these calculations arrives as an afterthought: Voutchkov (2008) assumes that the plant will be carbon neutral, because 47,000 tons of its emissions will be offset by a *reduction* in energy-intensive water imports from Met. Such a reduction does not make sense when regional plans promise a 30% increase in population by 2035 (RWMG, 2013), but it does when you consider that Voutchkov was a senior vice president at Poseidon LLC until 2009. This contradiction did not go unnoticed by the California Coastal Commission, which had turned the company's promise of 'carbon neutrality' into a condition for permitting the plant's construction. The commission is asking Poseidon to address this matter of non-compliance (CCC, 2016).

Are current policies sustainable?

The allocation of costs among existing customers for supply that will facilitate the arrival of newcomers suggests an unsustainable policy. The 20% drop in water demand in the most recent year of California's ongoing drought has rendered the plant's supply redundant, thereby strengthening that perception (Rivard, 2015; SDCWA, 2016). Politicians have responded, first, by pointing out that existing residents have received benefits from regional growth in return for subsidizing the arrival of new residents. Second, they can claim – given regional competition among cities – that growth will occur *somewhere*. An allocation of costs among all residents might be a pre-emptive policy for avoiding the conflict that might arise if cities built their own supplies. Private goods they might be in theory, but they would be common-pool in political reality should one city face shortages while its neighbour does not. These excuses are inadequate. The desalination plant strengthens the region's supply portfolio, but its cost allocation sends the wrong message. Southern California faces future water shortage risks as climate change reduces supply and projected population increases of 40% by 2050 increase demand (Keatts, 2015; Sanders, 2016). Politicians who allow this growth may be favouring special-interest developers over principals who want reliability.

Groundwater or exports in Almería?

It is conventional wisdom that irrigation is the lowest-value water use and desalination the highest-cost water source, but the value of irrigation water in Spain can exceed the cost of desalination (Calatrava & Martínez-Granados, 2012). This potential surplus explains why treatment plants are desalinating seawater and brackish water and recycling wastewater for irrigators in Almería, but it does not explain why farmers are paying a fraction of the cost for a fraction of the desalinated water produced (GWI, 2015). The explanation lies with policies that subsidize desalinated water while other policies fail to restrict groundwater over-drafting. Politicians have allowed farmers to benefit from the common-pool resources of citizens, but changes in the water supplies are making those policies obsolete.

Almería is one of the most important and profitable provinces for agricultural production in Spain (Colino-Sueiras & Martinez-Paz, 2002). Fernández, Thompson, Bonachela, Gallardo, and Granados (2012) estimate water's value in production (its shadow price) to be \$8–17/m^3 in this area (all currencies in the article have been converted to US dollars using August 2016 market rates). The cause of such values can be seen in Figure 2: immense investments in greenhouses, which simultaneously support a high willingness to pay for water and explain water's small, 3% share of total production costs (Cabrera Sánchez, Uclés Aguilera, & Agüera Camacho, 2015).

High values and a low share of total costs do not mean that desalinated water is popular, as cheaper supplies exist. According to CAPMA (2012), three desalination plants treat sea and brackish water (32 and 42 GL per year, respectively) for irrigators and/or cities but farmers use only 8.7 GL of those supplies. That quantity accounts for only 10% of their total use

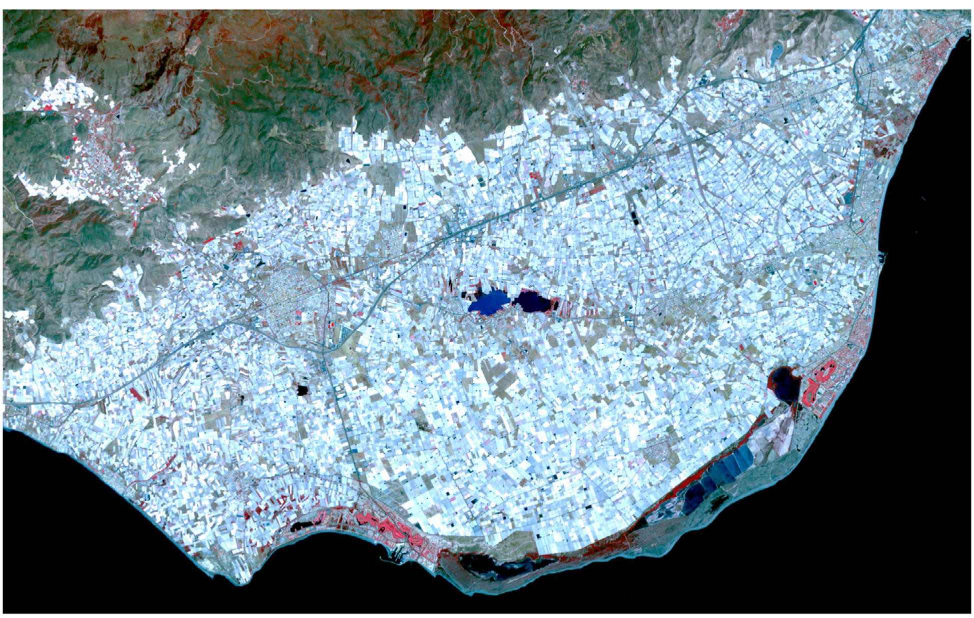

Figure 2. Satellite photo of Campo Dalías, Almería. Source: NASA Jet Propulsion Laboratory (2011).

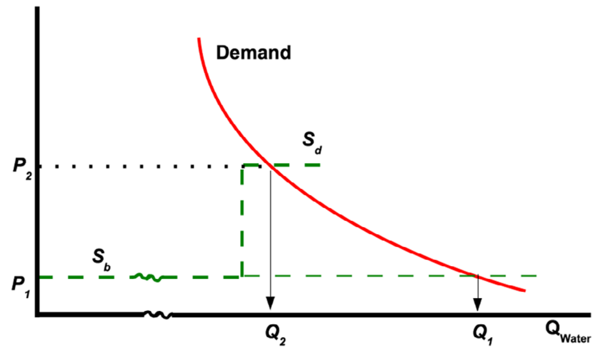

Figure 3. Farmers can afford to pay for desalinated water (S_d) although it costs more than groundwater (S_b), but weak regulations allow them to unsustainably over-draft groundwater for lower-valued uses, such that quantity Q_1 is demanded, rather than the sustainable quantity Q_2. Source: Author elaboration.

because desalinated water is too expensive: \$0.60/m^3 after subsidies that cover half its production cost. Farmers get most of their supply from cheaper imported water and groundwater, each accounting for 35% of total use. Surface and recycled wastewater supply the remaining 20% (CAPMA, 2012). Water accounts for a low share of total costs, but farmers are acutely aware of the politically negotiable price they pay. According to Giannoccaro, Castillo, and Berbel (2015), a representative sample of farmers from Almería are willing to pay \$0.44/m^3 under normal conditions, and \$0.63/m^3 under drought conditions. Those values explain their lack of interest in desalinated supplies that cost more than other sources.

Figure 3 provides a stylized representation of this situation, showing that farmers with high water productivity are willing to pay the full, marginal cost of desalinated water (S_d). It also illustrates that they would prefer – absent binding restrictions on groundwater use – to use more, cheaper (S_b) supplies. The question is how to shift their demand from critically over-drafted groundwater to desalinated supplies (López-Gunn, Rica, & Cauwenbergh, 2012).

Allocating costs and benefits

The Spanish government knew long ago that groundwater over-drafting was unsustainable (Albiac et al., 2003; Martínez Cortina & Hernández Mora, 2003). Over-drafting can be tackled by reducing demand or increasing surface supplies. Demand reductions could have come from irrigation efficiency or fallowing, but Almería's greenhouses were very efficient, and fallowing was a political non-starter (Berbel, Mesa-Jurado, & Pistón, 2011). Given increasing controversy over surface transfers (Avirama, Katzb, & Shmueli, 2014; Gómez, Delacámara, Pérez, Ibáñez, & Rodríguez, 2013), the government launched a programme in 2004 that aimed to increase supply via desalination, wastewater reuse and irrigation efficiency (De Stefano, Fornés, López-Geta, & Villarroya, 2015; García-Rubio & Guardiola, 2012). The programme assumed that farmers would turn to desalinated water and pay the government for construction and operating costs, but farmers continued to exploit a regulatory loophole on self-supply that gave them access to cheaper, convenient groundwater (Albiac, Hanemann, Calatrava, Uche, & Tapia, 2006; MacMillan et al., 2010). The government faced a choice between selling low volumes of expensive water or subsidizing prices to increase volumes, raise plant efficiency and perhaps decrease groundwater stress. It took the latter option, with a promise to tighten groundwater regulations (Gómez et al., 2013), but progress has been slow (De Stefano et al., 2015; Molina & Melgarejo, 2015). The only sustained trend has been politicians' willingness to give farmers easy access to common-pool water and money.

Are current policies sustainable?

Almería's farmers are producing record quantities of food on record hectares of land as local groundwater continues to fall (De Stefano et al., 2015; Hortinfo, 2015). Politicians have already spent enormous sums on providing a desalinated substitute for local groundwater, but weak or ineffective regulations have not prevented further groundwater depletion. Luckily for politicians, it seems that this unsustainable scenario is solving itself, as the rising cost of pumping groundwater is lowering desalinated water's relative cost. Indeed, De Stefano et al. (2015) describe *private* desalination as a logical extension to the government's programme. One private plant is already in operation, but capacity will double if four planned plants come online (CAPMA, 2012).

The best part of the end of commons and the rise of desalinated water as a private good is the reduction in risk to politicians who try to protect remaining groundwater (Yousef, 2004). The availability of desalinated water will make it much harder to claim that regulations are killing agricultural jobs by shifting the discussion of opportunity costs from lost jobs to lower profits.

This example shows how favourable conditions do not necessarily result in favourable outcomes; i.e. farmers may not shift from over-drafted groundwater to desalinated water even when they can pay. Politicians have allowed farmers to benefit from common-pool water and subsidies, but the unfair skewing of costs and benefits has helped end those policies. First came a halt to new transfers from other regions. Then came the end of the new supply programme. Now comes the potential shift to a sustainable policy in which farmers pay the full cost of desalinated water they use as a private good as they reduce their demand on the over-stressed groundwater commons.

Expensive or cheap in Riyadh?

Roman emperors spent their personal wealth on aqueducts that supplied free water to public drinking and bathing facilities. It is still possible to drink from free-flowing spouts on Rome's streets, but household water prices are much higher. Riyadh, in the Kingdom of Saudi Arabia (KSA), has pursued a similar path to Rome in a far shorter time. Until the end of 2015, water prices in the capital were kept at \$0.05/m^3 through royal subsidies funded by oil revenues (Abderrahman, 2001). The average household paid \$2 per month for its water service, and six million Riyadhis used an average of 280 litres each. At the end of 2015 and a year of unexpectedly low oil prices, the KSA government announced massive increases in water and sewerage tariffs at the National Water Company (NWC). A household consuming 30 m^3 per month would see water's marginal price rise from \$0.03/m^3 to \$0.41/m^3. A household consuming 50 m^3 per month would pay even more: \$1.62/m^3 (GWI, 2016).

These prices had not been considered politically feasible when they were proposed years earlier (Abderrahman, 2006; Ouda, 2013a), but people have not taken to the street. Yes, citizens threatened to drill their own wells to avoid charges rising from \$2 to \$10 per month, and yes, the minister in charge of water and electricity was fired, but the higher tariffs remain

(Zaid, 2016). Higher tariffs are likely to reduce both demand and quantity demanded as customers reduce wasteful use, repair leaks, and so on (Ouda, 2015). The relatively large increase in tariffs is also likely to overwhelm the fall in quantity demanded, such that water revenues increase, which will reduce NWC's reliance on government transfers. Both changes will make it easier for NWC and its partners to shift financing and attention from additional supply to improving operations, reducing leaks, increasing storage and so on (Ouda, Al-Waked, & Alshehri, 2014). The biggest losers from these changes – given government pledges to protect the poor from higher bills – will be construction firms deprived of new orders for desalination plants.

The recent radical changes in Riyadh make it possible to examine a change from the largest mismatch between costs and benefits to the closest match, two outcomes that are perhaps only possible with an absolute monarchy that can give a massive subsidy as easily as take it away. It is hard to imagine such a dramatic subsidy or change of policy in either San Diego or Almería. Luckily for the citizens of Riyadh, the move to higher prices promises to deliver greater benefits than costs, an improvement that might be best understood by looking into the not-too-distant past.

Allocating costs and benefits

Under past policies, the government subsidized water prices but citizens got poor service because the NWC was not receiving enough money to expand Riyadh's supply in pace with the demand for nearly free water. According to GWI (2014), total revenues to NWC covered only 10% of the \$0.80–2.00/m^3 in operating costs of the Persian Gulf desalination plants, located 500 km away and 600 m lower than Riyadh and the 400–2400 m deep wells drilled 50 km away (Al-Zahrani, 2010; Ouda, 2015; Rodriguez-Vidal, 2013). Figure 4 provides a stylized illustration of how official prices (P_1) were far lower than the cost of supplies from brackish groundwater (S_b) and desalinated water (S_d).[1]

Figure 4 also shows how the quantity demanded at P_1, by exceeding supply, leads to service interruptions that result in customers facing a shadow price (P_3) high enough to lower the quantity demanded to Q_3. Riyadhis 'pay' P_3 through lower reliability, contamination, and storage costs, and spending time and money on tanker water deliveries. Citizens probably saw such inconveniences as tolerable when water was so cheap, but some may have

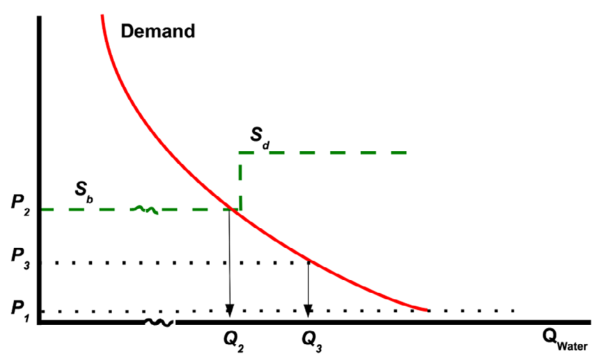

Figure 4. The cost of supply from groundwater (S_b) and desalination (S_d) is much higher than the price of water (P_1). Excess demand at that price is cut back by interruptions in service, such that the shadow price of water is P_3 and the quantity demanded is Q_3. Source: Author elaboration.

wondered whether subsidized water, electricity and gasoline represented a fair division of benefits between 21 million citizens and the plutocracy of 9000 princes (Economist, 2015a, 2015b, 2015c).

Putting governance issues aside, it is clear that the royal family and its government could afford to subsidize citizens as long as oil income flows were strong. KSA's annual water and wastewater operating budgets were $3 billion, and capital expenditures roughly twice that (GWI, 2014). To these direct costs must be added the opportunity cost of energy inputs. According to USEIA (2014), KSA uses 2.9 million barrels of oil per day (MBD) for 60% of its energy supply, most of which is bought at internal prices reflecting the $4–15/bbl domestic cost of extraction. Of the 2.9 MBD, 0.7 MBD goes to power. The assumption that one-quarter of that quantity goes to desalination (0.175 MBD, or 3% of total energy use), combined with an oil price of $50/bbl, gives an opportunity cost of roughly $7 million per day, or $2.5 billion per year. Water subsidies totalling $10–12 billion per year (around $500 per citizen) may have been acceptable in 2013, when oil export revenues were $280 billion, but not as much in 2015, with revenue projections of $160 billion (Mahdi, 2014; Nereim & Carey, 2015). It has long been known that subsidized domestic water prices increase consumption of water, money and energy (Al-Sheikh, 1998), but low oil prices made those policies unsustainable for KSA's leaders.

Are current policies sustainable?

Cheap water policies wasted water, money and energy while delivering bad service. The recent removal of most subsidies is likely to reduce demand (e.g. to point Q_2 in Figure 4), which is likely to reduce pressure on aquifers, reduce energy consumption, and help NWC improve reliability (Ouda et al., 2014).

The knock-on effects of the move to full water pricing might be considerable. Cheap water policies contributed to constantly increasing energy consumption and greenhouse gas (GHG) emissions. KSA had ignored those trends in domestic affairs and tried to block their discussion in IPCC reporting (Economist, 2014b), but emissions are likely to drop as recent increases in water and energy prices reduce quantities demanded. Higher energy prices might also curtail groundwater over-drafting.

According to Ouda (2013b), sustainable conventional (80%) and nonconventional (20%) supplies provide a total of 6.4 km^3/year. That is more than enough water to meet municipal and industrial demands totalling 3 km^3/year, but irrigation demand of 15 km^3/year (84% of total demand) depletes those sources as well as non-renewable groundwater. The government has been tackling agricultural water use by winding down subsidies for irrigated wheat, importing fodder for dairies, and investing in overseas farms (Karam, 2008; Zetland & Moeller-Gulland, 2012). Domestic agricultural output is likely to fall further as 'fully priced water' enters daily conversation, energy charges rise and water companies see aquifers as potential substitutes for costly desalinated water. Shifting water from farms to cities would be controversial in most countries, but Ouda (2014) says falling agricultural employment and production are not controversial in KSA because 80% of agricultural workers are foreigners and Saudi culture favours trade over farming. Low oil prices may have forced leaders to unwind cross-subsidies to water users, but those changes mean that KSA has radically improved on unsustainable policies that contributed to inefficiency and risk.

The global costs of local desalination

The discussion so far has focussed on the direct, local benefits of increasing desalinated water supplies whose local cash costs are buried in others' bills (San Diego), partially subsidized by the government (Almería), or paid almost entirely (or not) by rulers (Riyadh). Those local cost–benefit calculations are not complete, as desalination imposes indirect costs on others via GHG emissions (Lattemann & Höpner, 2008; Napoli & Garcia-Tellez, 2016). Table 1 provides a rough estimate of the local (CapEx and energy) and global (GHG) costs of desalination.

Are distant costs greater than local costs? In the case of Saudi Arabia – a country unapologetic about its massive GHG emissions – the answer is probably yes, but the net harm from San Diego and Almería emissions appears to be quite small. San Diego's plan to offset its GHG emissions will cost customers about \$0.25 per year each. Farmers in Almería pay indirectly for carbon because power plants participate in the EU's emissions trading system (ETS), but the low cost of ETS permits (\$8.60/ton CO_2e in 2016) means that GHG emissions cost almost nothing (\$0.003/m^3). Those small costs may suggest that governments can ignore the global impacts of cheap water policies, but the importance of climate change suggests otherwise (Economist, 2014a).

Tragedy and triumph in context

This article has explored how policies allocating the costs and benefits of desalinated water can treat the water as a private good for which users pay full costs or a common-pool good for which some water users are subsidized by others. Although politicians might gain from directing benefits to a favoured group and costs to another, they must also weight the impact of inefficiency from wasted money and water and the risk of protests from those left with more costs than benefits. Three case studies explored the ways those forces varied with larger political and economic trends, thereby enriching the basic cost–benefit analysis of desalinated water policies.

In many cases, desalination policies interacted with other common-pool goods. A lack of centralized control over growth in the San Diego region meant that regional water supplies were subject to common-pool dynamics. In Almería, groundwater has been over-exploited

Table 1. Production capacity, capital cost, energy consumption and GHG emissions for San Diego, Almeria and Riyadh.

	ML/day	\$ millions	GWh/year	CO_2e tons/year
San Diego	190	900	246	61,000
Almería	60	102	55	13,570
Riyadh	420	1,595	2,540	1,960,000

Notes: These figures reflect total capacity, use and cost in San Diego. In Almería, use is less than capacity, even with subsidies to costs. For Riyadh, figures reflect 20% of installed capacity, i.e. the marginal supply that allows consumption to rise from 224 to 280 litres per capita per day (C. Doublet, Operations Director of Veolia Water Saudi, *Personal communication*, 21 May 2014,). Energy and CO2e statistics from Voutchkov (2008) and GWI (2015), respectively. The largest shares of operating costs – and externalities – result from energy use. Saudi Arabia's energy consumption and carbon output are much higher due to differences in desalination technology. Facilities in California and Spain use reverse-osmosis (RO) technology while many Saudi plants use thermal multi-stage flash (MSF) or multi-effect distillation (MED). According to Anderson et al. (2008), RO produces 1.8 kg CO_2/m^3 while MSF and MED produce 23.4 and 18.0 kg CO_2/m^3, respectively.

due to weak restrictions on use. Riyadh suffered from water shortages because desalinated water was essentially free to households. These features help explain why the cost of desalination was spread among all of San Diego's residents to share the costs of growth, Almería's farmers are turning to desalinated supplies as groundwater costs rise, and the Saudi government massively increased Riyadh's water prices.

The discussion of costs and benefits at a larger scale and inclusion of special interests whom politicians might favour over average citizens clarifies the impact of desalinated water in a complex economic, political, social and environmental setting. Additional clarity does not, however, invalidate the relevance of economic efficiency, political risk and environmental impact to evaluating whether desalination policies are sustainable or not. San Diego's regional commons may justify using average-cost pricing to spread costs across all residents rather than charging marginal prices to new arrivals, but that policy does little to reduce the risk that new arrivals will reduce water supply reliability. In Almería, the problem is fixing itself as farmers abandon overused common-pool groundwater for excludable desalinated sources, but the government can still align or distort incentives. Riyadh illustrates this aspect in its switch from an unstable system in which heavy subsidies could not meet consumer demand to a more balanced system in which customers pay costs, reliability rises and energy use falls.

All of these cases show how political action depends on local institutions, but their lessons apply elsewhere. First, the mismatch between the incidence of costs and benefits indicates the degree of inefficiency and risk of collapse from economic, political or environmental ruptures. Figures 1 and 3 illustrate the gap between current and sustainable prices and quantities, i.e. P_1 and Q_1 versus P_2 and Q_2, in San Diego and Almería. In 2015 drafts of this article, the gap was even larger in Riyadh (see Figure 4), where the impossibility of meeting demand at P_1 reduced reliability by so much that the shadow price of P_3 reduced demand to Q_3. Price changes at the start of 2016 have moved the situation closer to P_2 and Q_2, simultaneously supporting the claim that larger gaps are likely to collapse and the prediction that higher prices are likely to be sustainable to the degree that they align costs and benefits to reduce inefficiency and political risk. Second, the effectiveness of and demand for desalination depend on local attitudes and relations. Greater trust between San Diego and Met would, for example, make it easier to exploit cheaper sources of supply, reduce risk via diversification, and utilize scarcity-based price signals to regulate demand (Zetland, 2008). Fair and robust groundwater management in Almería would make it easier to ration desalinated, ground and surface waters among users. Full-cost pricing in Riyadh makes it easier to discuss an end to irrigating with fossil groundwater – water that could protect the water security of a desert city of 5 million people living 500 km from the sea. Desalination has the potential to improve water security for all who share a water commons, but those improvements will be wasted if the new water is allocated to new demand rather than bolstering existing supply, if beneficiaries pay less than the cost of the new water, or if existing unsustainable practices are allowed to continue. Desalination is a tool, not a silver bullet.

Note

1. See Ouda (2013b, 2015) for detailed information on KSA's water supply and distribution network.

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