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Rethinking the economics of water: an assessment

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Abstract Water is rising on the policy agenda as population growth and climate change intensify scarcity, shocks, and access inequalities. The conventional economic policy recommendations—privatization, pricing, and property rights—have struggled due to a failure to account adequately for the politics of water and the associated distributional conflicts. We identify distinctive social and physical characteristics of water supply and demand, and explore their implications for three central areas of water policy: financing infrastructure, pricing, and property rights reform. Growing dependence on groundwater and non-networked water supplies exacerbates these challenges and reinforces the need to rethink the economics of water and tackle the political challenges head on. Meeting the water sustainable development goals would require institutional and technological innovations to supply, allocate, and manage water, as well as a sustained political and financial commitment to address those who might be left behind.

Keywords: water economics, water rights, water pricing, water infrastructure

JEL classification: D02, D23, D40, H54, O13, Q25, Q21

I. Introduction

Water shortages consistently rank among the global risks of greatest concern to policymakers and business leaders (World Economic Forum, 2019). The concerns are real. Water is indeed scarce in many places, and without clever intervention and implementation these challenges will intensify and spread as demand grows (Jaeger *et al.*, 2017). The global population experiencing severe water scarcity has increased from 32m people in 1900 to a projected 3.1 billion people by 2050 (Kummu *et al.*, 2010;

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Gosling and Arnell, 2016). Water infrastructure has also failed to deliver universal access to safe drinking water; in 2017, approximately 29 per cent of the world's population (over 2 billion) lacked access to safely managed drinking water in the home, and 55 per cent (over 4 billion) lacked safely managed sanitation (WHO and UNICEF, 2019). Already 4 billion people are affected by water scarcity for at least 1 month per year (Mekonnen and Hoekstra, 2016). Pollution compounds these risks due to unchecked flows of sewage, agricultural run-off, emerging contaminants, and stubborn gaps in sanitation (see the paper by Dale Whittington, Mark Radin, and Marc Jeuland in this issue: Whittington *et al.* (2020); Damania *et al.*, 2019). In the past decade, severe droughts have brought cities to the brink of running dry, posing systemic risks that cascade through the economy (see the paper by Richard Damania (2020, this issue) and Garrick *et al.*, 2019). As economic activity and human life are dependent upon water, these trajectories have significant implications for economic policy that are explored in this issue.

Three phases can be observed in the policy approaches to problems of water scarcity and quality. In the first phase, during the second half of the twentieth century, policies favoured big, centralized, and costly public water supply projects. Nearly 45,000 large dams were built to meet water and energy needs (World Commission on Dams, 2000). By the 1990s, however, it was clear that a sea-change was coming; such projects were increasingly viewed as being problematic for a variety of environmental and economic reasons (see the paper by Marc Jeuland (2020) in this issue).

In the second phase, at the turn of the century, there was a growing push to treat water as an economic good and subject to the laws of supply and demand, governed by price and market signals (United Nations, 1992; Thobani, 1997). Despite political resistance to the notion that water was an economic good, rather than only a human right, policy prescriptions were very much grounded in textbook economics and the search for 'efficient' or 'optimal' solutions, where water prices reflect marginal cost and property rights enable efficient water use as demand and supply fluctuate. Water markets and pricing were thus the first port of call to set appropriate incentives and raise revenues to cover the costs of capital investments in water storage and distribution infrastructure. Water prices could be set by a market in tradable water rights, making the tasks of policy-makers to establish a cap on water use, distribute rights, and enable trading. In this second phase, private ownership was also often seen as an important part of implementing the textbook solution. Big public dams were relegated to a last resort, while small dams proliferated with 11 small hydropower dams for every large one (Couto and Olden, 2018).

By 2010, however, failed experiments began to dim enthusiasm that water challenges could be met by 'getting the prices and property rights, right'. The 'water wars' over privatization in Cochabamba in 2002 chastened those promoting privatization as a solution of capital shortfalls. Challenges with pricing and water rights reform showed that economic fixes would not prove quick or lasting without careful design. Markets and pricing were recognized as servants of sound governance and regulation, subject to intense political struggles and technical challenges. Observers were now conceptualizing water crises as governance crises (OECD, 2011).

Australia's Murray-Darling basin illustrates this shift in thinking. In 2003, *The Economist* awarded Australia the 'top prize for sensible water management' and hailed the Murray-Darling arrangement as 'the best example of trading in action'. The reforms of Australian water rights and the establishment of vibrant water markets in the Murray-Darling were, indeed, notable accomplishments. But, by 2010, *The Economist* conceded 'there is now widespread recognition that the Murray-Darling system is over-allocated'. And, in 2019, there were major headlines in Australia about fish-kills due to, *inter alia*, lack of flow in the Darling River leading *The Economist* (2019) to acknowledge that 'the basin as a whole has yet to show real improvement' based on growing scientific consensus despite its active water market. A 2019 feature article in the *Wall Street Journal* (Pannett, 2019) called Australia's cap-and-trade reforms a failed experiment amid the growing controversies in New South Wales. The quest for efficiency proved insufficient. The Australian experience highlighted the need for better planning and governance to address equity and other policy objectives. Clearly, the second phase is over.

We are therefore now on the cusp of a new, third phase.[1] One task of this paper is to chart its contours and the implications for economic policy. The challenges are no easier than in decades past, and, indeed, if anything, the urgency and severity are now greater. Global initiatives are proliferating in response. Perhaps the defining feature of this third phase will be the overdue appreciation that water challenges are inherently multifaceted. Yes, water crises do arise from mismanagement and the lack of proper rules, rights, and incentives. Ownership, investment, pricing, and allocation challenges must indeed be addressed. But this is not all. The politics and governance are also crucial. If there is 'too much politics' in water, one must ask whether there are physical, social, and, in fact, economic factors that explain the persistent role of politics. Similar challenges are faced by those looking to implement economically-rational climate policies (Klenert *et al.*, 2018). Economic policies to allocate and manage water must be designed with those factors in mind, requiring a political strategy and coordinated effort to address the distinctive physical, social, and economic characteristics of water head on. This is the underlying notion that motivates this assessment.

The papers collected in this issue of the *Oxford Review of Economic Policy* explore how and why economic policy has struggled to address water management challenges, draw lessons from global experience and experiments, and explore the opportunities and limits of emerging innovations in technology, finance, and governance. What combination of organizational structures, economic incentives, political strategies, and changes in human behaviour can work to better define these problems and get them under control?

The papers also chart the implications of two major trends reshaping the economics of water. First, dependence on groundwater[2] has increased dramatically. Groundwater use more than doubled from 1960 to 2000 (Wada *et al.*, 2010). Groundwater accounts for 33 per cent of total water withdrawals and provides the primary water source for more than 2 billion people (Famiglietti, 2014). The proliferation of private tube wells has been equated with anarchy (Shah, 2009), and unsustainable groundwater pumping

[1] Other disciplines have explored the relationship between water and the economy, highlighted by the recent special issue on the economic anthropology of water. Wutich and Beresford (2019) identify several themes in their synthesis that overlap with those covered in this assessment, including the political struggles associated with privatization, property rights and markets, and the importance and diversity of institutions.

[2] Groundwater is defined as the 'water found underground in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers'. See Groundwater Foundation (2019).

can lead to declines in groundwater levels that threaten environmental flows and the functioning of freshwater ecosystems (de Graaf *et al.*, 2019). Variability of groundwater recharge and contamination problems compound the challenges of sustainable water management, even in regions where the volume of groundwater storage is not a primary concern. These trends raise distinct physical and hence political and economic challenges from surface water (see the paper by William Blomquist (2020) in this issue; Lin Lawell (2016)). The second trend is related. Piped water supplies are failing to reach peri-urban and rural regions in the Global South. Non-piped sources are filling the gap, ranging from point sources (private tube wells and community managed handpumps) to mobile vendors (e.g. tanker trucks and packaged water). Unlike piped water supplies, these point sources are not networked and exhibit limited economies of scale with low and variable demand (hereafter described as 'non-networked supplies'). Public policy has favoured non-networked investments in individual waterpoints in most rural contexts shaped by a least-cost logic. With institutional fragmentation contributing to poor maintenance of these waterpoints, the value to users is low contributing to a spiral of irregular or no payments and hence further disrepair (see the paper by Rob Hope, Patrick Thomson, Johanna Koehler, and Tim Foster (2020) in this issue). Together these trends involve different physical and social characteristics from the dominant paradigm of surface water stored, treated, and delivered through piped water networks.

The paper proceeds as follows. Section II identifies the factors that make water difficult to allocate and manage, demonstrating the implications for political strategies. The third section introduces three major economic policy areas—financing water infrastructure, pricing, and reforming property rights—examining the scope for water management to harness the advances in economic policy, and vice versa. The fourth section explores the implications of new technologies, financial models, and governance innovations for the future of water and economic policy. We conclude with the central lessons from the papers in the issue and a set of priorities for policy and research.

II. Economic roots of water scarcity

Policy responses to water scarcity address both supply and demand, and the interplay between the two. The six water-related targets of the Sustainable Development Goals (SDGs) illustrate the multi-dimensional nature of the challenge, and the focus of governments, policy-makers, and the private sector: (i) supplying water and sanitation (SDG 6.1 and 6.2), (ii) ensuring water quality (SDG 6.3), and (iii) reducing the impacts of water scarcity (6.4). They also call for integrated water resource management, ecosystem protection, and international cooperation to address the externalities, and hence conflicts, associated with complex hydrological and economic connections (6.5-6).

Controversies over large dams and supply-side solutions centre on their unaccounted costs and undelivered benefits (Ansar *et al.*, 2014; Jeuland, 2020), prompting a push for demand management—led by pricing and property rights—as a partial substitute for costly new large-scale infrastructure. The persistent push for this 'soft path' to water management (Gleick, 2018) has come with the recognition that water management challenges stem from water's difficulties in being valued and managed. Successful policy responses require a clear understanding of the distinctive physical, political, and economic characteristics that have stymied past efforts.

(i) Why water is difficult to value and manage

Water crises stem from the physical, social, and economic characteristics of supply and demand that make water difficult to value and manage (Hanemann, 2005). Water is a form of natural capital that involves both stocks (i.e. aquifers and river basins) and the flows of ecosystem services these generate (i.e. groundwater and surface water) (Barbier, 2019). Water supplies can be both renewable (e.g. surface water) and non-renewable (e.g. some forms of groundwater) on human time-scales. We identify five key features, three on the supply side and two on the demand side, that have constrained conventional economic prescriptions for water policy. On the supply side, first, water's mobility makes it difficult to bound and measure. Second, its variability makes it difficult to measure and allocate rights. Third, its heaviness makes it capital intensive to store and transport. On the demand side, fourth, water has multiple uses that make it difficult to compare the value of water across private and public goods. And, fifth, many of those uses are non-rival. As a consequence, economists have long recognized that 'market-oriented economic concepts have more limited analytical significance for explaining and evaluating the behaviour of water-producing and water-consuming firms than is true for other fields of economic inquiry' (Ciriacy-Wantrup, 1961, p. 200).

First, water is mobile: it flows, it seeps, it evaporates. Throughout this process, its quality changes. There can be multiple, sequential uses of the same molecule of water. For example, some cities are treating wastewater for reuse to support outdoor water use (Western US) and even potable supplies (Singapore). Egypt's allotted share of the Nile River is 55.5 km^3, but the amount of Nile River water applied in Egypt is 86.8 km^3 because upstream water is either unused or returns to the river rapidly after its use in Ethiopia and Sudan for productive hydropower or irrigation purposes (Perry *et al.*, 2009). The same molecule of water can also be used simultaneously for multiple purposes by multiple people; for example, a reservoir provides recreation, hydropower, and water supply. It functions as both a private good and a public good. Depending on how and where it is used, it generates an externality, for example sewage, a return flow, or a decline in groundwater tables. The externality can be harmful, or beneficial, or both. Because timing, location, and quality all matter, water is heterogeneous—it is not a standardized commodity.

Second, a distinctive feature of water is that supply is highly variable spatially, temporally, and in terms of quality. Spatially, fresh water is distributed very unevenly across much of the globe. Even within countries, there is unequal spatial distribution.[3] Storage

[3] The challenge is to match supply with demand both spatially and temporally—getting fresh water to where the people are, when they need it, and with adequate quality. In China, for example, the South-to-North transfer represents the world's largest inter-basin water transfer megaproject. The masterplan envisions up to 46 billion m^3 from the relatively water abundant Yangtze River basin to 100 water-stressed cities in the North (Pohlner, 2016). Urbanization has illustrated this spatial mismatch: a global review identified over 100 reallocation projects moving approximately 16 billion m3/year over 13,000km from rural areas to provide water for growing cities (Garrick *et al.*, 2019). This offers a lower bound estimate that fails to account for the growing dependence on groundwater associated with urbanization of agricultural lands.

is typically the key to controlling the temporal variability in supply, while conveyance facilities and inter-basin transfers are used to overcome the spatial mismatch between supply and demand. Even for within-basin use, conveyance facilities are needed to distribute surface water to the places of use. Because of economies of scale, the storage and distribution infrastructure is typically collectively supplied: whereas with groundwater, users often have their own individual wells, surface water users often share a diversion and distribution system. The largest projects outstrip local capital and have required infusions of external investment, along with the associated governance restructuring and dependence on more formal arrangements.[4]

Temporal variability is a particular challenge: what does it mean to have a property right to take water from a stream when the flow varies over the year by an order of magnitude? It doesn't make sense to create an exclusive right of use, as with land. Land is fixed in quantity and location: we cannot each build our own house on the same piece of land. But, we could (usually) each water our own farm from the same stream. What is the right to the use of surface water—a right to a *share* of the flow or a right to a *specific quantity*? Under appropriative water rights, it is a right to a specific quantity. Under the older, riparian right, it is a right to an *unspecified* share of the flow; all riparians have a co-equal right which they share as 'tenants in common.' What is the specific quantity under an appropriative right? Do you have a right to an *average* amount of diversion? To a minimum amount of diversion? Actually, the property right is neither of those: it is the right to divert up to a *maximum* amount of water. Often, that amount will not be available, so the property right is inherently uncertain.

Droughts and climate extremes add uncertainty and magnify the challenges of water scarcity and its spatial and temporal variability (Damania, 2020). The microeconomic impacts of changes in water availability and variability have been consistently linked with negative economic impacts on agriculture, human capital (via stunting and other health-related impacts), and conflict. Repeated dry shocks and crop failures have prompted cropland expansion and deforestation that can increase vulnerability to future variability (Damania *et al.*, 2017). Variability and uncertainty have led to a range of infrastructure and policy measures albeit with mixed success. In agriculture, irrigation infrastructure attempts to buffer variability and uncertainty but with ambiguous effects; agricultural subsidies or low prices facilitate unsustainable water use that can cause perverse consequences and exacerbate the impacts of relatively small shocks. In diversified economies, the impact of variability on economic growth may be offset by adjustments in less water-dependent sectors, if factors of production are mobile across sectors, food imports are available, and the sectors affected by drought are relatively small (Damania, 2020).

[4] At the smallest scales, the users themselves provide the labour to construct the necessary diversion and distribution facilities, and the system is managed by water users themselves through self-governance (Ostrom, 2015). But (i) irrigation is confined to land close by the stream, (ii) there is limited storage, and (iii) the system is of the simplest character. In other words, there is the challenge of scaling up collective action. In Utah, after 35 years of a local collective action, 'It soon became known that the higher lands were better than the bottom lands, but the problem of digging ditches to them offered too many difficulties for local accomplishment.' At that point external capital was required to finance the construction of irrigation canals to reach the higher lands (Chandler, 1913). The use of external capital required water users to adopt a different and more formal corporate or municipal structure. They often lost their individual ownership of the water right and were collectively obligated to pay for the infrastructure.

Third, water's mass creates distinctive economic problems. Centralized networks of stored, treated, and piped surface water supplies are consequently highly capital intensive. The capital is very long-lived and has no other value, and, because of major economies of scale, there is little scope for modularity in surface water development. The entire system—storage, diversion, transmission treatment, and local distribution—has to be in place before any water can be delivered (unlike groundwater, which can be developed one well at a time). If the costs were mainly operating costs, it would be easy to rely on the 'user pay' principle and pay-as-you go financing (see the paper by Dieter Helm (2020) in this issue), but that does not work in this case. Governments end up playing the major role in financing water supply because no one else is willing to take on the financing of such capital-intensive and long-lived infrastructure. This, combined with the fact that water is widely seen as a merit good, explains why water is often 'all politics'.

The challenges of the heaviness of water are different—but no less important—in largely non-networked systems found in rural areas and peri-urban areas in the developing world (Hope *et al.*, 2020). People rely on community-managed handpumps, haul water, or buy it from water vendors, including kiosks and mobile vendors. The supply is more modular and vastly less capital intensive. It is also far more expensive per litre, because of the lack of economies of scale. And users know very well both how much water they are using, and how much they are paying (in time or money) for this. Paradoxically, price is more salient for them and one expects to see a great price responsiveness, although water quality is virtually uncharted and poorly reflected by user behaviour. A global review of informal vending illustrates this phenomenon with the price of water supplied by tanker trucks a median of 10 times that of nearby piped systems (O'Donnell and Garrick, 2019).

Fourth, on the demand side, water has multiple uses, some simultaneous (hydropower and recreation), some rival (irrigation), and others for which rivalry depends on the infrastructure and timing (e.g. irrigation and urban uses can involve agricultural reuse of urban wastewater versus circumstances where cities transfer water from agriculture). These interdependencies complicate valuation, pricing, and allocation decisions. For domestic uses, there are special challenges created by the fact that water has multiple uses. With a networked water supply system, the amount of water an individual family uses is largely determined by physical features of the home, its appliances, and landscaping. Changing these is more onerous than substituting an LED bulb for an incandescent bulb. Moreover, the empirical evidence indicates that most residential users have no idea how much water they are actually using in any particular end use; therefore, they have only a hazy idea as to how they could control the amount they use. The result is that any price signal is at best veiled, and price responsiveness is dampened, or requires time to prompt adjustments (Dalhuisen *et al.*, 2000; Grafton *et al.*, 2011). Conversely, non-networked supplies often involve multiple sources for different uses, ranging from bathing in rivers to hauling of water from shared water points for drinking.

Fifth, water use can be non-rival, and hence prone to free-riding behaviour. Water has properties of a private good, public good, and common pool resource in its different uses. Typically, when water is used, it is not actually *consumed* in the sense of it undergoing an irreversible change in chemical form, although the impacts of pollution on water quality can render it unusable or lethal (Damania *et al.*, 2019). When you use a litre of oil to drive your car, the oil is physically combusted, with new chemical products. When you use a litre of water to wash clothes or to water your garden, the litre remains as H_2O in the water cycle, and is *not* physically consumed. If you are washing clothes, you end up with almost a litre of wastewater. If you water your garden, some of the litre is transpired by the plant, some evaporates to the atmosphere, and some either runs off the ground or percolates into the soil and replenishes the aquifer or ends up, eventually, as flow into a surface water body (return flow) (Grafton *et al.*, 2018). The characteristics of water-use lead to pervasive externalities that complicate water allocation and management by connecting neighbouring water users.

These five features make water difficult to value and manage. Groundwater poses additional challenges due to the complexity of the aquifers which rarely resemble the bathtub-shaped model assumed by economic models (Blomquist, 2020). The upshot is that groundwater supplies are subject to all of the key supply-side features above—mobility, variability, and its mass — albeit in different ways and via different mechanisms. Those pumping from a common aquifer may not be similarly situated in terms of access, depth, and so on. On the demand side, groundwater involves multiple uses, and non-rivalries, e.g. the benefits of shallow water tables for dependent riparian vegetation. Yet groundwater cannot substitute for all of the different surface water uses, particularly the benefits derived from having water in the channel of rivers (e.g. navigation, hydropower, recreation, instream aquatic habitat) (Blomquist, 2020).

Together these features create real challenges for the application of the price mechanism, which in turn implies that supply and demand tend not to be responsive to changes on the other side of the market. This state of affairs underpins intermittent challenges of water scarcity that can develop into full-blown water crises, where people die of unsafe drinking water, or the lack of sufficient water of adequate quality exacerbates poverty and ecosystem declines. How can economic policy respond?

III. Three priorities for economic policy

The unusual physical features of water set out in the previous section lead to three essential tasks for governments to enable this potential: financing and managing water infrastructure, pricing water, and reforming property rights. Successful interventions matter enormously: water is a key factor of production, so scarcity can slow economic growth and deepen inequalities. For example, modelling by the World Bank estimates that water shortages will cause economic growth in 2050 to be 6 per cent lower than it would be otherwise under business-as-usual scenarios of water mismanagement (World Bank, 2016). Conversely, regions with better water resource management stand to 'see growth accelerate as much as 6 per cent' if they adopt 'efficient water policies' that centre on improved water allocation and pricing. These policy tasks are inter-related. We start with financing infrastructure before moving to pricing and property rights.

(i) Financing infrastructure

Financing the water infrastructure that will be needed in coming decades is a massive challenge. In developing countries and in many developed countries, investment in water and sanitation in recent decades has fallen behind the growth in investment needs even more than for other sectors such as transportation and energy.

Globally, it has been estimated that an average capital investment of US$114 billion/year[5] is required through 2030 to meet the SDGs for water supply, sanitation, and hygiene (Hutton and Varughese, 2016). This is about three times the current spend. These estimates are only capital costs; after about 2023, the annual cost to operate and maintain the SDG facilities will be even larger. Nor are these costs evenly distributed with poorer regions often facing the largest relative cost to catch up. The annual, estimated costs of meeting SDG 6.1 is higher in rural Sub-Saharan Africa than any other region globally, totalling approximately US$5 billion annually in capital expenditures (Hutton and Varughese, 2016, p. 14; Hope *et al.*, 2020). In addition to the SDG goals, investment is needed for water infrastructure. Projections of the total global financing needs for water infrastructure are US$400–500 billion/year to 2030, more than doubling current water investment. Beyond then, investment needs increase greatly, with an estimate of total cumulative investment in water infrastructure of US$22.6 trillion by 2050 (OECD, 2018*a*).[6]

Compared to other infrastructure, financing water is a particular struggle. As noted above, networked, surface water supply systems are exceptionally capital intensive. In the US, for example, the water industry is 2.3 times more capital intensive than the electricity industry in terms of dollars of assets per dollar of annual revenue, and 2.4 times more capital intensive than the telecoms industry (National Academies Press, 2002). Economies of scale are a dominant feature, which makes it difficult to expand most of the supply infrastructure in a nimble and modular manner. The capital is long-lived with high sunk costs; it calls for a high up-front investment followed by a very long payback period (Jeuland, this issue). The water sector generally offers a low rate of return on investment because water tariffs are regulated or vulnerable to political pressure. In addition, foreign investors can face both political and exchange risk. Because of these features, the private sector has traditionally had a limited appetite for financing bulk water supply infrastructure (and even less for wastewater infrastructure). Experiments with privatization reinforce these concerns. The logic of privatization hinged on ownership and competitive pressure to incentivize investment, minimize costs, and improve management. The UK experience offers the paradigmatic example of privatization and has been upheld as the envy of the world, despite limited evidence to assess performance compared to the counterfactual, namely public ownership (Helm, 2020). Subsequent experiments in the Global South foundered due to political resistance associated with affordability concerns, as illustrated by the 'water wars' in Cochabamba, Bolivia. Privatization has not proven to be the panacea for financing and operating water infrastructure.

Where can the funding come from then? The usual answer is 'the three Ts'—tariffs (payments by water users), taxes (funding from the national government), or transfers (aid from other governments and philanthropic organizations).

[5] Monetary values referenced in this assessment are provided according to the data and sources cited and have not been adjusted for inflation

[6] These figures do not cover the water investments needed for irrigation or energy.

The typical experience is that water tariffs do not cover the full costs of water supply (Andres *et al.*, 2019): an estimated $320 billion in subsidies, representing half a per-cent of GDP, is poured into water and sanitation annually, excluding China and India. OECD (2015) cites data from UN Water where 70 per cent of countries report that water tariffs do not cover operations and maintenance (O&M) costs. Komives *et al.* (2005) cite a survey by Global Water Intelligence covering water utilities in 132 major cities worldwide, finding that 39 per cent of water utilities had average tariffs that were too low to cover basic O&M costs, and a further 39 per cent had tariffs too low to make any contribution towards recovery of capital costs. In high-income countries, only 50 per cent of water utilities charged tariffs that covered more than O&M costs; in low-income countries, barely 3 per cent of water utilities achieved this. The inadequacy of tariff revenue is not limited to developing countries. In the US, for example, most municipal water tariffs do not fully cover capital depreciation and new investment needs. The US currently invests about US$41 billion in water infrastructure annually, compared with an annual investment need of US$123 billion (Value of Water Campaign, 2017).[7]

If tariffs do not cover the full cost of water supply in rich countries today, how was this capital financed in the past? In the nineteenth century, in the US and other developed countries, water users did in fact finance the development of municipal water supply infrastructure—but not through tariffs. It was financed through property taxes. When homes were connected to piped water and sewerage, their property value rose, reflecting the reduced fire risk and improved public health. Municipalization of water supply proceeded hand in hand with the emergence of property tax as a revenue source for local government. Other government tax revenues supplemented property tax as the financial backbone for the development of water and wastewater infrastructure.

Transfers—official development finance flows to water and sanitation in developing countries—have grown over the past decade from about US$10 to 14 billion, annually (OECD, 2018*b*). But this is still small in relation to the investment needs and is unlikely to grow dramatically.[8]

The remaining financing pathway, in the conventional economic thinking, is commercial direct financing supported by targeted foreign aid, together with a market model where water pricing provides incentives and signals for investment and promotes cost-recovery from users. The question is whether this a realistic proposition. As noted above, the water sector has features that make it relatively unattractive for private investors. Thus, in 2015, water captured only 4 per cent of total private-sector infrastructure commitments in developing countries, as compared with transport (63 per cent) and energy (34 per cent) (Kolker *et al.*, 2016). Privatization is not *per se* a solution. The UK is a notable exception—under private ownership, investment in water infrastructure has doubled (Helm, 2020). Elsewhere (as in France), the private sector operates municipal systems, but investment is limited to treatment plants, not local pipe distribution systems, let alone bulk water storage or conveyance infrastructure.

[7] The US EPA estimates that US$473 billion of investment will be needed for drinking water infrastructure over the next 20 years (EPA, 2018). Another estimate puts the US investment needed to replace or refurbish pipe systems alone at over 1 trillion dollars between 2011 and 2035 (AWWA, 2012).

[8] USAID has launched in 2019 its new strategy on the 'Journey to Self-reliance' that sets out the case for donor retreat: https://www.usaid.gov/selfreliance

(ii) Pricing

Pricing is the often the first tool in an economist's kit. To ensure efficient use of a commodity, it should be priced at its (long-run) marginal cost. If there is excess demand for a commodity, for example in a drought, price should be raised to bring demand back in line with the available supply, or new sources of water supply must be developed. These conventional nostrums can be problematic in the real world, revealing a paradox: The price of water almost never equals its value and rarely covers its costs (see the paper by Grafton *et al.*, 2020 in this issue). The value of water is derived from multiple types of economic benefits; as a result, a single price will be ineffective due to the multiple, sometimes competing objectives of water management (Damania, 2020). The cost of water includes the capital intensive, natural monopoly characteristics noted above, and externalities (Grafton *et al.*, 2020).

For many residential water users in a networked water supply system, price provides at best a shrouded signal. Surveys show that most residential water users have little idea of how much water they are actually using in their home, whether in total or for specific end uses (Nauges and Whittington, 2017). Moreover, residential water use is heavily dependent on physical features of the home (built-in fixtures and appliances, lot size, etc.) that are non-trivial to change. For many users, the specific amount of water that they use in their home is hardly a conscious choice.[9]

Moreover, because there is a human right to water, using price to ration it strikes many people as unethical. Raising the price of water purely to send a signal to water users, when the increase is not cost-justified, is usually politically infeasible and sometimes illegal.[10] For many municipal water utilities, pricing every unit of water supplied at long-run marginal cost would generate a significant surplus of revenue, since their long-run marginal cost far exceeds their average cost and that, too, is politically challenging if not illegal.

The consequence is that one needs to think in terms of the design of a *rate structure*: setting not the right price but the right rate structure. A simple increasing block-rate structure can make it possible to ensure that the overall amount of revenue raised is proportional to costs while still providing an economic incentive to change behaviour at the margin if the location of the point at which price changes from one block to the other is chosen carefully. In effect, the switch point sends a *quantity* signal to water users: you can use more water if you like but, if you use more than this amount, you will be paying *more*. There is some evidence in behavioural economics and psychology that quantity signals, rather than the prices established by increasing block tariffs, can be potent because they provide a directive towards a specific behavioural response (Nauges and Whittington, 2017).

The issue of choosing a price signal versus a quantity signal was famously raised for economists by Weitzman (1974) who pointed out that, in designing a regulatory policy, there is a trade-off between two alternative objectives. One objective is certainty about

[9] The situation is different with non-networked supply systems. People hauling water five times a week know full well how much water they are hauling and, for them, this is certainly a conscious choice.

[10] For example, regulated investor-owned water utilities are required to show a cost justification for changing their rates. In California, Proposition 218 stipulates that municipal water rates be 'proportional to the cost of service'.

attaining a particular quantitative outcome (e.g. keeping water use below *x* litres, or pollution below *y* parts per million). The second objective is certainty about price: ensuring that, whatever reduction in quantity occurs, it occurs at the target price. Weitzman showed that the selection of a regulatory instrument is partly a function of which policy objective is the more important. If certainty about the specific quantitative outcome is the more important, then a quantity signal is preferred to a price signal. Arguably, this is sometimes the case for water managers, especially during a drought. The relative salience and power of a quantity signal can provide an independent consideration, separate from Weitzman's argument, for the choice of a quantity signal rather than a price signal to manage water use in the face of scarcity.[11] It also offers justification for the selection of a rate structure rather than a simple price.

(iii) Reforming property rights

Reforming property rights is a key component in an economist's programme for dealing with water. Developing exclusive, transferable, and enforced property rights promises to unlock the incentives for efficient water allocation (Libecap, 1989).

In any human society, there are always existing property rights to water which determine the ability to access, withdraw, and manage water in its various forms, including the infrastructure associated with water (Schlager and Ostrom, 1992). Because water is a multi-faceted commodity, the property rights to water are as multi-dimensional as the resources they govern, involving a 'multiplicity of values and a variety of uses', both public and private (Blomquist, 2011, p. 375). They are established in various ways—by custom, common law, courts, legislation, and regulation. An important distinction is that between the (usufruct) right to take water from a source versus the right to receive water from a water supply organization on certain terms. These are two different types of right and they involve different social relationships with water. The human right to water is about the latter—an obligation established by governments and delivered by utilities—not the former. It is essentially a declaration that water is a merit good, which must be made available. Despite the high-profile debates about ownership of water infrastructure, including the ongoing debate about nationalization in the UK, Helm (2020) argues that it is not ownership, but control (via regulation) that matters most. As water scarcity spreads, therefore, property rights issues increasingly focus on water itself, and not the networks and infrastructure to supply water.

The efficiency school of property rights (Anderson and Hill, 1975) has been influential in guiding water allocation policy discussions: the benefits of defining property rights increase as scarcity intensifies and, when the benefits outweigh the costs, property rights develop. The gains from tradable water rights have been estimated to demonstrate the benefits of property rights reform (Pujol *et al.*, 2006). For example, in Australia, models of water trading suggested that mean annual gains from trade are over AU$2.5 billion, and that the removal of barriers to trade could further increase these annual

[11] There is support in the psychology literature on norms for the salience of a quantity signal. A quantity signal corresponds to a *descriptive* norm in that literature, while a price signal corresponds to an *injunctive* norm; Ehn (2015), Wang *et al.* (2015), and Bruner *et al.* (2016) are recent studies finding a stronger impact associated with manipulation of descriptive than injunctive norms.

net benefits by AU$88m (Qureshi *et al.*, 2009). In regions with limited or no water markets, models suggest trading would prove beneficial, exemplified by a study of the Aral Sea, where the estimated annual benefits from trade range from US$373m to $476m (Bekchanov *et al.*, 2015). The potential gains from trade have motivated reforms from Chile to China.

In Australia, the process of 'unbundling' property rights—separating water and land rights to facilitate water markets—largely conforms to the expectations of the efficiency school; drought and competition for water spurred sustained reforms, particularly after a 1,000-km algal bloom along the Darling River in 1991 signalled a river in crisis. The reform process has yielded a vibrant market that increased the economic value of entitlements in the Southern Murray-Darling to AU$13 billion by 2013, although diversion levels remain unsustainable due to implementation challenges associated with water recovery for the environment (Grafton and Wheeler, 2018). Yet, even prior to the process of unbundling, the property right to water in Australia was fundamentally different from that in some other places, especially in the western US (see the paper by Hanemann and Young, 2020 in this issue).[12]

The failure to realize these benefits has a simple explanation: benefits are unevenly distributed, and the transaction costs are often large (Garrick *et al.*, 2013). Distributional conflicts and information asymmetries raise the costs of bargaining and enforcing water trades. Transaction costs are therefore a symptom of poorly defined property rights or overlapping property rights, which in turn reflect the political controversies (distributional conflicts) involved (Hanemann and Young, 2020). These political challenges are often rooted in the special technical and physical characteristics of water, noted above. These are particularly challenging for groundwater due to the complexity and heterogeneity for similarly situated pumpers and the fact that, despite important hydrological linkages between ground and surface water bodies, ground and surface water are typically regulated entirely separately (Blomquist, 2020). Groundwater pumping rights have therefore turned on several technical challenges regarding the relationship of groundwater pumping at one location to changes in aquifer depth or surface water flow at another.[13]

The basic formulation of the efficiency school of property rights is therefore too simplistic. The concept of economic efficiency is the Kaldor–Hicks criterion of aggregate net benefits, ignoring the distribution of benefits in costs; for water, like many environmental

[12] In the US the right to use water is treated as private property. But states exercise a strong interest in how the water is used. In some states (notably California) the right to water is often poorly quantified. A proposed water transfer can be challenged on the grounds that details of the right claimed by the seller are invalid, or that the transfer changes the pattern of return flows downstream and thereby harms other water users (regardless of whether they hold a senior or junior water right). While there is some variation between states, because water is private property these challenges play out through private litigation among individual parties, rather than being resolved by an administrative agency. Australia, by contrast, 'nationalized' water more than a century ago: a water right is not private property—it is a licence issued by the state government at its discretion, on terms it sets, which it can modify or revoke. Much of the uncertainty in a water right in the western US that can only be resolved through individual litigation is eliminated under Australia's administrative system. The right to water, therefore, is considerably less entangled in Australia than in the western US. Once an Australian state government decided to permit trading of its water licences, the path to water marketing was much smoother than in the western US with the requirements that a transfer cause no third-party injury and be in the public interest.

[13] The rapid proliferation of tubewells in India demonstrates that the pace of change can outstrip capacity of institutions to adapt, despite the enormous benefits of arresting unsustainable groundwater extractions (Shah, 2009).

issues, this is a fatal flaw. The passage of legislation is a political event, a form of collective action involving costly negotiation and lobbying (Libecap, 1989). Moreover, the relevant issue is not creating a property right *de novo* but rather modifying existing rights. The notion that property rights are modified when the benefits outweigh the costs of doing so lacks credibility (North, 1990). These modifications amount to cutting the entanglements surrounding existing water rights. While this can have some beneficial economic consequences, it is a quintessential political act. It ignores the impacts of path dependency as historic water users block changes that threaten their interests. The OECD (2015) therefore notes that 'broader political and structural reforms have provided imperatives to improve the efficiency of resource use and equity in allocation of water resources'. Droughts and other crises can offer a 'salient, visible' trigger for reforms, particularly when combined with fiscal resources to compensate historic water users who stand to lose.

The process of reform, not just its content and design, becomes a primary realm of economic policy. The strategy for communication and compensation is pivotal. Side payment schemes—water buybacks, subsidy programmes, and other forms of compensation—can assuage the distributional conflicts that can stymie otherwise desirable changes (see the paper by Wheeler and Garrick (2020) in this issue). The key issues centre on who receives and pays the compensation, how much and how to limit the lock-in that would prevent future adjustments.[14] Underpinning these strategies has been a growing appreciation for the importance of basic water accounting to understand water availability and use to ensure the resulting reforms are grounded in hydrological reality (Young, 2019).

The main message is that property rights reform, like all economic policy, is a political choice that requires special attention to distributional conflicts, and a sustained political strategy. 'With political decisions,' as Blomquist (2011) notes, 'nothing is ever over. Even when an authoritative decision is made . . . those whose preferences on that issue fail to carry the day rarely disappear or capitulate.' Even in Australia, with its progress on water rights reform and its commitment to compensation, irrigators and their lobbies are steadfast and strategic in slowing, or even reversing change. Yet, Blomquist (2020) also reminds us that any effort to devise a winning political strategy requires understanding the physical and social characteristics of water.

IV. Future pathways for water and economic policy

Aspirational targets such as the SDGs are leading to calls for bold approaches to achieve such ambitious goals. Water challenges have always inspired fascination with silver bullets, whether engineering feats or economic fixes, posing the risk that economists will double down on 'getting the prices right' or 'unlocking private finance'. As Damania (2020) notes, however, connections across the water cycle mean that multiple,

[14] The contrasting experiences of Australia and Mexico, both passing major reforms in the early 1990s, are a case in point. In Australia, the reform process has involved approximately AU$13 billion in compensation and related measures in the form of water rights buybacks and investment in irrigation efficiency schemes. By contrast, Mexico's reforms have languished, in part through the lack of a strategy for dealing with rural communities bearing the concentrated costs of urbanization and associated acquisition of land and water (Wilder and Romero Lankao, 2006; Garrick *et al.*, 2019).

complementary policies will be needed to address multiple objectives. These objectives include protecting water at its source and delivering water according to multiple, sometimes conflicting, criteria. Policy responses must be tailored to the objective, but also account for connections across sectors. The concepts of adaptive pathways and socio-technological transitions, prevalent in the policy dialogue on net zero carbon emissions, involve precisely such portfolio approaches. Yet the current focus on pathways often remains blind to the political economy, physical reality, or both.

We can restate the main argument that emerges from the papers in this issue: it is not enough to simply exhort adoption of economic principles and associated policy instruments. Instead, pathways must integrate economic policy into a political strategy that accounts for water's physical and social characteristics, and ensures a coordinated attack on interconnected challenges. This has three implications when considering the prospects for technology, finance, and governance innovations to address water challenges. First, the consumer is sovereign. This is obvious but its implications are not. Understanding the behavioural response to incentives, and the costs and benefits involved for investors and consumers, becomes critical in determining the value proposition associated with investments and policy reforms, and overcoming the political and technical obstacles to adoption. This comes out vividly in the case of rural Africa where less than one-third of the population pays for its water, creating a vicious cycle that may depend on rethinking the focus on least-cost institutional responses in favour of those that create value through new initiatives like performance-based models of service delivery (Hope *et al.*, 2020). It can also anticipate many of the surprises and unintended consequences that arise with efforts to nudge consumers through prices or information. Second, given the publicness of water, any innovations involving private finance or water markets will involve a blend of public and private roles, rather than a rehash of the privatization, pricing, and property rights panaceas of the past. In short, the private innovation will serve as a complement rather than a substitute for public roles. The precise mix will be an empirical question. Finally, with water the past is always with us; there is a mix of pre-existing uses or users along with new uses or users arriving over time, as well as because of physical properties of the resource shaped by past infrastructure decisions. One cannot start out with a blank sheet of paper. Path dependency will shape pathways of economic policy reform by foreclosing some options that may prove viable elsewhere. Efforts to develop solutions 'at scale' must therefore start by a sober assessment of the distributional conflicts and vested interests that would block and resist change.

The scale of contemporary challenges has spurred innovation and calls for 'leapfrog' solutions that promise to overcome the thorny difficulties and policy challenges identified earlier. At the same time, growing reliance on groundwater, non-networked water supplies, or both are transforming the nature of the challenges and the opportunities.[15]

[15] Over a third of the global population, and 20 per cent of crops, rely on groundwater (Richey *et al.*, 2015). Yet local dependence can range much higher, including 85 per cent of drinking water and 60 per cent of irrigation in India, and the sole source in parts of the Middle East and North Africa (World Bank, 2010, 2018). As a consequence of the dramatic reductions in the costs of groundwater development, over 2 billion rely on non-networked water supplies. Despite over 1 billion people gaining access to piped supplies between 2000 and 2015, the population with non-piped supplies increased from 1.7 to 2.1 billion in the same period (WHO and UNICEF, 2017). Even those with piped connections often suffer from reliability and quality issues leading to reliance on packaged water. Access to sanitation is lower (Hope *et al.*, 2020; Whittington *et al.*, 2020).

In this light, we consider the significance of emerging technologies, financial models, and governance innovations.

Can technological innovation spur decentralized solutions and desalination?

The lumpy, centralized, capital-intensive, and high-cost technologies of the twentieth century remain entrenched, and are unlikely to be fully replaced. Yet the early twenty-first century has witnessed some promising developments. There is, obviously, no shortage of saltwater on Earth, and desalination technologies have seen increased uptake, and a decline in costs with technological innovation (Burn *et al.*, 2015). Historical desalination technologies have been energy intensive, resulting in greenhouse gas emissions, although new approaches are designed to work with solar energy (Jones *et al.*, 2018). Scientists are exploring the use of various nanomaterials to increase efficiency (Alabi *et al.*, 2018). Yet many existing plants are planned, financed, and built amid crisis without the planning and governance to ensure the benefits outweigh costs, posing a risk of lock-in that constrains future adjustment. Other possible future prospects include the potential for solar-based water harvesting from the air; there is, indeed, 'water, water everywhere' (Tu *et al.*, 2018).

More immediately, decentralized technologies promise to lower capital costs dramatically, spurring new financial, pricing, and allocation models in the process. Emerging technologies are promising to catalyse smart grids—whether mobile phone enabled rural water supply networks or modular urban water utilities. This is not necessarily new; groundwater development across India and China has been credited with expanding access to irrigation and lifting millions out of poverty (Mukherji, 2008). Yet these past disruptions came at high environmental costs, as water levels plummeted in parts of Northern and Western India. For these decentralized technologies to realize their promise without locking in a legacy of overexploitation, the accompanying economic policies must anticipate and monitor behavioural responses to new incentives to reduce the risks of perverse consequences. As a corollary, subsidy and pricing policies will not involve a set-and-forget model, but instead sustained government roles, and attention to vested interests motivated to exploit the loopholes in such schemes.

Will blended finance bridge the infrastructure finance gap?

There is some hope of expanding private-sector participation in the financing of water infrastructure in the future through the use of *blended* finance, the strategic use of development finance aimed at mobilizing additional sources of finance from non-traditional actors such as impact investors (Money, 2019). This holds some promise. The key requirement is to create investment projects that are bankable, i.e. offering a sufficiently attractive rate of return plus socially satisfactory outcomes, while sufficiently protected against political and economic risks (Gruère and Le Boëdec, 2019). In essence, this is about catering to the interests and preferences of potential investors, both those motivated socially and financially.

For this to work, these projects also need to cater to the interests and preferences of the water users themselves. Users will be willing to pay higher charges only if they perceive they are getting a better service in return. Successful water infrastructure finance needs to offer an attractive value proposition to water users and investors. In focusing on private-sector financing, the conventional economic view assumes that governments in developing countries have inadequate capacity to finance water infrastructure themselves. This may be the only explanation consistent with empirical experience to date. But perhaps that assumption should be revisited, at least in middle-income countries. If water infrastructure targets are to be met, national governments may need to step up to the plate with additional tax revenue. In South Korea, for example, the national government earmarked revenues from a national liquor tax to finance water infrastructure. While instituting a functioning local property tax system is a Herculean task, and particularly intractable in parts of Asia and Sub-Saharan Africa, this may be the key to creating a financing mechanism for local water and wastewater provision.

So far, we have focused on the financing of conventional networked water supply infrastructure. What about non-networked water supply? A decentralized, non-networked water distribution system would be more expensive per litre delivered, but it could be vastly easier to finance and it could be expanded in a nimbler and more flexible manner. It might also create some opportunity for self-finance by water users or blended approaches that rely on performance-based models (Hope *et al.*, 2020).

There is no single solution to the challenge of financing the water and sanitation infrastructure that will be needed. Neither higher tariffs, more foreign aid, private capital using blended finance, nor earmarked local nor national government tax revenues is likely to be forthcoming at sufficient scale to alone meet the financing challenge. Rather, without a portfolio of actions along all these dimensions, financing will be inadequate.

Will smart markets ensure sustainable water use?

New technologies and financing models are spurring interest in governance innovations to tackle unsustainable water extractions. Forty-five years after the US National Water Commission touted water markets as the future of water policy, will tech innovations finally signal the start of a new era? In 2019, for example, *Wired* magazine[16] was one of many to herald the potential of a 'blockchain for water' to spur solutions to water scarcity, highlighting their potential to unlock groundwater markets in California. Because water users have been historically suspicious of water metering as a gateway for regulations to reduce access to water, 'the new tech could help water users better understand their water use and come to a consensus'.

Experimentation with water markets and other forms of incentive-based water management is not new, offering lessons for the next generation of innovation. Progress has been more limited than envisioned, raising questions regarding the 'scalability' of such markets and the potential for technologies and financing innovations to overcome failed institutions or distributional conflicts. Initial reforms were guided by the logic of free market environmentalism—reform property rights, and spur the private sector and non-profit groups to enter the marketplace on behalf of the environment (Anderson and Leal, 2001). Technological innovations, such as cheaper monitoring, promised to lower transaction costs, while new financing from developers, polluters, and impact investors would secure water for the environment. Janet Neuman, the former board president of the Oregon Water Trust, the first non-profit created in 1993 to purchase and lease water for salmon habitat restoration, noted: 'that was then, this is now' as such initiatives encountered predictable political resistance and struggled to build on

[16] https://www.wired.com/story/how-blockchain-could-protect-californias-aquifer/.

pilot efforts (Neuman, 2004). The third-party impacts on rural economies triggered staunch resistance. The burden of monitoring and enforcing such systems of environmental water rights at a landscape scale has proven enormous, despite the technological innovations in metering, in part due to regulatory capture (Grafton and Wheeler, 2018).

Twenty-five years ago, the first wave of experiments led to calls for new organizational models, occupying two extreme points on the spectrum—private water trusts in the US or a basin-wide government agency in Australia. The lack of resources in the former and legitimacy for the latter has prompted a rethinking of the institutional design (Garrick, 2015). These approaches almost universally encountered a set of hydrological, socioeconomic, and political barriers that seem obvious in hindsight. The ability to tap markets and other forms of incentive-based water management approaches to ensure sustainable water management is no longer seen as a matter of free-market environmentalism, but one of institutional diversity, and sustained institutional reform, coupling public and private roles. Innovations in monitoring and finance can facilitate creative models but must build on historic institutions and address vested interests head on. Like the recent innovations in finance, where private roles have proven complementary but no substitute for strong community and government roles, the experience with water markets and environmental flows suggests successful governance approaches will be blended—an 'institutional tripod' of markets, governments, and self-governance by users (Meinzen-Dick, 2007).

V. Central lessons

Rethinking the economics of water suggests five central lessons for research and policy.

(i) **Institutions for coordination are necessary.** Multiple actors and multiple institutions are involved, controlling different aspects of water. Externalities are pervasive, posing collective action hurdles at multiple scales. For example, institutional arrangements must facilitate cooperation and conflict resolution between multiple sectors (e.g. cities and agriculture) and countries or states (e.g. international rivers) competing for water. Yet, the costs of integrated water resources management are substantial and unevenly distributed with different economies of scale for different types of water management objectives. The challenge is to coordinate these diverse institutions and align their interests. Multiple instruments will be required to accomplish this, involving both monetary and non-monetary outcomes that create value for these parties. In (large) part, this is a political process. There is no unique silver bullet, but it is possible to draw lessons about institutional design that can be translated and adapted for other regions with similar challenges and contextual features (e.g. cultural, technological, political, and economic). The Colorado River and Murray-Darling River Basin have exchanged lessons for over a century (Hanemann and Young, this issue), learning from both successes and failures over time.

(ii) **Blended solutions will require blended governance**. The stubborn financing gaps and governance investments that have caused under-investment and misallocation will depend on a blend of public and private roles, rather than either in isolation. The 30-year experience with privatization in the UK illustrates this starkly. Ownership has proven less important than envisioned, merely setting the context for regulation and spurring a call for 'mixed ownership' and system-wide regulation. A different set of blended models is needed to integrate non-networked supplies into public and community water systems across the Global South. Doing so will require accounting for the distinct set of physical and social challenges associated with rapid urbanization and growing dependence on groundwater in regions confronting fragility and other gaps in government capacity.

(iii) **Quantity signals are as important as price signals**. Establishing limits, establishing rate *structures*, appealing to non-monetary interests and concerns are required, rather than simply 'getting the price right'. The realm of economic regulation is an important complement to pricing and property rights. Markets and pricing emerge from well-designed regulation, sustained reforms, and adaptation. Improved pricing requires attention to inequalities and affordability concerns that have fuelled resistance and perverse consequences in the past.

(iv) **Economic policy levers outside of water are important**. Agricultural subsidies, energy pricing, competition policy, health policy, urban policy, taxation policy are important to address. Complementary policies and investments are needed, as illustrated by the analysis of randomized controlled trials for sanitation. The success of Singapore's water management hinged on a comprehensive strategy that addressed water in connection with housing policy and related infrastructure investments. In non-networked water systems across the Global South, other infrastructure (e.g. roads, telecoms) may create new possibilities to overcome the historically intractable barriers to safe, affordable water supplies.

(v) **Never waste a crisis but don't wait for one**. The concept of dynamic adaptive pathways implies that a sustained sequence and strategy for investment and reforms are required. Political crisis, economic restructuring, or climate extremes all provide openings to overcome the vested interests that would block otherwise beneficial and well-designed policies and investments in water infrastructure, pricing, and property rights reforms. Australia's experiences with water markets—both its successes and struggles—can be explained partly by its ability to prepare for and respond to crises, whether droughts or political changes. Grandfathering water entitlements may have proven a necessary political bargain, but it reinforced the vested interests and rent seeking that have stymied reforms and hindered environmental water buybacks. Reform is never complete, suggesting that each stumbling block will require a proactive strategy to lessen future crises and seize the opportunities created by crises when they occur.

In 2015, the economic losses caused by water risks were estimated at approximately US$500 billion annually (Sadoff *et al.*, 2015). Climate change and population growth will multiply and accelerate these threats. The Sustainable Development Goals call for billions of investment in infrastructure that will set the water development paths for many cities and regions. The scale of the challenges will require technological innovations, and government policies to facilitate research and development. However, past experience illustrates clearly that technological innovation is not enough. Technology must go hand-in-hand with institutional capacity to supply, allocate, and manage water. In this regard, this issue of the *Oxford Review of Economic Policy* suggests that promising policy innovations have struggled to keep pace with the severe water challenges confronting society now and in the future. A strategy for strengthening institutions to support economic policies for supplying, allocating, and managing water, backed by a sustained political and financial commitment to address those who might be left out, is an urgent priority.

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