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Chapter 6

Economics and water allocation reform

C. Dionisio Pérez-Blanco[1,2]

[1]Associate Professor, Universidad de Salamanca, Salamanca, Spain
[2]Associate Researcher, Centro Euro-Mediterraneo sui Cambiamenti Climatici, Venice, Italy

ABSTRACT

This chapter discusses major economic challenges and outlines key economic considerations in the design and implementation of water allocation reforms where agriculture is a major water use. It first examines key economic issues in water allocation reform, focusing on the challenges brought by the trade-offs between efficiency, social (distributive) justice, environmental sustainability and institutional reform, and the inherent uncertainties in managing these trade-offs, which are amplified by the complex nature of social-ecological systems. Based on this analysis, the chapter outlines a series of principles towards a water allocation reform that achieves sustainable, equitable and robust economic growth, and discusses the role of economic instruments in such reform. Finally, it identifies persistent research gaps towards delivering actionable science for informed water (re)allocations.

Keywords: Economic instruments, institutional reform, water scarcity

6.1 INTRODUCTION

Water crises are among the greatest global societal risks in terms of potential impacts (WEF, 2020). If current water use patterns continue, 'water demand will exceed supply by 40% by 2030, decreasing the growth rate of the GDP by up to 6%' in water-stressed regions (2030 Water Resources Group, 2019). Avoiding this 'misery in slow motion' calls for systemic and paradigm shifts in water resources management (World Bank, 2017). In mature water economies with inelastic supply (i.e., supply cannot be readily expanded and eventually becomes fixed), such transformation will need water allocation reforms that redistribute available water resources among uses (including redistribution to/from the environment). In order to address present and future challenges, most countries will need to modify their water allocation regimes (Young, 2014).

Some authors argue that water, being an economic good, should be freely reallocated through exchanges in water markets. The economic value of water arises spontaneously from the actions of willing buyers and willing sellers through prices, which ensures the good's reallocation towards uses that are more highly valued in that market and the maximization of economic efficiency (Mendelsohn, 2016). This is the rationale behind the development of water markets in several parts of the world

The chapter is from the book *Water Resources Allocation and Agriculture: Transitioning from Open to Regulated Access*, Josselin Rouillard, Christina Babbitt, Edward Challies and Jean-Daniel Rinaudo (Eds.)

(Wheeler, 2021). Yet, water is not like most goods or services that are usually found in a market (Savenije, 2002). Water is essential for life and society. It is simultaneously employed for private and public uses, including essential drinking water and sanitation services. Water is bulky, variable across space and time, and part of a complex system of water bodies (e.g., river–aquifer dynamics). This means that alternative water uses (environmental or economic) are interrelated and affect each other.

This chapter discusses major economic challenges and outlines key economic considerations in the design and implementation of water allocation reforms where agriculture is a major water user. In contrast to the classical principles of a market economy which assume that existent allocation problems can be addressed by transforming collective concerns into private decisions and public authorities only have to properly define and protect/enforce property rights (Mendelsohn, 2016), some scholars argue that the unique characteristics of water (e.g., conjunctive use; return flows and reuse; public, private and common pool goods) call instead for collective action where governance and institutions (and the reform thereof) play a decisive role (Gómez *et al.*, 2017). Rather than providing panaceas (Meinzen-Dick, 2007), the economics of water (re)allocation involves institutional changes and high transaction costs. Re(allocation) decisions must be implemented with a thorough understanding of human–water systems dynamics, uncertainties, and limits in order to avoid future surprises and crises (Marchau *et al.*, 2019; Sivapalan *et al.*, 2012).

Hence, this chapter first examines economic issues in water allocation reform, focusing on the challenges brought by the trade-offs between efficiency, social (distributive) justice, environmental sustainability, institutional reform, and uncertainties in complex social-ecological systems (Section 6.2). The chapter then sets out a series of principles for water allocation reform (Section 6.3) and discusses the role of economic instruments in reforming agricultural water allocations (Section 6.4). Finally, the chapter discusses the role of scientific research in informing efficient and effective water reallocations that are robust—that is, low-regret/no-regret (re)allocations that are capable of tolerating and adapting to perturbations (Section 6.5).

6.2 ECONOMIC ISSUES IN WATER ALLOCATION REFORM

6.2.1 Reforming allocation regimes results in large transaction costs

Numerous water (re)allocation reforms with the potential to lead to improvements in economic efficiency have been identified in the literature. Yet, very few have been implemented (Gómez *et al.*, 2017). Several factors explain this resistance and the barriers to water allocation reform.

- *First*, users can exert pressures on public institutions to build new infrastructures to expand the amount of water available for use to increase private gains, even if the total costs (largely paid by the public) exceed the benefits—which is typically the case in mature water economies. There is abundant evidence that building new infrastructures towards expanding supply is significantly costlier than water (re)allocations, but the former is politically expedient (while reallocations can be politically very costly—see below) (Garrick, 2015).
- *Second*, water (re)allocations will often create winners and losers. Naturally, those who lose will have incentives to oppose these (re)allocations. This can lead to regulatory capture, where those benefiting from the current allocation regime increase their capacity to co-opt decision-makers to serve their private interests, usually through lobbying and corporatism (Lopipero *et al.*, 2007; Wiarda 1996). Regulatory capture can be exerted through regulations (*de iure*) or in a *de facto* manner through insufficient or non-existent enforcement of adopted regulations. Notably, it is estimated that between 30% and 50% of water supply worldwide is appropriated by irrigators without a formal license; yet, despite increasing detection rates, prosecution rates remain as low as 2.2% in many developed economies, which undermines compliance (Loch *et al.*, 2020).
- *Third*, users and decision-makers may not accept economic efficiency as a relevant factor to assess water (re)allocations (or at least not as the only factor). In their view, water allocation

reform should be (at least in part) based on other criteria, such as equity. These alternative views explain why certain (re)allocation mechanisms based on economics, notably markets, are rejected by users, which leads to inefficient allocations (Hérivaux *et al.*, 2020).

- *Fourth*, institutions have their own dynamics, and changing their trajectories is costly. As a result, while conventional economic analysis argues that incremental improvements in performance (efficiency, robustness) are sufficient to drive the adoption of superior (re)allocations, the costs of the design and implementation of new institutional organizations can be high and can require improvements in economic efficiency to make the reform viable (Unruh, 2002).

Together, these barriers add additional costs to policy reform in the form of transaction costs, which add up to neoclassical abatement costs (Marshall, 2013). Transaction costs consist of the costs of arranging a (re)allocation ex-ante and then monitoring and enforcing it ex-post, as opposed to neoclassical abatement costs which are the costs of executing the (re)allocation (Matthews, 1986).

Transaction costs can be further subdivided into private and institutional transaction costs. Private transaction costs include search and information costs, bargaining costs (e.g., time to negotiate a reallocation), as well as policing and enforcement costs incurred by human agents in economic trades. Institutional transaction costs include institutional investments (rules and regulation capacity) and organizational investments (people and knowledge capacity) required to achieve water policy objectives (McCann, 2013).

Recent research has monetized the transaction costs of water market reallocations in the United States and Australia, showing that private transaction costs can represent up to 30% of total policy costs (i.e., transaction costs plus abatement costs), institutional transaction costs up to 35% of total policy costs, and aggregate public and private transaction costs up to 53% of total policy costs (Garrick *et al.*, 2013; Loch *et al.*, 2018; McCann, 2013).

These non-trivial magnitudes mean that transaction costs will affect the optimal choice and design of (re)allocation policies. Economic analyses (such as cost-effectiveness) must consider abatement and transaction costs when comparing alternative water (re)allocations. Ignoring any of these considerations would underestimate the cost of (re)allocations, leading to only a partial understanding of the system as well as misleading policy recommendations. However, the empirical base on transaction costs of water policy reform beyond water markets in the United States and Australia is virtually non-existent. As a result, transaction costs are typically excluded from empirical assessments of water or other environmental policies (Garrick, 2015).

6.2.2 Water allocation reforms require compromises between economic efficiency, environmental performance, and social justice

Population growth, higher standards of living, and changing societal perceptions of environmental problems increasingly constrain policymakers in efforts to reallocate increasing amounts of water resources to urban and environmental uses. Water resources to meet these needs are typically sourced from agriculture, the largest water use (about 70% of total global water withdrawals) (FAO, 2021). As water becomes scarcer and its value increases, agriculture and irrigation are progressively transformed from traditionally extensive (high water input to output ratio) to intensive (high output to water input ratio) systems through the adoption of new more technically efficient irrigation technologies (e.g., drip irrigation, greenhouses) (Pérez-Blanco *et al.*, 2021). This process is asymmetric and can create non-trivial equity issues, where the remaining traditional farmers are targeted to achieve further water savings at the least cost which are then made available for the environment or higher value-added economic uses (Gómez *et al.*, 2017). In addition, intensive agricultural systems often demand less labor than traditional extensive systems, which can lead to rural depopulation and migration to urban areas that, if left unaddressed, can further aggravate other environmental and social problems, such as inequity, marginalization, and violence (Todaro, 1969).

Farmers will likely oppose this transition to water (re)allocation and in many places they already do. However, the question is not whether water will be reallocated from agriculture towards urban and environmental uses (as it inevitably will be), but rather how the specific transition process will occur (organized v. disorganized transition) and consequently, what the subsequent social impacts of the specific transition process will be (Perry, 2019). Under disorganized (re)allocation of water from agriculture, farmers and urban users will be negatively affected by reduced water availability, including the more productive users. Uncertain supply will reduce on-farm investments and the production of higher value-added crops (e.g., greenhouses). Loss of flexibility through reduced buffer stocks will often test systems to breaking points and lead to irreversible losses (e.g., disinvestments through loss of permanent crops) (Adamson & Loch, 2021). Unconventional water resources such as treated wastewater and desalinated water will be introduced in agriculture (at a higher cost). Initially, these unconventional resources will be used mostly as a buffer stock during drought years—in normal years, cheaper conventional resources will be preferred. As conventional water resources are exhausted, non-conventional resources will be progressively added to the regular irrigation supply base. This will lead to inequitable impacts (another option is that these sources are subsidized, which may partly correct inequity but lead to inefficient allocation) (March *et al.*, 2014). In the urban sector, under disorganized reallocation of water, water will be unreliable at the margin during part of the transition period, creating costs. Non-conventional resources and transfers from distant areas (if possible) will be progressively added to stabilize supply, while (overexploited) agricultural resources will be intermittently transferred to urban uses. This will create supply costs and rising prices, and affordability issues. This disorganized transition is inefficient from an economic standpoint, ineffective from an environmental standpoint, and inequitable from a social standpoint even if it may be more practical from a policy standpoint.

Organized reallocation can be planned over time to help ease the transition for less productive farmers to minimize overall losses, conserve buffer stocks to minimize capital losses and facilitate investments, and involve progressive introduction of non-conventional resources, which are only added where they are financially sustainable (i.e., high value-added uses) (Strosser *et al.*, 2013). Urban organized reallocation buffers consumers from major price shocks and sudden water conservation emergencies and enables continuation of existing mechanisms that provide a basic supply of water to the poor (e.g., low-cost water fees and low-cost basic water supply blocks). A major issue is how to create compensation mechanisms to address equity issues (including reduced income from the users relinquishing their water rights, reduced employment, reduced GDP and services—hospitals, schools, etc.) arising from organized reallocation (e.g., buy-back, markets). This alternative will involve significant opposition and institutional transaction costs and conflict but offers superior environmental and economic performance.

6.2.3 Reallocations may result in externalities, which are poorly accounted for in conventional water policy

A water reallocation from an agent with a low technical efficiency (e.g., flood irrigation at 50% efficiency) to an agent with high technical efficiency (e.g., drip irrigation at 95% efficiency) will increase the amount of water consumed, and significantly reduce return flows back into the environment, which are often reused downstream (see Figure 6.1). These potential impacts on environmental and other third-party uses are typically not internalized by markets and lead to externalities, namely costs to third parties not directly involved in the market exchange (Pérez-Blanco *et al.*, 2020a, 2020b). Internalizing externalities (such as an increase in technical efficiency upstream that reduces return flows, water available, and income to third parties downstream—including environmental income through amenities) in complex socio-ecological systems is far from simple and requires complex valuation and modeling exercises.

Over the past decades, environmental economics has developed and improved techniques to estimate the environmental values of water (e.g., the sheer enjoyment of a free-flowing river) (Dasgupta, 2021).

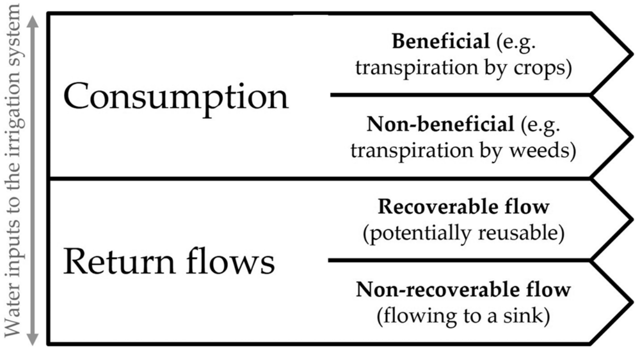

Figure 6.1 Water accounting balance.

By estimating environmental values and modeling trade-offs, a more comprehensive measurement of abatement costs (i.e., the cost of implementing a reallocation) and benefits of water (re)allocations is feasible. The environmental value of water is significant and sometimes can greatly outweigh other commercial benefits (UN, 2021). Yet, despite its advantages in terms of transparency and visibility of environmental values, environmental valuation faces many technical challenges and it is rarely used to inform economic analyses (e.g., cost–benefit analyses) supporting water allocation reforms (Arrow *et al.*, 1993; UN, 2021).

All water entering the irrigation system goes to either: (1) productive consumption, water that is purposefully converted to water vapor, primarily crop transpiration; (2) unproductive consumption, water that is not purposefully converted to vapor, such as through transpiration by weeds or evaporation from wet surfaces; (3) reusable return flows, water reaching a usable aquifer or stream with downstream demand; and (4) non-reusable return flows, water flowing without benefit to a sink such as the sea, and therefore not usable (adapted from Pérez-Blanco *et al.*, 2020b).

6.2.4 Reallocations must account for large uncertainties intrinsic to complex social-ecological systems

Even with significant information on the costs and benefits of water (re)allocations, decision-makers should exert caution due to the uncertainty involved in most estimations. Most cost and benefit estimates use hypothetical scenarios and a complete set of probabilities to produce point predictions (i.e., a single benefit/cost estimate) using a model. However, some scenarios that are deemed implausible and are accordingly allotted very low probabilities may happen. Also, some futures that were completely unknown may be realized down the road. Finally, models can be wrong, creating (significant) biases in predictions.

In this context, point predictions may attribute a relatively minor importance to, or directly ignore, plausible tipping points leading to catastrophic outcomes with major environmental and economic implications. This is the case with several irrigation modernization policies worldwide, some of which initially aimed to abate the impacts of water overallocation through 'water savings'. There, we encounter the paradoxical outcome of a project with an expected positive welfare gain (reduced water inputs, higher income, water saving) turning into minor economic gains or even losses (higher incomes from adopters are obtained by cannibalizing return flows previously used by downstream users, see Figure 6.1) and significant environmental damage (downstream users attempt to mitigate losses by appropriating resources previously allotted to the environment) (Pérez-Blanco *et al.*, 2020b).

Risk and uncertainty should thus feature as a basis for any target setting and water allocation choice. At a minimum, alternative plausible futures/scenarios must be considered, including future inflows, increased demand, transformational industry, and so on. In addition, the precautionary principle should drive decisions (Bishop, 1978). The precautionary principle prescribes the protection and conservation of renewable natural resources so that they cannot go below a minimum threshold beyond which uncertainty is deemed too high (e.g., minimum environmental flows in rivers). The precautionary principle doctrine pervades Integrated Water Resource Management, as exemplified by the European Union (EU) Water Framework Directive (WFD), whose objective is to achieve the 'good ecological status' of water bodies, for which the policies with the lowest economic cost should be chosen (i.e., robustness first, followed by economic performance) (OJ, 2000).

When considering uncertainties, the priority in the economics of water (re)allocation shifts from efficiency first (cost–benefit analysis) to the achievement of robustness (i.e., no-regret); efficiency is then pursued conditioned to this priority target (UN, 2012). This involves an economic trade-off since prioritizing robustness will typically come at the expense of sacrificing uncertain (re)allocations with a potentially higher payoff. Thus, decisions may lead to second-best solutions in economic terms (Hino & Hall, 2017).

6.3 A ROBUST BASIS FOR ECONOMICALLY-SOUND WATER ALLOCATION REFORM

Based on the previous analysis, it becomes clear that any water allocation reform that promotes sustainable, equitable and robust economic growth and welfare must be based on a number of preconditions. We highlight the following principles, which can respond to some of the challenges highlighted above.

First, the water allocation reform should be underpinned by a unified, *transdisciplinary* accounting framework that integrates knowledge and methods from different disciplines (Willardson *et al.*, 1994) (see Figure 6.1). A readily available, but often overlooked, accounting framework is the fractions approach (Willardson *et al.*, 1994), which is represented in Figure 6.1. The fractions approach avoids value-laden terminology such as modernization, losses, or inefficiencies; all of which can lead to divisiveness and a loss of focus in water allocation and institutional choices. The accounting framework should be supported by innovations that can enhance its accuracy such as data provided by satellites, smart meters, or citizen science (e.g., involving citizens in water-use monitoring). Accounting and monitoring should be complemented with a single public register of all allocations within the basin.

Second, total allocable resources must be decided conditional on available supply, and individual allocations defined so that their sum does not exceed these total harvestable resources. This 'unbundling' process of total harvestable resources and water allocations has two key advantages (Rouillard & Rinaudo, 2020; Young, 2014). First, it complies with the theory of economic policy, or Tinbergen Principle, which states that in order to achieve a number of policy objectives, an equal number of interventions is needed (Tinbergen, 1952). In an unbundled scheme, environmental sustainability (target 1) is achieved by defining the total volume of harvestable resources (intervention 1); while water is distributed to economic uses (target 2) through an allocation mechanism (intervention 2).

Next, through unbundling, risk and uncertainty are fully transferred to users. This sets an efficient framework where the institutional level does not necessarily interfere with the operational decisions of private users (Ciriacy-Wantrup & Bishop, 1975). This occurs when authorities focus on defining harvestable volumes and then leave it to users to define individual (re)allocations. Instead of investing public funds to protect users against growing scarcity (e.g., by building additional storage), and deciding in the process what farm-level interventions are desirable (e.g., irrigation modernization), the decision on how to adapt at the farm-level is left to farmers. Note that robust institutions that are capable of tolerating and adapting to perturbations, including extreme ones, will nevertheless still be required to support the allocation decision-making (e.g., water users associations).

Third, hydrological integrity must be ensured. The process of defining harvestable resources requires objective indicators in order to avoid the vested interests of economic users undermining hydrological integrity by setting too-high harvestable caps (Pérez-Blanco & Gómez, 2014). It is crucial that allocations account for return flows (to surface and sub-surface water bodies), interconnections between water bodies and any remaining informal/unlawful use. It is also important to revise allocations where autonomous adaptation responses by users affect the consumption rate—most notably, in those cases when farmers adopt modern irrigation systems that increase technical efficiency and the fraction of water consumed (Pérez-Blanco *et al*., 2020b).

Young (2014) proposes two mechanisms to address the challenge of growing technical efficiencies: (1) defining harvestable resources as net harvestable resources (i.e., based on consumption rather than withdrawals), which seems the most straightforward option but presents non-trivial technical difficulties; or (2) reductions in the amount of water received via individual allocations as the consumed fraction increases. This change is necessary to avoid rent-seeking behavior, where technology adopters extract rent from the appropriation of water resources of downstream users.

Fourth, users must be provided with institutional certainty to ensure they undertake the necessary investments to successfully adapt to water scarcity (Young, 2014). This means having pre-determined allocation mechanisms, defined for instance as shares of the harvestable resources, fixed volumes defined with a security of supply and modulated on actual available resources in any one year, or as pre-defined priority rights based, for example, on seniority (Rouillard & Rinaudo, 2020; Santato *et al*., 2016; Young, 2014). Once the indicators used to define the total amount of harvestable resources and the allocation mechanisms are defined, they can only be changed based on clearly established and fair rules that are understood by all users (e.g., through predetermined formulas, through regulated market (re)allocations).

Fifth, gathering longitudinal data on transaction costs over time and across places can help identify and evaluate reforms that were successful in changing the trajectory of institutions towards sustainable and inclusive economic growth; this data can also illustrate the annealing forces that gave change momentum and inform the development of successful water allocation reforms elsewhere (Garrick, 2015). Information on transaction costs can be valuable when assessing the suitability of proposed water allocation regimes. That is, if the decision-maker is unwilling to commit to the required transaction cost investment required to support the (re)allocation, then that proposal could easily be removed from a choice set or shelved until such time as it was feasible to invest as necessary.

The principles above conform to the building blocks for a robust water allocation regime that can tolerate and adapt to uncertainty, while supporting water bodies' ecological integrity, and enabling economic growth. In the next section we explore how, building upon this set of principles, economic instruments can be used to underpin and enhance economic, social, and environmental performance.

6.4 THE ROLE OF ECONOMIC INSTRUMENTS IN REFORMING AGRICULTURAL WATER ALLOCATIONS

6.4.1 Defining economic instruments

Water challenges, such as scarcity, pollution, and increased water insecurity, are driven by inadequate economic incentives that promote responses such as using more water than is available or getting private benefits while transferring costs to third parties (externalities). These incentive-driven drawbacks cannot be sorted out by defining regulations alone. Users within the water allocation regimes must comply with the regulations, as has been repeatedly shown in cases of widespread non-compliance with water allocation rules (often referred to as 'water theft') (Loch *et al*., 2020). It is also necessary to define economic instruments, namely, 'incentives designed and implemented with the purpose of adapting individual decisions to collectively agreed goals' (Strosser *et al*., 2013). Thus, while economic incentives are at the source of the problem, they are also called to be an essential part of the solution.

Several taxonomies of economic instruments are available in the literature (eds. Gómez *et al*., 2017; Lago *et al*., 2015; Rey *et al*., 2019). The most relevant categories in relation to water allocation reforms include markets of water use rights (Wheeler, 2021), sanctions for non-compliance with water allocations (Figureau *et al.*, 2015; Loch *et al.*, 2020; Rouillard & Rinaudo, 2020), subsidies (e.g., to adopt water-efficient technologies or to compensate the economic impact of reduced allocations) (Pérez-Blanco *et al.*, 2020b) and charges to incentivize water savings (eds. Dinar *et al.* 2015). More recent studies also explore the role of insurance (e.g., drought insurance that substitutes natural capital from aquifers with financial capital) (Gómez-Limón, 2020; Pérez-Blanco & Gómez, 2013), as well as pecuniary (i.e., Payments for Ecosystem Services—PES) (Asbjornsen *et al.*, 2015) and non-pecuniary voluntary agreements (Gómez *et al.*, 2014).

6.4.2 Designing appropriate economic instruments to support water allocation reforms

Early attempts to mainstream economic instruments into water resources management were primarily concerned with enhancing efficiency; for example, by allowing water trading to expand the economic surplus of willing buyers and sellers or by setting water charges (commonly referred to as prices) at the 'right' level (Briscoe, 1996; Dinar & Subramanian, 1997). However, water management problems are complex and do not result from the lack of efficiency, but rather from the lack of coordination that results from an incompatibility between multiple individual actions that pursue private benefits on the one hand, and the long-term sustainability of water resources and the economic activities that depend on them on the other (Gómez *et al.*, 2017). Thus, while water markets clearly maximize the returns for those involved in the transaction, they are not necessarily beneficial to third parties potentially affected by the transaction (including the environment) or to society as a whole (Connor & Kaczan, 2013). Similarly, while setting the 'right' water charge level can contribute to cost-recovery, much more can be achieved by setting the right *type* of charges. For example, volumetric levies can induce water conservation and contribute to restore the balance in overallocated basins (Caswell *et al.*, 1990).

The vision of economic instruments changes radically when we put the focus on the problem and not on the instrument. In this case addressing water management challenges is equivalent to making the multitude of decisions people make about water compatible with collective water governance objectives such as curbing water depletion and pollution trends or building inclusive water security for the future. This approach provides the basis for assessing the performance of existing economic instruments such as charging and trading schemes, as well as for reshaping economic instruments to serve the objectives of Integrated Water Resources Management (IWRM).

Economic instruments differ from regulatory instruments in their capacity to achieve IWRM objectives in an efficient manner, that is, at a lower economic cost and/or higher benefit for society. This capacity manifests when two preconditions are met: appropriate rationales for participation and incentive compatibility (Laffont & Tirole, 1991). The former precondition indicates that individuals will only engage in a specific action when they expect a positive return from said action (or a negative return from non-compliance). The latter precondition indicates that these positive returns should be made available to individuals only when their actions contribute to IWRM objectives (including economy-wide efficiency, but also inclusivity and sustainability). Accordingly, use of economic instruments is advised when 'there are welfare-improving opportunities that can be transformed into private benefits for water-users', and 'collective gains then follow' (Gómez *et al.*, 2017).

The use of economic instruments that only achieve private benefits is not warranted under this framework. For instance, the use of water markets that can potentially create externalities with a negative impact on the environment and other economic uses is not advised, *unless complemented with a sound regulatory and water allocation regime that ensures hydrological integrity and addresses other third-party impacts*. Conversely, where only collective benefits are expected, economic instruments will not be capable of putting in place the necessary incentives to drive individual actions towards the desired objectives and other instruments such as regulations will be necessary. In this vein, it should be noted that economic instruments are not a substitute for norms and regulations; rather, they should be designed to complement them, as a part of a comprehensive water allocation regime that serves the objectives of IWRM (eds. Lago *et al.*, 2015).

Table 6.1 Definition, advantages, and disadvantages of economic instruments for water allocation reform. Adapted from Rey *et al.* (2019).

Instrument	**Definition in the context of water allocation reform**	**Advantages**	**Disadvantages**	**Example(s) of economic instruments that align individual choices with collectively agreed IWRM goals**
Charges	Levies on water use related to conveyance and storage services and the opportunity cost of the resource (resource and environmental costs). They can be earmarked (tariff) or not (tax).	• Effective, compliance with polluter-pays • principle • Revenue-raising	• Resistance (lobbying) and related • transaction costs • Willingness and ability to pay may lead to equity issues	Charging mechanism that recovers, beyond financial costs, the environmental and resource costs of water. In 2017, the Piedmont Region in Italy introduced a pioneering reform that stated that in order to access the EU's Common Agricultural Policy (CAP) funding, irrigators should pay the environmental and resource costs of water use. However, the implementation of such conditionality is still pending.
Trading	Institutional setting that allows transferring of (marketable) water allocations across agents, places, and time, in exchange for a pecuniary compensation	• Efficient reallocation of water • Enables buy-back/ PES	• High transaction costs • Institutional/legal complexity • Limited acceptance across stakeholder groups • Asymmetric impacts • (e.g., selling areas with negative impact on food industry) and potential externalities • Incentive towards increasing consumptive use • Illegal markets	Water markets that observe hydrological integrity (rarely achieved; in some legislations hydrological integrity must be *de iure* observed, but *de facto* it is often bypassed–e.g., Spain)
Sanctions	Pecuniary penalty imposed by the judiciary when a specific behavior is observed (e.g., overdraft)	• Effective, compliance with polluter-pays • principle • Revenue-raising	• Monitoring can be expensive • Limited enforcement	Sanctions for non-authorized water uses in Spain can amount to EUR 500 000, but are often not enforced

(*Continued*)

Table 6.1 Definition, advantages, and disadvantages of economic instruments for water allocation reform. Adapted from Rey *et al.* (2019) (*Continued*).

Instrument	Definition in the context of water allocation reform	Advantages	Disadvantages	Example(s) of economic instruments that align individual choices with collectively agreed IWRM goals
Insurance	Insurance is the most commonly used instrument for financial protection against risk contingent losses, in which ‘the insured party or policyholder transfers the cost of potential loss to the insurer in exchange for monetary compensation known as a premium’ (DRMKC, 2017). The insurer thus absorbs, pools, and diversifies the individual risks acquired from policyholders, making them assessable and manageable.	• Deters groundwater withdrawals that are difficult to monitor • Privately funded (largely)	• Willingness and ability to pay may necessitate subsidies to become feasible (particularly systemic risks such as drought), budgetary issues (public reinsurance), high institutional uncertainty (allocation mechanism during scarcity). As a result, drought insurance in irrigated agriculture is very rarely made available to farmers.	The EU CAP funds an income stabilization tool through mutual funds (non-profit, cooperation and self-help organizations that gather groups of farmers who conform their own contingency fund and assume responsibility for their own risk management) that addresses both production and market risks, including drought risk; yet it has limited uptake, since insurance policies are typically issued by commercial insurers.
Subsidies	Financial aid or support. Can be explicit (price supports, subsidized loans and direct payments) or implicit (reduced regulation and tax/charges relief)	• Limited transaction costs, can enhance equity	• Infringement of polluter-pays principle • Budgetary constraints • Coupled subsidies may aggravate scarcity (e.g., subsidization of irrigation modernization) • Low effectiveness and cost-effectiveness	Subsidies to farmers that agree to practices that mitigate scarcity (e.g., forested infiltration areas in Northern Italy that recharge groundwater aquifers by channeling surface waters during non-irrigation months)

(*Continued*)

Table 6.1 Definition, advantages, and disadvantages of economic instruments for water allocation reform. Adapted from Rey *et al.* (2019) (*Continued*).

Instrument	Definition in the context of water allocation reform	Advantages	Disadvantages	Example(s) of economic instruments that align individual choices with collectively agreed IWRM goals
Payments for Ecosystem Services	Conditional payments offered to water users in exchange for the voluntary provision of some sort of ecological service (e.g., water reacquisitions to enhance environmental flows)	• Limited transaction costs • Flexible • Cost-effective	• Infringement of polluter-pays principle • Budgetary constraints • Crowding-out of intrinsic • motivations to protect ecosystems • Equity issues	Water buy-back in the Murray–Darling Basin (Australia)
Voluntary agreements	Non-pecuniary and voluntary incentives, based on opportunities for individual profit or loss mitigation, to enhance negotiated arrangements among agents to achieve public policy objectives	• Flexible • Acceptable • Inexpensive	• Low performance if incentives not properly defined • Limited to win-win situations • Technological, institutional and/or legal barriers, can delay action during droughts • Exclusion of some users	Voluntary agreement to release pulse flows in the Lower Ebro River (Spain) between the hydropower company (which benefits from reduced costs of removing macrophytes from the dam outlet, and from enhanced social corporate responsibility) and the river basin authority (which achieved an improved ecological status of the river)

6.4.3 Economic instruments and water allocation reforms: some examples

There is a wide array of economic instruments at the disposal of policymakers concerned with water allocation reform. Some have been extensively tested in multiple real-life settings, most notably subsidies (e.g., subsidies for irrigation modernization) or penalties for non-compliance. Others like PES are becoming increasingly relevant, although some legal and other barriers towards their implementation remain. For instance, water-related PES have rehabilitated an area one and a half times the size of India, with a total investment of $25 billion ($10^9$); however, in the EU context for example, public authorities often issue lawsuits against PES since they do not comply with the polluter-pays principle (Bhaduri *et al.*, 2021). A third group of economic instruments includes markets and charges which, despite the promising performance suggested by a growing research body (Rey *et al.*, 2019), have a limited geographical scope (full-fledged water markets have predominately been implemented in Australia, Chile and the western United States), or their implementation is incomplete (water charges typically recover financial costs but not opportunity costs, including resource costs – foregone income from alternative uses of the resource – and environmental costs). Finally, some economic instruments are very uncommon (e.g., voluntary agreements and drought insurance for irrigated agriculture). Table 6.1 presents how each type of economic instrument can contribute to water allocation reforms.

6.5 THE WAY FORWARD: ACTIONABLE SCIENCE FOR INFORMED (RE)ALLOCATIONS

Science has supported the production of increasingly sophisticated data and models to deal with water (re)allocation challenges, including high-granularity earth observations (FAO, 2020; IMPEL, 2017), digital twins (very high precision digital models of socio-ecological systems to monitor and predict impacts, such as the European initiative Destination Earth), improved integration between human and water systems (Sivapalan *et al.*, 2014) and enhanced understanding and management of uncertainty (Cloke *et al.*, 2013; Marchau *et al.*, 2019), among others. Such mechanistic frameworks have undoubtedly improved our understanding of water (re)allocation challenges and performance and delivered valuable insights into their design. However, any analysis of water (re)allocations must go beyond the boundaries of quantitative outcomes provided by mechanistic models and rely also on heuristic frameworks and the expertise of stakeholders, so as to make the best possible use of available information and adequately balance the multiple targets pursued by IWRM (efficiency, sustainability, equity) and the trade-offs between them. Stakeholders' expertise can be highly instrumental for the solution of complex problems, particularly under uncertainty, for example, from *ad-hoc* interpretations of their experience that are applied to speculate upon the consequences of alternative water allocation regimes. Notably, stakeholder expertise can contribute to robust decision making, guided by frameworks such as 'deliberation with analysis' (Groves *et al.*, 2015) or 'bounded rationality' (Quiggin, 2007), which leverage on stakeholder knowledge and experience to complement conventional mechanistic approaches (i.e., modeling) to decision making. The resultant combination of models and expertise is critical to understand the functioning of socio-ecological systems, explore plausible futures, and anticipate potential surprises and vulnerabilities to proposed (re)allocations, as well as identify and exploit spill-over effects and synergies across instruments and sectors.

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