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Water scarcity, prices and quotas: a review of evidence on irrigation volumetric pricing

François Molle

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Abstract Underpricing of irrigation water is frequently identified as a primary cause of excessive use of water for irrigation. Higher prices are believed to have the potential to promote conservation. Changes in user behavior are predicated on a quantitative relationship between water charges and the volume use, but volumetric management is quite rare in practice. This paper reviews irrigation schemes that combine conditions of water scarcity and volumetric pricing, either at the bulk or individual level, and provides clear evidence that scarcity is almost invariably dealt with through the definition of quotas. In contrast to the large theoretical literature that has promoted price-based regulation as a key instrument of water demand management, it appears that prices are mostly used to regulate use at the margin, beyond the quota, rather than for rationing scarce water. This is an important role but one that falls short of efficiency pricing. The advantages and drawbacks of quotas are discussed, and an interpretation of why they are selected in practice is given.

Keywords Water pricing · Economic instruments · Demand management · Irrigation · Quotas · Volumetric management

Introduction

Lasting problems of water management in irrigated agriculture have long received treatment from various disciplines. The role of infrastructure, for example, has been addressed through rehabilitation, modernization or automation. Social scientists have also worked on establishing ad hoc water user organizations, often at the tertiary or secondary level, and on instilling forms of participatory management. In the 1990s, economists have stressed the importance of treating water as an economic good and, in particular, of 'setting the price right' in order to provide the right economic incentives to water users (World Bank

F. Molle (✉)
Institut de Recherche pour le Développement, 911, Avenue Agropolis BP 64501,
34394 Montpellier Cedex 5, France
e-mail: francois.molle@ird.fr

2003; Cornish et al. 2004; Hellegers and Perry 2004; Molle and Berkoff 2007). After decades of water resources development based on systematic supply augmentation, often at very high financial or environmental costs, emphasis was shifted to demand-management, roughly defined as "doing better with what we have," in opposition to increasing supply (Winpenny 1994).

Underpricing of irrigation water is frequently identified as a primary cause of excessive use of water for irrigation, a sector that accounts for 70% of world withdrawals (and much more in most developing countries) (Cornish et al. 2004; Hellegers and Perry 2004; Molle and Berkoff 2007). The World Water Vision reckons that 'users do not value water provided free or almost free and so waste it' (Cosgrove and Rijsberman 2000), while Sandra Postel (1992) considers that 'water is consistently undervalued, and as a result is chronically overused.' Environmentalists have placed hopes in water pricing as a means of reducing human abstraction and improving ecosystem health (WWF 2002); and the EU (2000) also considered that 'efficient water pricing reduces the pressure on water resources' and has stressed the importance of full cost pricing and made it a cornerstone of the recent Water Framework Directive.

One of the main water problems is insufficient water in the face of growing and competing uses. If water is allocated through markets then prices tend to reflect the marginal value of willing buyers and sellers and transactions allow the continuous reallocation of water to higher values. In the absence of markets, administered prices can theoretically approach market mechanisms if they are set at a level at which demand and supply are more or less balanced. Price mechanisms may thus offer a way to manage scarcity while maximizing aggregate economic welfare, as opposed to bureaucratic management of scarcity through ad hoc patterns of water allocation, for example based on priority, distance from main canals, type of crops, political preferences, or even on corruption. These allocation decisions are generally translated into entitlements, or quotas, whereby fixed amounts of water are attributed to the different users.

In this paper I review the empirical evidence of how—in practice—societies manage water scarcity, both in the short term (when, for a given season, the available stocks fall short of demand) and in the longer term (when conservation is needed to restrain use). My scope is public irrigation schemes. Because pricing mechanisms associate water quantities and costs, the only situations relevant to our discussion are those where water is distributed to users volumetrically. This necessarily narrows our scope to only a minor fraction of public irrigation worldwide, as most public schemes in the world—especially gravity irrigation schemes—do not use volumetric management (Tsur 2004; Burt 2002). Even limited in scope, the review will provide an important insight on how water scarcity is actually managed in technically more efficient schemes.

Managing water scarcity in irrigation schemes: lessons from the literature

Public irrigation seldom resembles the distribution of water in the urban sector. *Supply* is variable because runoff is variable and because surface hydraulic infrastructures rarely allow a precise regulation of water distribution. *Demand* is variable because rainfall and crop water requirements are variable. As a result, situations where water is available to farmers on demand are exceedingly rare and farmers generally rely on whatever water is effectively supplied to them, rather than on what they wish to receive.

Metering of individual consumption is costly and problematic: a hydraulic device that measures flows is needed at the head of each farm (or plot) and the collection cost of data regarding the evolution of flow with time tends to be prohibitive unless water is pressurized and meters can be installed. In the latter case, monitoring of meters is often problematic because users tend to tamper with them, if they severely constrain their use or raise their water charges. In gravity irrigation systems, cases of metering at the individual level can be found in Australia (Dethridge Wheel at the farm level) or in the US and thus tend to be confined to situations with rather large farms and strong enforcement and monitoring capacity. In developing countries with numerous smallholders there are situations where quantities are estimated based on the time of delivery: the flow in the tertiary (or sometimes secondary) canal is assumed to be more or less stable and the duration of supply provides an approximation of what the users receive: in a tertiary canal, for example, farmers can receive water during a fixed amount of time, sequentially or following other types of predefined arrangements. This is the case of the warabandi system in northwestern India and Pakistan, where all outlets to tertiary canals (chaks) in a secondary are designed to ensure a discharge proportional to the area served and to the inflow in the parent channel; or in schemes in Morocco.

To offset this problem of monitoring of use, it is often advocated to monitor water use at the bulk level, typically that of water user associations (WUA) at the secondary (or tertiary) level (World Bank 1986; Carruthers et al. 1985; Repetto 1986; Asad et al. 1999). If users pay fees to the WUA that reflect their real water use, and if prices are high enough for demand to be responsive, then bulk allocation potentially enables conservation. As suggested above, this requires robust and transparent arrangements that ensure equitable sharing of water within a tertiary unit. The difficulty often comes when water gets scarcer, as the flow or the duration of supply tends to vary, which generally undermines the arrangements that are established for average conditions and gives way to conflicts and free-riding strategies. The following review will therefore distinguish between volumetric management at the secondary/tertiary level (or "block") and volumetric management at the level of the individual user.

Bulk allocation

Several countries have adopted bulk allocation, often as part of a policy of management transfer, where farmers are left responsible for management at the block level. Examples include:

- Experience in the Mahaweli System H in *Sri Lanka* showed that allocation at block level can lead to lower diversions. Distributary canals under the responsibility of Water User Associations (WUAs) had their inflow monitored daily by both the agency and a water master paid by the WUAs. Water charges were not differentiated at farm level, and though WUAs were charged in proportion to water allocations, charges were not based on actual volumetric measurement and were too low to provide incentives for water savings (IWMI unpublished data). Pricing was thus ineffective but the discipline coming from the bulk allocation system was beneficial. Improvements primarily came from stricter scheduling and improved main system management, resulting in more predictable and uniform flows and reduced conflicts.
- In 1993, Turkey accelerated the transfer of the management of 87% of its 1.9 million ha of large-scale irrigation, mainly because "the financial burden of O&M for the DSI [the irrigation agency] and the government was becoming unsustainable” (Ünver and Gupta 2003). DSI implemented a bulk allocation system whereby irrigation districts (IDs) (generally corresponding to a secondary canal), are informed before the start of the

season about the total amount of water allocated to them. The IDs are expected to levy a fee that covers the O&M costs of the area under their purview but receive bulk water at no cost. While the program was successful in transferring costs to farmers (recovery was around 95% in 2003, against 32–50% in DSI-managed schemes: Çakmak et al. 2004; Özlü 2004), and in improving the reliability of supply at the secondary level (Yercan 2003), farmers have little say on the amount of water allocated to them: even if farmers were to pay for their allotment there would be little incentive for individual farmers to improve water management because they do not control how much water flows into their areas (transfer agreements do not mention specific water allotments). In such a situation, bulk allocation improves reliability, equity, and cost recovery of O&M costs at the WUA level but prices have no impact on short- or long-term conservation.

- Bulk allocation as defined in the Mexico transfer program goes one step further (Kloezen 1998, 2002). Allotments to *módulos* (blocks) are defined each year based on the water available in the dams but these decisions are taken by the National Water Commission (CNA) together with a Hydraulic Committee which represents users. The WUAs are responsible for O&M and funded through a user fee they collect; the delivery of bulk water is paid for through a small portion of the fee that is channeled to the CNA. These seasonal allotments are tradable (within the district) and WUAs of the same irrigation district can freely make arrangements to sell/purchase water among them. The fee is internal and proportional to the area cultivated and is rather low (between 2% and 7% of the gross product in the scheme studied by Kloezen). There is therefore no relation between the water received by the WUA and what farmers pay, and their fee is determined by O&M costs, not by conservation objectives. It is not clear whether water distribution has improved overall but because the WUAs and ditch-riders are now accountable to farmers, each individual farmer is in a position to demand his (planned) share of water[1] (Kloezen and Garcés-Restrepo 1998). Economic efficiency is raised by the possibility of internal trading.
- Lessons from China are masked by the diversity of physical and institutional settings (Lohmar et al. 2007; Mollinga et al. 2005). Water reforms supported by the World Bank have focused on improving O&M and on higher financial user participation, as a means of reversing degradation of infrastructure and maintaining or expanding agriculture in a situation of declining overall supply. Water is often delivered by Irrigation Districts to villages or to secondary canals where management is entrusted to townships, villages, WUAs or to private operators. Water is often charged volumetrically but these entities are quite large and individuals have no incentive to adopt water-saving practices because (1) they frequently pay per unit of land, (2) they are often unaware of how much they pay for water and how the fee is used, (3) they have already effectively adjusted to scarcity by improving practices, shifting calendars or developing conjunctive use (wells, farm ponds, etc.). Many of the reasons for inefficient water use lie beyond the scope of the farmers (Yang et al. 2003). Yet, the Chinese experience is particularly interesting because of attempts to instill incentives at the level of the WUA or of the private manager who receives financial incentives to reduce water deliveries, part of which may be passed on to farmers in order to ensure their support (Lohmar et al. 2007). Recent research by Liao et al. (2005) showed that fees remain too low to cover full O&M costs, that elasticity is very small, and that significant price increases would "seriously impair" production in areas which could not be compensated

[1] Most of the instances of water trading observed were triggered by WUAs which had exhausted their quota and could not meet the contractual demand of all their members (Kloezen 1998).

with groundwater. Water prices are fixed by special provincial Price Bureaus that take into account national policies such as rural poverty alleviation and self-sufficiency in grains. Prices are not used at levels that could constrain demand but internal incentive mechanisms are being tested.

- In Israel, water to different sectors and bulk users is allocated through quotas to cooperatives and communities. They are designed to be fixed on an annual basis but, in practice, tend to be sticky and are only curtailed in times of drought. Consequently, these quotas have been gradually perceived as water rights by agricultural users (Plaut 2000; Kislev 2001). Prices are fixed by the government and by sectors and are made uniform so that farmers in the Negev desert pay the same price as farmers close to the source. For a given allotment, farmers pay for water following an increasing block rate established in 1989 and frequently revised.[2] Since the mid-eighties farmers have not, on average[3], consumed their full quota (Kislev 2001). This suggests that the tiered system contributes to regulating water demand at the margin, but other factors such as low world prices for agricultural products and high labor costs also contribute to this situation (Kislev 2005). In addition, most cooperatives charge their members an average price and these, therefore, do not face tier pricing. The Israeli case shows that quotas are combined with a block-tariff system, the former allowing a transparent[4] and equitable way to share scarcity, and the latter providing both flexibility at the margin and incentives to save in the last tier.

  However, several economists (Plaut 2000; Shevah and Kohen 1997) stress that the problem with quotas is that they do not allow flexible reallocation of water and increase in economic value, unless they are allowed to be traded. Ironically, the official justification for not allowing trade was the need to allow flexible policies, should circumstances change and the needs arise (Kislev 2001). The political clout of the agriculture sector, however, makes reallocation out of agriculture very problematic, except in case of severe drought, when priority is given to nonagricultural uses. In the last 10 years, this problem has been obviated by substituting treated wastewater for freshwater. Wastewater now represents 40% of the water used in agriculture.

  Distribution within the community, although supposed to be equitable and based on landownership, has sometimes evolved over time, as land endowments, crop types, and technology have changed. This reallocation both within and among communities has probably been insufficient to ensure maximum efficiency (Plaut 2000; Lees 1985) but has combined a degree of equity and flexibility. Water markets have been advocated but the shift from a resource owned by the state and allocated for specific uses to a commodity with water rights is encountering cultural resistance as well as opposition from vested agricultural interests (Feitelson 2001).

- In Japan, water is distributed to around 7,000 Land Improvement Districts (LIDs) that serve an average area of 500 hectares. LIDs receive a volume that is calculated to be ensured 9 years out of 10 but that that is specified each fortnight. They are totally autonomous within their area (including headwork management) and they act as authorized suppliers of water in their command areas (Kobayashi 2006). Charges are

[2] The charge for the first 50% is US$ 0.24/m^3; for the next 30%, 0.28/m^3, and for the last 20%, 0.38/m^3 (Kislev 2005).

[3] While farmers in some areas have lowered their consumption, others would readily use more water if it were available, even at higher prices (Kislev 2005).

[4] Plaut (2000) disagrees with the statement that quotas are transparent and sees the definition of quotas as secretive and rife with rent-seeking and arbitrariness.

defined as per cultivated area flat rates and calculated to recover O&M costs and part of the investment costs. Farmers' rights are not specified at the individual level and monitoring and metering at this level are deemed unrealistic. In case of shortage, all users meet and agree on voluntary reduction; the agriculture sector is usually the most affected and deal with deficits through stricter internal scheduling and monitoring, reuse of water, and sometimes fallowing of some land (Kobayashi 2006). The basic principle of this charging system lies in preserving equity among members.

- Other examples of volumetric bulk allocation include Andhra Pradesh and Maharashtra (India), Northern Vietnam, Iran, and Taiwan. In the Zayandeh Rud basin, Iran, bulk allocation is done at the secondary and tertiary levels; canals are equipped with baffle distributors which allow managers to fix the discharge in both secondary and tertiary canals. A new semi-private agency manages water down to the outlet of the tertiary and charges water by the volume. Farmers collect fees that correspond to 2–3% of the income of the main crop and cover only 25% of the agency costs. Within the tertiary area water is distributed by the farmers themselves (under the supervision of a ditch tender elected among them). Allocation is not directly proportional to landholding and is also based on the type of crop, the history of the water use of individual farmers, and the kind of water rights. In times of scarcity, the agency adjusts allocation at all levels from the scheme to the outlet, more or less based on equitable shares (Hoogesteger 2005). Price mechanisms are ineffective because charges are too low and far below the marginal value of water.

Several conclusions can be drawn from these examples of bulk allocation. First, bulk allocation is primarily a mechanism that goes with partial financial and managerial autonomy of WUAs, allowing agencies to shift part of the O&M costs on to them. Second, bulk allocation improves the predictability and reliability of deliveries at main canal and block levels (Bosworth et al. 2002). Third, bulk water pricing can generate revenue, but even if farmer charges are assessed in relation to delivered quantities, they are seldom charged on a volumetric basis; and even if they are so charges are seldom high enough to promote conservation (Asad et al. 1999; Tiwari and Dinar 2001). Fourth, incentives from volumetric pricing are seldom passed on to users, although innovative schemes in China show there is potential for this to happen. Fifth, when supply availability is below demand, quotas are reduced in proportion to the shortfall; prices remain constant and are not raised in order to reduce demand in line with supply. The deficit is generally spread more or less equally across quota-holders. In sum, although water pricing at the block level could theoretically elicit conservation and/or be used to reduce demand when supply drops, management is first and foremost based on reasonable use (block quotas), with occasional deficits distributed over the blocks.

Internal trading (like in Mexico) improves scheme efficiency but potential conservation effects are cancelled by the fact that individual payments are not volumetric. It is only in China's experiences, where (private) managers have an incentive to reduce bulk allocation, with the benefits shared by farmers, that a potential for reducing diversions can be identified.

Individual quotas and on-demand irrigation systems

In some cases, technical control over the distribution of water is high enough to allow volumetric monitoring of water supply at the farm level. These systems tend to be concentrated in developed and/or arid countries, and are generally pressurized rather than gravity systems.

- In the large-scale irrigation systems of Morocco, farmers pay a fixed minimum fee that entitles them to 3,000 m^3/ha (Ait Kadi 2002). The water charge is based primarily on cost-recovery rather than on conservation criteria, though in pump schemes the water bill can be up to 65–70% of gross income (e.g., in Souss Massa groundwater scheme: Ait Kadi 2002) and in these cases it undoubtedly influences farmer behavior. Water use is regulated by supply—not by demand—management through quotas. When reductions are needed (in case of drought) or possible (because of a shift to micro-irrigation, as subsidized by the government), quotas are modified by varying the number of irrigation turns or the duration of delivery according to the crop (e.g., some crops like sugar beet or trees are given higher priority) (see Petitguyot 2003, for the example of the Tadla scheme). Quotas are thus adjusted to circumstances and can hardly be trimmed. In most cases, farmers have to pay for their quotas even if they do not use them fully but this is rarely the case since, on the contrary, many supplement supply with groundwater for which they pay a higher price per cubic meter. With water charges already covering O&M costs in gravity schemes it is unlikely that charges will ever be at levels that constrain individual demand, no elasticity being anticipated even with a 100% increase (El Gueddari ABS 2002). Again, the regulation mechanism used is quotas, with adjustment in case of shortage (Hellegers et al. 2007).

- In the Jordan Valley, individual quotas are based on crop type, thus partly promoting water savings (Molle et al. 2008). Water is sourced from a regulated open canal and delivered through pumping stations and collective pressurized networks. Yet, water variability and canal capacity preclude arranged or on-demand irrigation and water is rotated at block level within the area served by a network (pumping station are also 'on' according to a given schedule). Charges are set in relation to O&M costs (65% at present), not to regulate use or demand, and would have little impact on demand if they were to fully cover O&M costs. Adjustments in times of shortage are obtained by reducing crop-based quotas uniformly, not by increasing prices. On-farm conservation is hindered by uneven pressure in networks, poorly designed micro-irrigation equipment, the cost of adopting improved technology, and by the already low quotas. If raised, water costs could make some crops like citrus or open-field vegetables hardly profitable but the result would be a shift in farm management and economic efficiency, rather than water savings (Molle et al. 2008).
- Montginoul and Rieu (2001) report an experience from the Charentes region, western France, where two dams were built to increase supply to irrigation but with a strong concern to limit demand. A binomial pricing policy (with a fixed part and a component varying with the volume consumed) was shown to be impracticable "because to have a meaningful impact on consumption the price would have to be increased to such an extent that the farmers' income would be lower than before the dams were built" (Montginoul and Rieu 2001). The system eventually selected was a quota system (fixed for 10 days, depending on the amount of water in the river), with extra volumes charged at 10 times the nominal variable charge and threats of withdrawal of the EU subsidies. Acceptance of the system by farmers ensured self-monitoring and curbed opportunistic behaviors.
- The Neste system, in the southwestern part of France, is an intricate set of reservoirs distributed over 11 interlinked catchments that distribute water to 50,000 hectares supplied by 2,000 individual or collective pumping stations and irrigated by sprinklers (Hurand 2001). Water requirements per unit of land are rather low (1,750–2,000 m^3/ha). Metering is possible at the farm level and the pricing system adopted consists of an allocated quota priced at an average price together with an overconsumption price for any excess use. Prices are calculated to ensure full recovery of running costs and the price structure arranged to respond to the high marginal value of water during the

irrigation period, while "leaving [each] farmer free[5] to manage his water efficiently according to his own water value function" (Tardieu and Préfol 2002).

- In the south of Italy, which is subject to dry climatic conditions, the Capitanata region also offers an example of a pressurized irrigation system where scarcity is handled through quotas (Mastrorilli et al. 1997; Altieri 2001). These quotas are low by all standards (2,000 m^3/ha) but some relative flexibility is offered at the margin through a block system in which the upper tier is heavily priced. This flexibility is, however, relative because continuous overuse is dealt with by threats of disconnection; while water is generally delivered on demand, some problems (e.g., combined peak demands for areas with homogeneous cropping patterns) have led to establishing a rotational delivery schedule.
- Irrigation in Spain is also based on volumetric management either at the bulk level (6,188 *comunidades de regantes* are granted volumetric water use licenses, which are distributed among members according to varied methods) or at the individual level (farmers within state-managed schemes). A total of 41% of the Spanish irrigated area is under sprinkler or micro-irrigation (Berbel et al. 2001), which allows easier volumetric control. The Genil Cabral and Fuente Palmera irrigation cooperatives in the Guadalquivir basin, for example, are quite recent pumping schemes "designed to minimize water losses in distribution and to maximize yields per drop in water application through automated, on-demand watering (sprinklers and drip irrigation)" (Maestu 2001). In Genil Cabral, the automated computerized control system allows the cooperative to impose penalties on those who exceed consumption by more than 10% of a limit that is reviewed every year. The excess, up to 10%, is billed at twice the price and any volume over this limit at 25 times the unit cost. This high-tech system is adapted to high-scarcity conditions (allotments of 2,000 m^3/ha) and enables control of marginal use through pricing.
- A system that comes close to fully on demand is that operated by the Canal de Provence in France, where the main canal is dynamically regulated to meet agricultural and municipal demands and includes additional temporary storage capacity (water towers, tanks). Farmers are free to irrigate as they wish (under the conditions of discharge and pressure they have subscribed to). Prices are set to recover full financial costs and not to control demand, but the price structure is complex (Jean 1999), distinguishing between users, fixed and variable charges, and peak and normal demands. The system is not water-short and managers only discourage water use beyond the subscribed amount by specific tariffs.
- Many other (surface water) systems with individual volumetric control can be found in the US, especially where farms are large and the number of farmers small. In 1989, the Broadview District, supplied by the (California) Central Valley project, accepted a two-tiered price system. The district had triggered public outrage after the discovery that its effluents were loaded with selenium and had devastating effects on wildlife in the Kesterson Refuge (Wichelns et al. 1996). At the same time, a 5-year drought was starting to affect the region. Under pressure to limit their water diversion and drainage flows, farmers realized that improved practices could reduce their use of water and keep them in the first tier. However, because of the drought, Broadview's water supply had to be decreased by more than 50% during the 1990–1994 period. Instead of raising prices

[5] However, in 3 years out of the last 10 years, exceeding the quota was simply banned because of water shortage.

in order to reduce demand accordingly, it was found preferable "to begin allocating water among individual farmers" proportionally to the size of their farms, while providing cheap loans to encourage farmers to purchase sprinklers and gated pipe irrigation systems (Wichelns 2003). While the price structure may have contributed to encouraging farmers to improve management, quotas were eventually adopted when scarcity arose.

- Other cases include Peru, China and Canada. In one system of northern Peru studied by Vos (2002), pricing was volumetric but was not used to manage scarcity: rather in times of shortages the rules employed promoted equity and quotas were set up to limit use. In Shangdong, China, the use of prepaid cards ensures that farmers cannot obtain irrigation water without paying (Easter and Liu 2005) and seems to provide reliable on-demand water (no evidence is provided on whether prices regulate demand). The southeast Kelowna Irrigation, Canada, is a "mixed" provider, supplying not only 400 farms but also 1,900 domestic connections. Irrigation uses 85% of the resources and the district is periodically relatively water-short. Increased domestic use due to development and requests for additional land to be serviced with irrigation water have put pressure on the irrigation district to seek opportunities for system expansion. With the lack of adequate locations for new reservoirs, users are under pressure to prove that their licenses correspond to "responsible use." Individual metering has been introduced to instill conservation, allow equitable distribution and drought-management plans. This did not impact on use and, in 2001, irrigation entitlements were defined, with a metered rate penalty for excess use following an increased block system (in 2003). The system was seen to enhance equitable use of water and avoid the pitfalls of open-access regimes (Pike 2005).
- In some countries (e.g., in western states of the USA, Australia, Chile) quotas are defined as individual rights and a legal framework has been developed for trading these rights. Management continues to be determined by entitlements and water distribution is still, usually, by 'arranged demand.' However, water trading redistributes entitlements and contributes to higher economic returns. System constraints, third-party concerns and regulatory aspects may confine trades to neighboring farmers, with little impact on the overall irrigation water use, but in some contexts water is traded out of agriculture (e.g., the Colorado-Big-Thompson scheme: Howe 1986; Mariño and Kemper 1999; Howe and Goemans 2003). In Australia, users enjoy individual water entitlements and they can schedule deliveries to their farms. In case of shortage, entitlements are reduced proportionally to the deficit but trading among right-holders is possible (Turral et al. 2004). Although water charges are covering O&M costs, resource management at the basin level and, lately, part of the remediation of environmental externalities, they remain much under the marginal value of water. Thus administered prices are not used to instill conservation or allocate water in times of scarcity, a function devoted to market transactions that amount to around 10% of total water entitlements for temporary lease, and less than 1% for permanent transfers.
- Collective wells (public or otherwise) also provide metering facilities and individual usage can often be monitored. Jourdain's (2004) study on collective wells in central Mexico considered available combinations of crops, cropping techniques and levels of deficit irrigation and showed that a reduction in groundwater use of 30% would need water charges to be multiplied by four, at the cost of a drop in income between 15% and 77%. The only alternative to avoid the transfer of wealth to the state would be a mechanism that reinjects the charges levied back to farmers but in a way that is decoupled from input use.

Quotas vs. regulation through prices

Several lessons can be drawn from the above review. The first (obvious and reiterated) lesson is that both bulk allocation/quotas and pricing policies are only possible with quite stable water regimes and/or modern hydraulic infrastructures. Pressurized distribution networks primarily lend themselves to such policies but there are also cases of individual quotas in high-tech surface water systems associated with pumping stations. The Neste system in France, for example, has 200 river flow measurement locations, 40 automated regulators with remote control, and 150 real-time monitoring points of the amounts of water pumped by collective stations (Tardieu 1999). The Canal de Provence and the Central California canal systems are even more sophisticated, with open-channel dynamic regulation. The Capitanata (Italy) and many collective Spanish systems are fully pressurized.

Second, our examples showed that the use of bulk water pricing (where it exists) is mainly oriented toward revenue generation and maintenance, rather than toward economic efficiency or incentives for users to change consumption patterns (Asad et al. 1999; Tiwari and Dinar 2001). Rather than impacting users' behaviors, the main benefit lies in the improvements in overall management demanded from irrigation agencies. Even where bulk water management and pricing are established, incentives are generally not passed to persons individually. Experience in China suggests that incentives to block managers or semi-private contractors may have the potential to redistribute collective gains and elicit improvements in collective management.

Third, even if volumetric supply is possible at the farm level, in practice price incentives are predominantly used *at the margin*, to control use in excess of defined quotas or entitlements. Even in such cases, the option to resort to the second tier has to be cancelled sometimes when supply is insufficient (Capitanata, Neste). This gives users some flexibility, regardless of whether water is distributed by ‘arranged demand’ or is under the control of users, and provides incentives for water saving at the margin. However, allocation is always based on equitable 'reasonable use' quotas and falls short of both true on-demand irrigation and efficiency pricing.

Fourth, systems with quotas, either at the individual or at the block level, generally deal with droughts and shortages by revising quotas downward. The frequency of such adjustments depends on the variability of the resource and on the total amount of water allocated relative to average supply, but since irrigation invariably receives a low priority in allocation this frequency increases as nonagricultural uses claim a larger share of the resource (Molle and Berkoff 2006). It is only 1 year out of 10 in Japan but more frequent in Mexico or Jordan. In some cases, quotas can even be reduced to zero, as seen in the Zayandeh Rud basin (Iran) in 2001 (Molle et al. 2007).

Fifth, reduction of quotas is generally done in a uniform manner across users. However, there are particular situations where some entitlements are less affected either because of economic reasons (e.g., trees vs. short-duration crops) or social reasons (areas with ancient water rights). This also shows that although they allow equity when defined uniformly, quotas may also integrate local perception of rights.

In other words, even in the rare cases where water is scarce and where conditions are met to regulate demand through pricing, supply is invariably managed through administered quotas or water entitlements. None of the systems reviewed has used prices to raise pressure over users in order to crowd out underachievers and reduce demand according to available supply. This holds true for both the short term (seasonal shortages), and the longer term (conservation objectives).

Reasons for the predominance of quotas include: their transparency; their ability to ensure equity when supply is inadequate (Tsur and Dinar 1995); their administrative simplicity and relatively low transaction costs; their capacity for bringing water use directly in line with continuously varying available resources; and the more limited overall income loss incurred (as compared with price-based regulation). Indeed, regulation through prices would be tantamount to raising financial pressure on users in order to eliminate those who have less capacity and capital to adjust. In other words, if water supply is short of demand by, say, 30%, quotas consist in reducing every user's supply by 30%, while regulation through prices consists of raising prices until the least "economically efficient" operators reduce their overall demand by 30%. But raising prices also reduces the income of those who are more efficient and—when the fees accrue to the state—entails a transfer of wealth from farmers to public coffers, two consequences that are likely to face opposition. Latinopoulos' (2005) study of farmers' response to raised water prices in Greece found that elasticity corresponded with price levels which created serious income losses and observed that quotas are "a more natural and effective way" to obtain the same result with no dramatic reduction in income.

Quota-based equity is also preferred because irrigation systems are socio-technical systems in which farmers are bound by a multitude of social ties and by their use of water, labor and other inputs. Whenever social relations are not too critically lopsided, equity is generally preferred to allocation to the higher bidder (unless water rights are linked to the initial investments in the system itself). However, there are exceptions to this rule, as illustrated by the well-known water markets in Valencia (Spain) (Maass and Anderson 1978), which combine community-driven irrigation and auction of the available water in times of scarcity. In public irrigation, equity is understandingly preferred and promoted through quotas, partly because of a cultural inclination (e.g., in Japan: Kobayashi 2006, or France: Tardieu and Préfol 2002), partly because it is clearly the mechanism that encounters less opposition and minimizes political and transaction costs.

Based on a worldwide review of irrigation pricing policies Cornish et al. (2004) concluded that 'When water is scarce, the surest and most common way to make customers use less water is to limit supply;' this has indeed been the most favored solution for restraining demand (Bate 2002). As stressed by Wichelns (1999), farmers respond to water rationing or changes in water allotments "by modifying crop choices and input decisions, just as they would respond to changes in explicit water prices:" since quotas fulfill the goal of curtailing demand and provide incentives to intensify agriculture, the additional benefits they provide in terms of formal equity and lesser economic impact on users help explain the prevalence of this regulation mechanism.

But quotas also have their drawbacks (Chohin-Kuper et al. 2002; Bate 2002). While price or market regulation tends to promote economic efficiency at the cost of equity (Okun 1975), quotas (when nontransferable) foster equity at the cost of efficiency and can lack flexibility in response to changing circumstances, as in Israel. The Israeli case is instructive of the difficulty to readjust quotas once they have been defined and, at the same time, of the growing mismatch which can materialize between one village quota and its real use or needs (Plaut 2000). The trajectories of kibbutzim and cooperatives depend not only on ethnic composition, level of education, and political linkages but also on the links to markets, the availability of nonagricultural opportunities, and the possible development of additional local resources (Lees 1998). With time, some settlements (and some farmers within each settlement) tend to intensify agriculture, while others shift to partial farming. Resulting imbalances between quotas and needs have led to some inefficiency; in the 1980s, some farmers would irrigate carelessly so as to fully use their quota for fear of seeing it reduced

(Lees 1998) and trading within, as well as between, communities has emerged (Kislev 2005). Quotas are also rarely adjusted to rebalance overall combined supply when the use of groundwater develops, as in Morocco, and they may hinder intensification, as in Jordan where citrus farmers are reluctant to shift to vegetables because their entitlements would be divided by two, with little hope of obtaining it again if they ever would like to revert to trees (Molle et al. 2008). While the Neste system in France has publicly known lists of subscribers with their entitlements, as well as waiting-lists of unserved users and clear rules ("young farmers," ranking in the list, etc.) for selection of new beneficiaries when contracts are cancelled (Tardieu 1999), these criteria may perhaps not be considered as fair by some users, while they also do not attempt to maximize economic return.

Cases from Australia, Chile or western US have also shown that trading of entitlements solves the problem of quota 'stickiness' and of the limited potential of administered prices for reducing use and managing scarcity, while at the same time ensuring a better economic efficiency of water use. Such situations remain rare because there are several cultural, technical and institutional constraints to their development, most notably in developing countries (Livingston 1995; Siamwalla and Roche 2001; Colby 1990; Gaffney 1997). A combination of both desired priority principles and state-regulated transactions may address equity concerns while promoting efficient allocations (Seagraves and Easter 1983; Bjornlund and McKay 1999; Johansson et al. 2002).

It is true that management of quotas cannot fully simulate the economic scarcity signals of a market price. But given the socioeconomic and practical constraints to, and the political costs of, promoting irrigation pricing for managing scarcity, the establishment of quotas (the 'visible hand of scarcity') appears a far more satisfactory and practical solution to water savings in almost all real-life circumstances (Molle and Berkoff 2007). Even in Europe, where pricing is being strongly promoted, Garrido's (2002) review concluded that 'irrigation pricing reforms should not expect significant reductions in farmers' water consumption' and that 'efficient allocation can be made without prices.' The virtues of rationing (in the short term) and/or the allocation of quotas (for long-term allocation) are getting more attention from the World Bank (2006) who reckoned that 'quotas work better than prices when water users are not very responsive to water price changes.' Bosworth et al. (2002) also concluded that 'getting the prices right' is not the most appropriate solution to managing scarcity, while Dinar and Maria Saleth (2005) reckoned that "The fact that efficient water pricing schemes are rare, if not completely absent, even in economically advanced regions with extreme water scarcity levels, provides sufficient evidence for the persistence of a vast gap between the development of pricing theory and its practical application. Use of pricing for rationing scarce water use is almost non-existent."

Conclusions

A review of situations of water scarcity where irrigation schemes are able to distribute water volumetrically, either at the bulk or individual level, provided clear evidence that the definition of quotas is almost invariably chosen as a regulation mechanism. In contrast to the large theoretical literature that has promoted price-based regulation as a key instrument of water demand management, it appeared that prices were mostly used to regulate use at the margin, beyond the quota, rather than for rationing scarce water. This is certainly an important role but one that falls short of efficiency pricing and remains limited to those relatively rare schemes where water is supplied volumetrically, on demand or on arranged demand (Hellegers and Perry 2004; Cornish and Perry 2003).

Quotas may be subject to arbitrariness if their definition is not transparent and do not easily adapt to changing economic circumstances, incurring losses in overall economic efficiency. However, quotas were found to be consistently preferred to purely economic regulation for managing scarcity because they are more equitable, more transparent, and more efficient in putting demand in line with supply, with limited overall income loss compared with price-based regulation. These combined advantages explain why quotas are adopted as a mechanism to manage scarcity and curtail demand use.

If made tradable, quotas or entitlements can be more easily reallocated among users according to criteria of economic efficiency. Such situations still remain rare because there are several cultural, technical and institutional constraints to their development, most notably in developing countries. Yet, where conditions are not met for free trading, transactions controlled and regulated by the state and by civil society can help obviate third-party impacts and constitute a possible option to be explored. Whatever their shortcomings and the reasons for their widespread use in practice, quotas do appear to be the preferred solution for managing and sharing scarcity, with price mechanisms confined to a secondary role, far more modest than often assumed.

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