Investing in Adaptation: The Challenge of Responding to Water Scarcity in Irrigated Agriculture

By Susanne M. Scheierling and David O. Treguer

Water scarcity is increasingly acknowledged to be a major risk in many parts of the world (World Economic Forum). Projections indicate that water-related problems may significantly worsen over the next several decades due to rising water demands as a result of demographic, socioeconomic, and technological changes, and due to the effects of climate change (World Water Assessment Program; Jiménez Cisneros and Oki). Significant advances in water management and more integrated policymaking, including increased investment in adaptation measures, will be necessary to reduce the risk of dramatic consequences for economic growth and environmental sustainability.

The need for water-related adaptation measures will probably be most critical in the agricultural sector, especially in irrigated agriculture. Irrigated agriculture accounts for about 70 percent of total freshwater withdrawals worldwide (Molden and Oweis). Water use in agriculture, especially in semi-arid and arid regions, tends to be closely linked

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to water scarcity, and improvements in agricultural water management would have large implications for overall water management. In addition, water use in agriculture tends to have relatively low net returns compared with other uses (Young 2005). Thus, as water becomes scarcer and supply augmentation more expensive, other users tend to turn to agriculture as a potential source of water. At the same time, agriculture is expected to increase production—and concomitantly agricultural water use—to meet the likely demands from a growing population with changing diets (Alexandratos and Bruinsma). The effects of climate change will further increase the need for water-related adaptation measures and add layers of complexity for agriculture (Pachauri and Reisinger; Jiménez Cisneros and Oki). Freshwater resources will be affected due to altered amounts and frequencies of precipitation—especially in semiarid and arid areas that often already experience water scarcity. Due to more intense precipitation and prolonged dry periods, rainfed cropland may need to be irrigated. Crop growth more generally will be affected not only by changes in precipitation but also by changes in temperature, evapotranspiration, and soil moisture.

To at least partially respond to these challenges, the agricultural sector is considering and increasingly applying a wide range of water-related adaptation options (Noble and Huq). Adaptation investments can occur at different scales, from the field and farm levels to the policy and institutional levels (Porter and Xie). Given the complexity of the challenges, adaptation measures may have one or more of three different objectives (Scheierling and Treguer). The two key objectives are maintaining or increasing agricultural production, in some cases without worsening water scarcity, and conserving agricultural water in response to pressures to reallocate water to other uses such as the environment or coping with water scarcity. A third objective that may be linked to the other two is increasing, or at least maintaining, agricultural net revenues. However, in many cases, the objectives of adaptation investments are not clearly stated and their broader results not closely assessed. This adds to the constraints facing adaptation measures, limits their effectiveness in implementation, and may even lead to unintended or counterproductive outcomes. This article aims to further shed light on these issues.

Section I highlights some of the unique characteristics of water that complicate responses to water scarcity in irrigated agriculture. Section

II illustrates the links between irrigated agriculture and water scarcity with data at the global level. This is followed by a discussion of two broad categories of adaptation measures. Section III examines engineering and technical measures, which are probably the most common adaptation measures and usually applied on-farm with private investments and often supported with public subsidies or technical assistance. Section IV focuses on policy and institutional measures. While both types of measures may pursue any or all of the three key objectives, engineering and technical measures tend to contribute to the first and, in particular, the third objective; policy and institutional measures have an important role to play in achieving, in particular, the second objective. Section V presents recommendations going forward.

I. Characteristics of Water Important for Considering Adaptation Measures

Water has unique characteristics that distinguish it from most other resources and commodities and pose significant challenges for selecting appropriate adaptation measures (and for designing water policy in general). Based on Young (1986; 2005), who provides a full discussion of these characteristics, this section focuses on the features that may be most important to keep in mind when considering adaptation measures.

A key physical attribute of water is its mobility. Typically found in liquid form, water tends to flow, evaporate, and seep as it moves through the hydrologic cycle. This makes it a high exclusion cost resource, implying that the exclusive property rights, which are the basis of a market or exchange economy, are relatively difficult and expensive to establish and enforce.

Water supplies, although generally renewable, also tend to be relatively variable and unpredictable with regard to time, space, and quality. Local water availability usually changes systematically throughout the seasons of the year and over longer cyclical swings, with climate change now affecting both short- and longer-term supply trends as well as the extremes of the probability distributions—specifically, floods and droughts. Due to these supply variations, as well as variations in local demand, water-related problems are typically localized, and interventions, such as adaptation measures, often need to be adapted to the local context.

The physical nature of water, combined with supply variability, causes unique interdependencies among water users that become more pervasive and complex as water scarcity intensifies. Water is rarely completely "consumed" in the course of human consumption or production activities. In irrigated agriculture, for example, it is not unusual for half of the water withdrawn from a water source to be returned to the hydrologic system in the form of surface runoff or subsurface drainage (an even larger proportion is typically returned from municipal and industrial withdrawals). Other users, particularly downstream users, are thus greatly affected by the quantity, quality, and timing of releases or return flows of upstream users.

These interdependencies among water users have several implications, especially for on-farm adaptation measures. They make it difficult to derive water-related insights from what is observed on the field or farm level for the overall effects at the basin level. They lead to externalities (or uncompensated side effects of individual activities) where the full costs of the activities are not incorporated in individual users' decisions and outcomes for society are suboptimal. Thus, there is a need for public policy to complement individual activities and orient them toward more desirable outcomes from a social point of view.

II. Irrigated Agriculture and Water Scarcity: A Global View

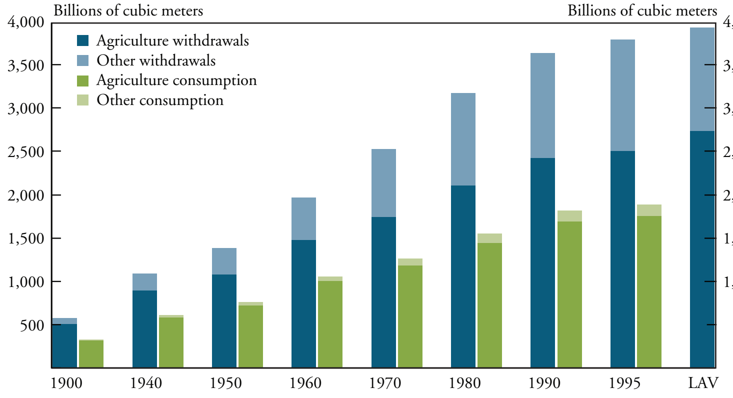
Establishing a link between irrigated agriculture and water scarcity is difficult due to a number of factors. Among them are not only the special characteristics of water discussed in Section I, but also the definition of water scarcity as well as the availability of data related to current and projected agricultural water use, especially at the global level.

Central role of water use in agriculture

As a first step, it is useful to keep in mind the global trends in agricultural water use. Based on data from Shiklomanov and Rodda and the Food and Agriculture Organization of the United Nations (FAO 2016a), Chart 1 shows the development in agricultural withdrawals, total water withdrawals, and consumption since 1900.[1] The agricultural sector has continually accounted for the largest share of total water withdrawals. From 1900 to 1995, the agriculture share decreased from 89 percent of total water withdrawals to 66 percent; more recently, it

Chart 1

Global Trends in Agricultural and Total Water Withdrawals and Consumption



Note: Blue bars show withdrawals, and green bars show consumption. LAV=latest available value.
Sources: Authors' calculations based on Shiklomanov and Rodda; FAO 2016a.

increased to 70 percent (FAO 2016a). Almost all of total water consumption has been agricultural consumption, with the share slightly decreasing from 97 percent in 1900 to 93 percent in 1995. Agricultural consumption as a share of agricultural water withdrawals increased from 63 percent to 70 percent over the same period. Overall, both total and agricultural water withdrawals have increased dramatically since 1900, but since about 1980, their rates of growth have declined. Contributing to this outcome is that in most Organisation For Economic Co-operation and Development (OECD) countries, total and agricultural water withdrawals have tended to remain stable or decrease (OECD 2013).

Table 1 presents data on the 10 countries with the largest annual agricultural water withdrawals based on the latest available data from FAO (2016a; 2016b). These countries are also responsible for the largest total withdrawals. The 10 countries are among those with the largest areas equipped for irrigation and among the 17 most populous in the world (World Bank Group).[2] Except for the United States and China, the 10 countries' percentage of total water withdrawals allocated for agriculture is larger than the worldwide average of about 70 percent. When dividing the amount of agricultural water withdrawals by the area equipped for irrigation, half of the 10 countries are shown to withdraw an irrigation depth of 1 meter or more for their respective area equipped for irrigation. The lowest value of 0.5 meter is shown for China, followed by 0.7 meter for the United States.

Table 1
Countries with the Largest Agricultural Water Withdrawals

Country	Agricultural water withdrawals (billion cubic meters)	Total water withdrawals (billion cubic meters)	Agricultural water withdrawals as percent of total water withdrawals (percent)	Area equipped for irrigation (million hectares)	Area equipped for irrigation as percent of agricultural area	Agricultural water withdrawals per area equipped for irrigation (meters)
India	688	761	90	67	37	1.0
China	358	554	65	69	13	0.5
United States	175	486	40	26	6	0.7
Pakistan	172	184	94	20	75	0.9
Indonesia	93	113	82	7	12	1.3
Iran	86	93	92	10	19	0.9
Vietnam	78	82	95	5	42	1.6
Philippines	67	82	82	2	13	3.4
Egypt	67	78	86	4	100	1.5
Mexico	62	80	77	7	6	0.9

Sources: FAO 2016a and FAO 2016b.

When considering all countries with agricultural water withdrawals, a close relationship can be established between agricultural water withdrawals and total water withdrawals as well as area equipped. According to Panels A and B of Chart 2, agricultural water withdrawals are highly correlated with total water withdrawals; specifically, an increase of 1 cubic meter in total water withdrawals is associated with an increase of 0.74 cubic meter in agricultural water withdrawals. According to Panels A and B of Chart 3, agricultural water withdrawals are also highly correlated with the area equipped for irrigation; an increase in 1 square meter of area equipped for irrigation is associated with an increase of 0.77 cubic meter in agricultural water withdrawals.

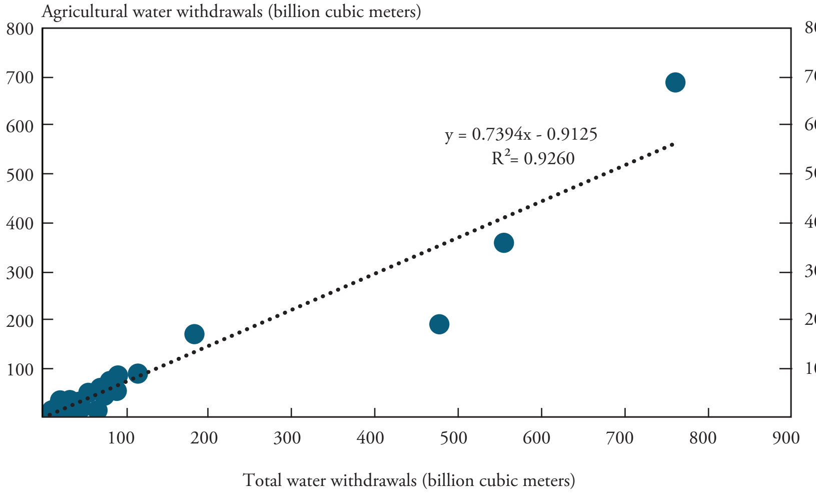
Linking irrigated agriculture and water scarcity

Various definitions of water scarcity have been proposed and different indicators applied (UNEP). One widely used indicator is based on a comparison of total water withdrawals and total renewable water resources at the national level.[3] A country is considered to experience "scarcity" if total water withdrawals are from 20 to 40 percent of total renewable water resources, and "severe scarcity" if this value exceeds 40 percent. Map 1 displays this indicator based on the latest available data

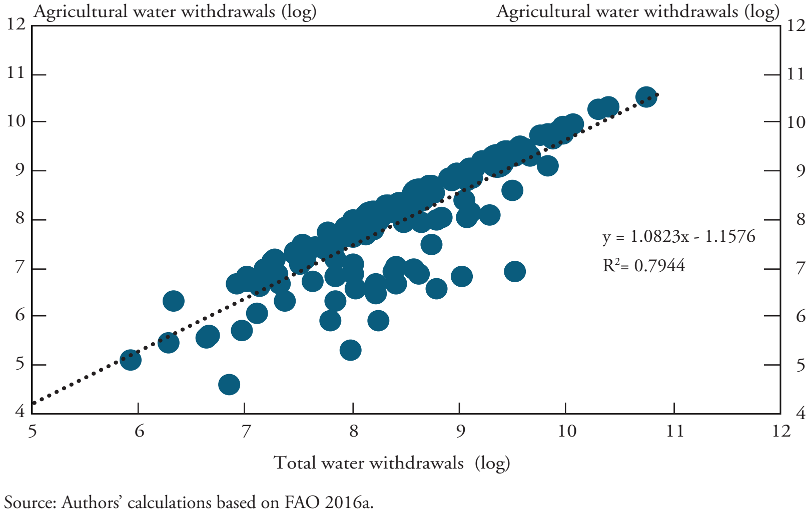
Chart 2

Agricultural Water Withdrawals and Total Water Withdrawals by Country

Panel A



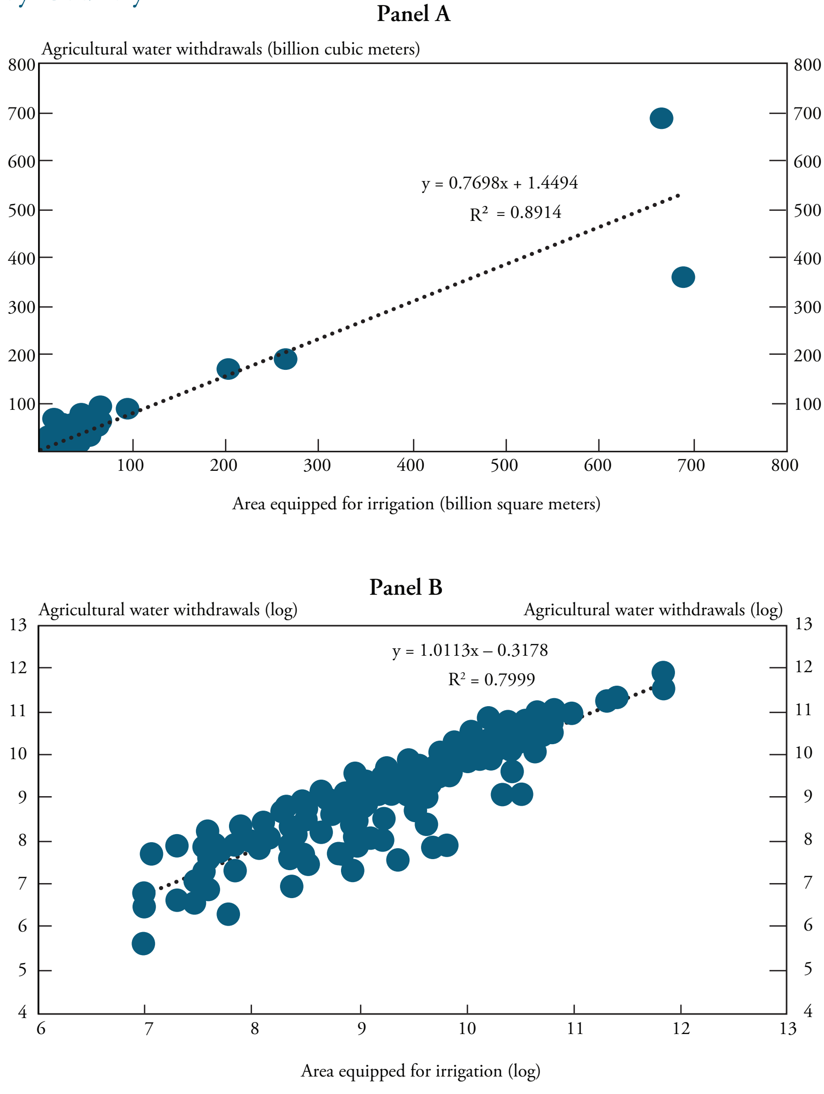
Panel B



Source: Authors' calculations based on FAO 2016a.

Chart 3

Agricultural Water Withdrawals and Area Equipped for Irrigation, by Country



Sources: Authors' calculations based on FAO 2016a and FAO 2016b.

from FAO (2016a). Countries in the Middle East and North Africa (MENA) are all shown to experience severe water scarcity. In other parts of the world, including most countries in South Asia and Central Asia, water is also considered scarce or severely scarce. Some countries' water withdrawals are even higher than their total renewable water resources. Saudi Arabia is the most extreme case, withdrawing almost 10 times the amount of renewable resources available and thus relying mostly on nonrenewable groundwater.

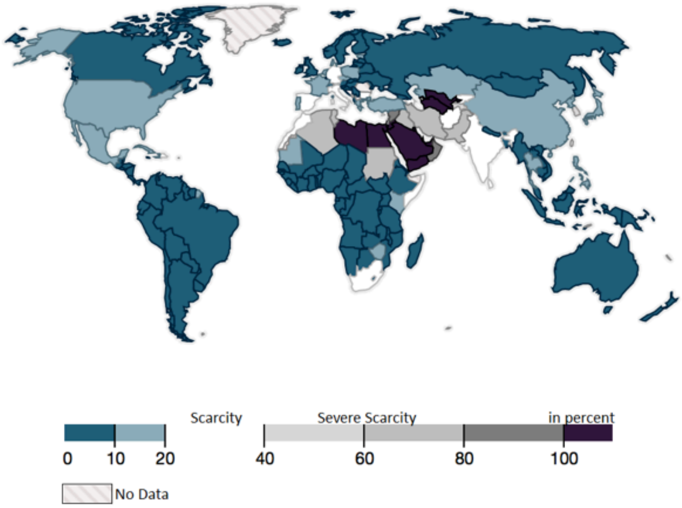
To illustrate the link between water scarcity and irrigated agriculture, we modify the indicator and, instead of total water withdrawals, compare agricultural water withdrawals to total renewable water resources (Scheierling and Treguer). Map 2 shows the data for the modified indicator. The astonishing result is that the classification of countries with "scarcity" and "severe scarcity" is almost the same as in Map 1, even though only agricultural withdrawals are considered. This shows the central role of irrigated agriculture in assessments of water scarcity at the national level. The most extreme cases are in MENA: in Saudi Arabia, water withdrawn for irrigated agriculture alone is more than eight times the amount of total renewable water resources; in Libya, it is about five times, in Yemen one and a half times, and in Egypt slightly more than the amount of total renewable water resources.

Some caveats apply to both indicators. On the one hand, they may underestimate water scarcity: since they refer to the national level and apply annual water data, they do not indicate water scarcity situations that may occur at the regional or local levels (especially in large countries such as China) or during the year. They also do not consider water quality issues or water requirements for the environment. On the other hand, they may overestimate water scarcity, since data on withdrawals would include the reuse of return flows that can be substantial in many cases (such as along the Nile in Egypt).

The available data do not allow for an analysis of how changes in agricultural water withdrawals have affected water scarcity over time. However, a look at historical data on area equipped for irrigation can provide some insights (FAO 2016b). Globally, the area equipped for irrigation increased from 164 million to 324 million hectares (ha) over the past 50 years. Chart 4 shows the trends by geographical region (excluding high-income countries) from 1962 to 2012. The biggest

Map 1

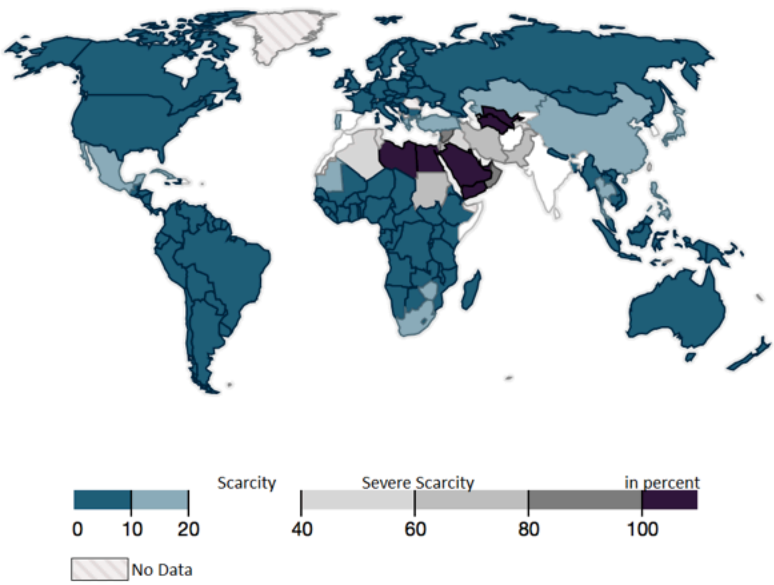
Total Water Withdrawals as Percent of Total Renewable Water Resources



Source: Authors' calculations based on FAO 2016a.

Map 2

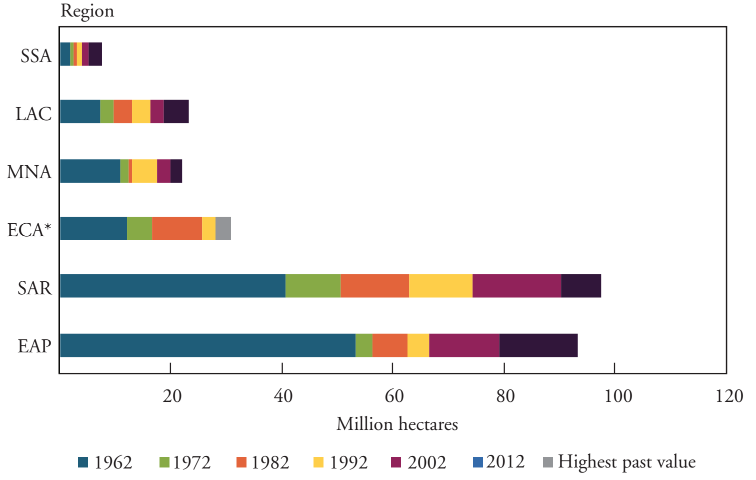
Agricultural Water Withdrawals as Percent of Total Renewable Water Resources



Source: Authors' calculations based on FAO 2016a.

Chart 4

Trends in Area Equipped for Irrigation by Region, 1962–2012



Notes: SSA=sub-Saharan Africa, LAC=Latin America and the Caribbean Region, MNA=Middle East and North Africa, ECA=Europe and Central Asia, SAR=South Asia Region, EAP=East Asia and Pacific. ECA* includes data for the USSR/Russian Federation.
Source: Authors based on FAO 2016b.

growth occurred in South Asia, followed by East Asia and the Pacific. Only Europe and Central Asia have seen a reduction in area equipped for irrigation since the 1990s, mostly due to reductions in the countries of the former Soviet Union.

The largest percentage increase in area equipped for irrigation of any country occurred in Saudi Arabia (from 0.3 to 1.6 million ha), followed by Libya (from 0.1 to 0.5 million ha) and Yemen (from 0.2 to 0.7 million ha). These three countries are now experiencing some of the most severe water scarcity. Large area increases, in both percentage and absolute terms, also occurred in India (from 26 to 67 million ha), a country now considered water scarce, and in China (from 45 to 68 million ha).

Projected trends

Agricultural water withdrawals will continue to be a major factor shaping the water situation worldwide, particularly given the expected need for an increase in irrigated area due to rising demand for agricultural products. Projections vary depending on the models employed and the assumptions and scenarios used. For example, projections by the FAO indicate that agricultural production in 2050 would have to be 60 percent higher than in 2005/2007, and irrigation water withdrawals would need to increase from 2,761 to 2,926 billion cubic meters per year to meet the likely demand (Alexandratos and Bruinsma). Considering the historic data in Chart 1 and rapidly growing water demands, especially from the municipal and environmental sectors, this projected increase—which is based on rather optimistic assumptions—is quite worrisome.

Projections become even more dire—and more uncertain—when the effects of climate change are taken into account (Elliott and others). Such projections suggest that by the end of this century, renewable water resources may allow a net increase in irrigated agriculture in some regions (such as the northern and eastern United States and parts of South America and Southeast Asia), while in other areas (such as the western United States, China, MENA, and Central and South Asia), the previous expansion from rainfed to irrigated agriculture would need to be reversed.

III. Investing in Engineering and Technological Adaptation Measures

Probably the most common adaptation investments for responding to water scarcity in irrigated agriculture are engineering and technological measures. These measures are usually applied on-farm and financed with private investments, often supported with subsidies or technical assistance. They include more capital-intensive irrigation technologies, improved seeds, and precision farming to help optimize the use of water and other inputs tailored to local conditions. As water scarcity or the variability in supplies increase, large private and public sector investments are being made in many countries for such adaptation measures.

Conversion to more capital-intensive irrigation technologies as a popular measure

One popular and widely adopted measure is the conversion to more capital-intensive irrigation technologies. These technologies increase the “efficiency” of irrigation water on a field by reducing evaporation and losses from surface runoff or subsurface drainage. The implicit assumption is that a switch to such technologies will allow farmers to maintain agricultural production with less water withdrawn and applied to a field while at the same time conserving water for reallocation to other uses.

In pursuit of the objective of water conservation, farmers in both advanced and emerging market economies often receive financial and technical assistance from the public sector to help them convert to more capital-intensive irrigation technologies. For example, the U.S. Department of Agriculture has long provided such assistance to farmers under the Environmental Quality Incentives Program first authorized in the 1996 Farm Act (USDA). The Incentives Program provides cost-sharing of up to 75 percent to help farmers install more capital-intensive irrigation equipment such as sprinklers and pipelines, with the aim of conserving ground and surface water resources. Subsidies of over $10 billion have been provided under the program for technology adoption, including for water conservation (Wallander and Hand). Similarly, Morocco is currently implementing the National Irrigation Water Saving Program, launched under the government's Green Moroccan Plan in 2008 and supported with planned public investments of $4.5 billion. The Moroccan program aims to conserve irrigation water by helping convert about 550,000 ha of agricultural land from surface to drip irrigation by 2020, with subsidies of up to 100 percent for farmers' on-farm investments (Badraoui).

Effect on water scarcity when return flows are important

In many contexts, on-farm investments in "irrigation efficiency" contribute more to the objective of maintaining or increasing agricultural net revenues (and, frequently, to the objective of maintaining or increasing production) than to the objective of conserving water for alternative uses. For the United States, an increasing number of studies show that while such investments may reduce on-farm water applications, they do not necessarily provide real water savings and thus may not have much effect on water scarcity. In contexts where return flows matter to downstream uses, real water savings (that is, a "new supply" of water for reallocations) would require a reduction in water consumption. In many instances, the conversion to more efficient irrigation technologies may have the counterproductive effect of increasing consumption, thus worsening water scarcity.

Furthermore, in some situations, the introduction of more efficient irrigation technologies may even lead to increases in the amounts of water withdrawn and applied. In energy economics, this is known as the rebound effect, or Jevons paradox, whereby efficiency increases in the use of a resource result in more being demanded (Alcott). In the field of water management in agriculture, the rebound effect is increasingly being discussed—usually in connection with the risk of increasing water withdrawals and applications (Chambwera and Heal; OECD 2015a). However, the rebound effect can also be observed—and may be even more prevalent—for consumption.

Hartmann and Seastone were among the early water economists who drew attention to the interdependencies among water users and the resulting externality problems. They pointed out that only part of the water withdrawn from a river is used consumptively, whereas the non-consumptively used part typically returns to the stream as runoff or percolates into the underlying groundwater deposits and becomes available for pumping. Using a simplified river system as an example, they illustrated that any change in these return flows (in magnitude, timing, or quality) may affect downstream users. Huffaker and Whittlesey (1995) and Whittlesey (2003) use similar examples to show that improvements in on-farm irrigation efficiency reduce withdrawals and applications, but that in the presence of significant usable return flows, this effect does not produce additional water. If the "saved" water is used to increase irrigated acreage, consumption may even increase.

Subsequent studies based on normative models show that by converting a larger share of water applications into consumption, more efficient irrigation technologies reduce the effective cost of consumption. Farmers optimally respond to this cost change by increasing consumption and irrigated acreage, all else equal. Furthermore, these changes may decrease or increase the demand for applied water (Whittlesey). Scheierling, Young, and Cardon (2006) show that a subsidy policy may increase consumption even in places where an expansion of irrigated land beyond the original land to which a water right applies is not permitted, such as under Colorado's prior appropriation system. This would occur when farmers find it profitable to alter the crop mix or change the irrigation schedule. Ward and Pulido-Velazquez analyze the effect of subsidies by applying an integrated basin-scale programming model to the Upper Rio Grande Basin and find that while water applied to irrigated lands may fall, overall consumption increases. Where return flows are an important source of downstream water supplies, water right holders that depend on these flows would be negatively affected. Contor and Taylor show more generally that whenever an improved irrigation technology reduces the non-consumed part of applied irrigation water, consumption will increase at any non-zero marginal costs for water.

In a study based on an econometric approach, Wallander and Hand use farm-level panel data from national samples of irrigators to estimate the effects of the Environmental Quality Incentives Program on water conservation—in particular, changes in water application rates and irrigated acreage. Results suggest that for the average farm, payments may have reduced water application rates but also may have increased total water use and led to an expansion in irrigated acreage.

Effect on water scarcity when return flows are not important

In river basins, where return flows constitute a considerable part of the downstream supplies, a reduction in consumption is the appropriate measure for water conservation; the measure may be different, however, in cases where return flows are less important. For example, return flows would be less important in a region irrigated from a deep aquifer, such as the Ogallala beneath the Great Plains, where return flows to the aquifer are minimal and very slow. Water conservation may then be appropriately measured by reductions in withdrawals. Studies have shown that the switch to more efficient irrigation technologies in such a situation may increase or decrease withdrawals depending on the context; empirical analysis is required to determine the effect.

Various approaches to generating empirical estimates have been used for the Ogallala region, not least because of the relatively good availability of water-related data. For example, Peterson and Ding apply a risk-programming model to corn production on the Kansas High Plains and find that even under simplifying assumptions, the effect of an efficiency change on withdrawals is ambiguous. Their results suggest that a conversion from flood to subsurface drip irrigation would decrease both irrigation application per acre and the volume of groundwater withdrawn. A conversion from flood to center pivot, on the other hand, would increase irrigation applications per acre but decrease the overall volume pumped, because fewer acres would be irrigated. The latter conversion would also be cost-effective.

In an econometric evaluation, Pfeiffer and Lin use panel data from over 20,000 groundwater-irrigated fields in western Kansas from 1996–2005, when farmers converted from flood irrigation or traditional center pivots to more efficient center pivots with drop nozzles—supported by subsidies from state and national sources, including the Environmental Quality Incentives Program. They find that with the conversion, the amount of groundwater pumped and applied to fields increased. This is because farmers tended to shift toward a crop mix with relatively more corn—a more water-intensive crop than the traditional wheat and sorghum—and apply more water per acre. Farmers also irrigated a slightly larger proportion of their fields, and were less likely to leave fields fallow or plant rainfed crops.

These considerations, such as the local context and the relative importance of return flows—illustrated above using the example of more efficient irrigation technologies—are likely to be similarly important in determining the effect of other engineering and technological measures applied on-farm on water scarcity. However, there will also be exceptions. In the case when returns flows are important and the focus is on reducing consumption (while at the same maintaining agricultural production), this would include adaptation measures that directly aim to either decrease evaporation (for example, the application of mulching techniques or conservation tillage) or transpiration (for example, the switch to crop varieties with shorter growing season length).

IV. Investing in Policy and Institutional Adaptation Measures

As water scarcity grows, investments in policy and institutional adaptation measures become increasingly important. These investments may range from raising awareness and fostering innovations to applying economic instruments for balancing water supplies and demands (Noble and Huq). While supply-side measures such as investments in water storage infrastructure and alternative sources of water supplies (for example, desalinized water or treated wastewater) may continue to play a role, the emphasis on demand-side measures is increasing

(OECD 2015a). As engineering and technological adaptation measures applied on-farm are often focused on maintaining or increasing agricultural net revenues and production, policy and institutional measures are essential to contribute to the objective of conserving agricultural water for reallocation to other uses or for coping with water scarcity. Policy and institutional measures also need to promote and ensure private adaptation investments are aligned with this objective.

Measures for facilitating reallocations

Arrangements for water allocation (the apportioning of water among users within and between sectors) can be grouped into price-based or quantity-based measures. With increasing water scarcity, water allocation arrangements need to facilitate transfers of water use (a change in type of use, location, or point of withdrawal) while also protecting affected interests (Young 1996).

Price-based measures—in particular, price incentives involving higher costs of irrigation water—are increasingly considered as a potential tool for reducing water applications. Price measures could encourage farmers to use water more efficiently and make water available for other uses. An economic measure often used to assess the effectiveness of price increases is the price elasticity of the derived demand for irrigation water, indicating the proportional change in water demand for a given change in price. Most studies present price-inelastic demand estimates (Scheierling, Loomis, and Young), and caution against pricing policy. The common argument is that even small reductions in irrigation water applications would require large price increases, which, in turn, would cause large negative effects on agricultural net returns.

Yet as long as farmers have a range of adjustment options (such as changes in crop mix, irrigation scheduling, or irrigation technology), even a price-inelastic demand does not necessarily imply water applications cannot be substantially reduced as the price starts to rise (Scheierling, Young, and Cardon 2004). Even if water prices rose significantly, however, they would not be very effective in reducing consumption. In contexts where return flows are important, volumetric charges would therefore not generate much real water savings. In such situations, it would be more appropriate to encourage farmers to switch to crops with lower seasonal consumption or to dryland crops, possibly with subsidies. Theoretically, irrigation water pricing could be an effective policy instrument if volumetric charges were imposed on consumption. However, to our knowledge, this has so far not been attempted, possibly because the cost of measurement and administration would be even higher than for charges on water applications or withdrawals.

Quantity-based measures, or quotas, can be designed to minimize externalities and to ensure security of tenure and consistent enforcement—and, in principle, to achieve efficient allocation (Young 1995). A number of difficulties, however, including variations in water supply, need to be addressed. An example of a quota system is the prior-appropriation doctrine of "first in time—first in right" in the western United States that assigns entitlements in terms of water withdrawals. An alternative to this concept of "release sharing" is the concept of "capacity sharing" that assigns entitlements as shares of stored water. Capacity sharing has recently been introduced in Australia in response to increased water scarcity.

Exchangeable quotas allow reallocations through water markets. These reallocations may involve permanent or temporary transfers, including water-supply option contracts in which transfers occur only during contractually specified drought conditions. Water markets provide price signals that encourage the movement of water from lower- to higher-valued uses, thus enhancing economic efficiency (Young 1995). As water scarcity increases, more countries are experimenting with water trading (Griffin and Peck). A number of challenges to water trading need to be overcome: addressing externalities and protecting the entitlements of potentially affected third parties, considering non-efficiency goals (such as ensuring access to a certain amount of water per person per day), safeguarding instream benefits (for example, for environmental or recreational purposes), and reducing information and transaction costs for market participants (Young 1986; Griffin and Peck).

Water markets have mostly been observed so far in countries with strong legal, institutional, and regulatory arrangements. In many emerging market economies, other reallocation mechanisms dominate (Scheierling). These mechanisms include transfers of informal rights (such as farmer-to-farmer transfers), transfers made by legal means (such as when legislation establishes priorities at times of drought), transfers by formal administrative decisions (for example, by national, provincial/state, or basin entities), and informal transfers by stealth (for example, when expanding cities encroach on irrigated areas). While farmers are compensated in the case of water markets, and compensation may be paid in the case of administrative decisions (for example, if farmers giving up water supplies are readily identifiable and can bring political pressure to bear on decision makers), farmers are not usually paid in the case of transfers by stealth (although later complaints can trigger measures after the fact). Only limited information is available on many of these transfers and their effects—not just on water scarcity but also on efficiency and equity. Much could be done to shed more light on these reallocations and help improve them.

Measures for promoting and aligning private adaptation investments

While many of the adaptation investments will be carried out by the private sector, the private sector alone may not provide the desirable level of adaptation (for example, due to cost considerations). Private adaptation investments also focus on protecting and enhancing production systems and possibly supply lines and markets—they may not align with broader social objectives such as water conservation without public interventions, including incentives, coordination, and regulation (Chambwera and Heal; Noble and Huq).

One illustration is the conversion to more capital-intensive irrigation technologies. While farmers using groundwater to grow high-value crops may find it profitable to switch to drip irrigation, this may not be cost-effective for others. If public subsidies are to be provided to encourage further conversions in response to water scarcity, the objective(s) of such investments should be clearly stated. In addition, context-specific assessments should be carried out to avoid unintended or counterproductive outcomes with regard to irrigation water use—as well as uncompensated third party effects and related conflicts. In areas where return flows are important, care should be taken that farmers' consumption will (at least) not increase. A necessary, though not sufficient, rule should then be that the irrigated area not increase. In advanced water rights systems such as Colorado's, legal provisions specify the area to which an agricultural water right may be applied. Remote sensing via satellites can help enforce such rules. In areas without well-specified and enforced water rights, farmers should be informed if and to what extent reallocations are planned in connection with the subsidy program to allow them to adjust their practices accordingly.

More generally, care should be taken to ensure that a conversion program and the associated changes do not increase farmers' water-related (and other) risk exposures (OECD 2015a). A switch to more "efficient" irrigation technologies may provide incentives to farmers to follow a path toward more specialized production involving higher-value crops that may be more susceptible to a periodic lack of water, for example.

Improved groundwater management, not only in areas with deep or nonrenewable aquifers, will be necessary to make any significant progress with water conservation efforts in irrigated agriculture. In large parts of the world, groundwater irrigation remains largely uncoordinated and unregulated. In many instances, groundwater entitlements are linked with land property rights, which does not necessarily encourage water conservation or the consideration of externalities imposed on other aquifer users (OECD 2015b). If strong legal provisions exist, they often apply to irrigated areas with conjunctive water use and aim to prevent groundwater pumping from affecting stream flows and surface water rights or violating interstate water agreements (such as along the Platte River in eastern Colorado and Nebraska).

V. Going Forward

As water scarcity intensifies in many parts of the world, the need for adaptation investments from both private and public sectors in irrigated agriculture will increase. While engineering and technological adaptation measures are important, urgent progress will have to be made with policy and institutional adaptation measures. Such progress will include raising awareness on the severity of the water situation and its link to agricultural water use, but also on the complexities of designing adaptation measures for water resources compared to other resources or commodities. Progress will also require a much greater emphasis on research and development for fostering innovations not only in the traditional area of technologies, but in new policy and institutional arrangements to provide a framework for their effective implementation (Dinar).

Many adaptation measures in irrigated agriculture are currently not well explored, due in part to the lack of data on key water measures (including water withdrawn, applied, and consumed) and how they may change as a result of different interventions. An increasing number of studies are being carried out in advanced economies such as the United States, but due to the localized nature of many water problems, their insights are not readily transferrable to other situations. Since adaptation measures often need to be designed with the local context in mind, many more pre-implementation assessments should be carried out to estimate the costs and benefits and the associated risks of different investment options—incorporating, among other issues, hydrological aspects as well as the likely behavior of farmers and other affected parties. In addition, more emphasis should be given to post-implementation assessments that evaluate the implementation processes and results in line with the underlying objectives. These assessments would help inform decision makers in both the public and private sectors.

Adaptation investments related to irrigation water will increasingly have to take into account, and be integrated within, the wider policy framework, including in the agricultural and energy sectors. For example, subsidies that encourage crops with high water consumption may distort incentives for addressing water scarcity. Similarly, subsidies for cheap electricity or for solar-driven pumps may exacerbate groundwater exploitation.

As ever larger shares of total renewable water resources are being withdrawn and consumed for agricultural and other purposes—and as the level of interdependencies among users increases—even relatively minor shortfalls in water supplies may create unexpected economic, social, or environmental crises that currently applied adaptation measures will not be able to address. Planning for such events must attract increasing attention.

Endnotes

[1]Data from FAO (2016a) on agricultural water withdrawals include the annual quantities of water withdrawn for irrigation, livestock, and aquaculture purposes. Data from FAO (2016a) on total water withdrawals include the annual quantities of water withdrawn for agricultural, industrial, and municipal purposes. In-stream uses, such as recreation, navigation, and hydropower are not considered. Consumption, or evapotranspiration in the case of agriculture, is the amount of water actually depleted by the crops—that is, the amount of water lost to the atmosphere through evaporation from plant and soil surfaces and through transpiration by the plants, incorporated into plant products, or otherwise removed from the immediate water environment.

[2]Data from FAO (2016b) on the area equipped for irrigation include areas equipped for full and partial control irrigation, equipped lowland areas, pastures, and areas equipped for spate irrigation. They do not necessarily represent the area that is actually irrigated. The available data from FAO on the area actually irrigated are too limited for further analysis.

[3]Total renewable water resources comprise internal renewable water resources (specifically, the long-term average annual flow of rivers and recharge of aquifers generated from endogenous precipitation) and external renewable water resources (such as surface and groundwater inflows from upstream countries).

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