1. Introduction

Water is a major constraint to continued and sustainable agricultural development both in the developed and developing countries. A recent 2020 study by the International Food Policy Research Institute identified water as the most critical constraint to food self-sufficiency and security. The food and agriculture sector is currently facing a multitude of problems relating to water resources that will need to be addressed by economists and policymakers in the coming years.

The most important issue is that demand for water is increasing both in agriculture and, in particular, in the municipal sector at significant rates. Given the scarcity of additional freshwater generation capacity and its prohibitive cost, agriculture will in the future have to produce ever-increasing quantities of food with decreasing quantities of water. A second concern of more recent vintage is the environmental impact of agricultural water use. Increased chemical use and the intensification of agricultural systems around the world have led to serious water quality issues. Water laws and compacts both within water districts and at the regional and transboundary levels, are often insufficient in addressing these emerging quantity and quality concerns, mainly because these laws and institutions were developed in an era when water supplies were abundant and quality was not a severe problem.

How can the available water resources be better managed both to enhance the efficiency of food production as well as the quality of the environment? The selection of papers in this volume focus on an important set of issues, beginning with water quality issues at the farm and industry levels, to problems of basinwide management, and finally dealing with regional and transboundary water conflicts. Among other things, they focus on the dynamics of managing multiple water sources and investing in backstop technologies such as desalination, the on-farm and industry-level variability in the response to water quality legislation, the design of mechanisms for dealing with farm-level heterogeneity, the importance of modeling water allocation and quality at the level of the river basin, and the strategic and institutional issues relating to the cross-border flow of water resources.

A serious concern of water policy makers in both developed and developing countries is the growing threat of pollution from chemical use. The effect of nutrient runoffs, build-up of salinity and other chemicals in the water on downstream agricultural and environmental uses of water has given rise to a host of management problems in both developed and developing countries. This has resulted in attention being drawn to the efficiency of farm level chemical use.

Khanna, Isik and Winter-Nelson point out that uniform application of nutrients on the field may achieve a plant nutrient uptake of as low as 30% of the applied nitrogen. They do an economic analysis of Site Specific Crop Management (SSCM) technology, which uses information on the spatial variability of soil, and targets input applications that match this variability. Various studies have shown that SSCM has the potential to increase crop yields, reduce input use and input residues in the soil. However, adoption rates among farmers have been surprisingly low, in spite of the significant economic and environmental benefits.

An option value framework is used to examine the extent to which farmer uncertainty about output...
prices, expectations of declining fixed costs of the technology and the irreversibility in decision making contribute to low adoption rates. The uncertainty and fixed costs of adoption are then used to design a cost-share subsidy policy that could achieve pollution reduction by accelerating adoption. They find that using the option value rule, farmers will tend to wait to invest in pollution reduction technologies unless average soil fertility levels are high and variable, in which case the benefits from SSCM are higher. Thus they point out that the subsidised rates currently offered may be insufficient to the extent that farmers are influenced by uncertainty and irreversibility of investment.

The distributional impacts of agricultural nutrient reduction policies are examined by Parker. New legislation by the State of Maryland to reduce nonpoint source pollution in the Chesapeake Bay is supposed to be the most restrictive nonpoint pollution control law in the nation. Many states within the United States are beginning to enact similar laws. The paper examines the impacts of the law on poultry firms that apply nutrients and evaluates the tradeoffs between those who will benefit from the law and those who will be adversely affected by it. Three alternative measures to local land application of poultry litter are considered: compost for wholesale and retail markets, energy conversion, and transport to alternative agricultural lands out of the area. The study suggests that there may be significant costs imposed on the poultry firms who would now incur costs of litter disposal. However, if a market for litter as fertilizer were created, firms could benefit from selling litter to growers, who would then use less chemical fertilizers. As in the earlier study by Khanna et al., a key recommendation is the need for cost subsidies that could mitigate negative distributional impacts of nutrient control legislation.

Water quantity and quality management at the level of a river basin needs the use of sophisticated hydrological and economic information. Rosegrant et al. develop a detailed basinwide integrated economic-hydrologic model and apply it to the Maipo River Basin in Chile. The model incorporates several non-economic parameters that are not included in traditional water economics models. It is based on a node–link framework, where source nodes include rivers, reservoirs, and groundwater aquifers and demand nodes consist of irrigation fields, industrial plants and households. Water flows into the network from the rivers as well as through rainfall. At each agricultural demand node, water is endogenously allocated to selected crops, based on their profitability. Crop area and yield are determined within the model. Instream uses of water such as flows for waste dilution and hydropower generation are included.

Their analysis suggests that relative to water use in the industry and municipal sectors, agricultural water supplies are highly sensitive to supply shocks. In drought years when normal water supplies were reduced by half, agricultural water use declines by nearly a half while municipal and industrial use is reduced only by 13%. In dry areas, there is a reallocation of water from agricultural to non-agricultural uses. Reduction in crop prices by 25% reduces water use in agriculture by a mere 5%, but profits drop 60%. Increased salinity leads to an increase in irrigation water withdrawals for salt leaching and reduces profits from irrigation. There is also a resulting shift in cropping pattern away from crops with a lower salt tolerance such as maize to more salt tolerant crops such as wheat.

The model examines how the agriculture sector can profit from water trading as well as the critical role of low transactions costs in ensuring trading volume. For this purpose, it computes shadow prices at each demand node by varying water withdrawals and calculating the marginal values from the water balance equations. A smooth shadow price function is derived by regressing shadow prices with water withdrawals. A comparison between the trading and no-trading cases suggest that in the former, the irrigation sector sells almost 11% of the dry year inflows to municipal and industrial users. Without trading, the optimized value of benefits from the basin is less than one half of the optimal scenario and the benefits from municipal and industrial use triples because of the availability of additional water. Higher transactions costs, the study finds, leads to significant reductions in the volume as well as the benefits from trading, in particular because the assumed values of transactions costs are high relative to the prevailing shadow prices of water.

Huffaker and Whittlesey model third party effects from basinwide water management, when farmers make optimal investments in irrigation technology. This question is important from a policy point of view because in many countries, improvements in irrigation efficiency are promoted within an irrigation district,
without taking into account the possible negative externality impacts in terms of reduced diversions at the level of the basin. The federal government and several western states in the US have passed agricultural water conservation laws encouraging farmers to invest in on-farm irrigation technology. For example, the state of Oregon’s equitable division policy distributes the reduced diversions between the efficiency-improving farmer (who may then expand irrigated acreage) and the public for instream uses. The interspatial optimization problem is solved using a continuous framework and generates equilibrium conditions for basinwide efficiency. The model is then discretized as a nonlinear programming problem to facilitate the introduction of critical instream flow and policy constraints. A numerical example with representative numbers shows the real impact of an efficiency-enhancing measure, which is to increase the consumptive water use of this farm, and reduce water transfers to downstream irrigators.

The analysis suggests that one option may be to allow unrestricted private investment in improving on-farm efficiency, but facilitate bargaining between the efficiency-improving user and those impacted negatively in the downstream reaches of the basin. However, the transactions costs inherent in this bargaining process may be prohibitive. California statutes which give efficiency-improving farmers an amount of conserved water that is equal to “the reduction of the amount of water to the consumer or irretrievably lost in the process of satisfying beneficial uses.” This measure prevents “paper” savings of water through efficiency improvements.

How could water resources be efficiently allocated in a dynamic setting when adjoining water districts share surface water resources? Smith and Roumasset deal with a problem in which a water authority manages water allocation across two districts — one of which relies primarily on groundwater from a coastal aquifer while both districts can withdraw water from a common surface water source. They model the water allocation situation in Hawaii where one district draws water from the Pearl Harbor Aquifer, which is a coastal aquifer, while the other relies on surface water. Both districts have recourse to a backstop technology, desalination. The optimal solution involves allocating each successive unit of water to the district with the highest marginal value of water. If water is available in sufficient quantities, this will lead to equalization of marginal values across districts. If not, a corner solution results, in which the entire amount of water is diverted to the district with the higher marginal price, and the efficiency prices across districts are divergent. Ceteris paribus, a higher allocation of water is made to the district with lower transport costs.

These results have major implications for water planning in regions where both ground and surface water supplies may be available. Because of the opportunity for arbitraging groundwater supplies over time, districts that rely primarily on surface water will run out of water in time because of demand growth and the common water that may be available to water planners will be allocated in increasing proportions to supplement scarce surface water supplies. The authors conclude that reliable benefit–cost analysis of investments in new water facilities should not be made without computing the time-dependent shadow prices of water.

The above theme of water allocation across multiple users and jurisdictions is extended by Tsur and Zemel to multiple sources, specifically, the time of arrival of backstop technologies and optimal investments in them. In many countries, especially in the arid and semi-arid regions of the Middle East, if water prices reflected their true opportunity costs, desalination technologies would be quite close to being economically viable. However, the cost of desalination technologies, currently ranging between $0.6 and $1 per cubic meter is itself a function of current investment decisions in research and development. In this paper, water can be supplied from two sources: a renewable fresh water stock of finite size and desalinated seawater. The latter is unlimited in supply but its cost can be reduced through endogenous technological progress. This formulation is different from standard treatments of endogenous backstop technologies in the exhaustible resource literature because the freshwater stock is renewable while the stock of fossil fuel in the latter is usually treated as an exhaustible resource.

The renewability of the freshwater resource changes the optimal R&D policy substantially. One possible solution is that in an initial period of time, the freshwater stock may be depleted with increasing demand for water while investments are made in reducing the cost of backstop technology. When the backstop becomes sufficiently cheap to use, it substitutes for freshwater. Freshwater use may decrease below the
recharge rate and the freshwater stock may get fully or partly refilled from recharge. Such behavior is not possible in the case of nonrenewable resource deposits where knowledge accumulation usually approaches a steady state. The optimal R&D policy is of a non-standard Most Rapid Approach Path (MRAP) type, in which the stock of knowledge is accumulated as fast as possible to mimic a pre-specified target process.

Moving to a higher level of aggregation, water management across state and national jurisdictions require the use of models of strategic behavior especially in cases where there may be more than one resource or environmental problem to be resolved. Just and Netanyahu derive insights from the water conflict between the Arab States and Israel in the Middle East and suggest that the complexity of international negotiations can be better handled by linking independent games, especially when there are significant asymmetries in each. If each individual issue between two countries is treated as a game, linking two asymmetric games can be useful because countries are more likely to exchange in-kind side payments rather than monetary side payments, and sustain self-enforceable agreements that provide credible threats against defection. Thus linking games with compensating asymmetries could be advantageous. The authors use a stylized example to show that linking may be preferred only in situations where one party agrees to lose in one agreement for the benefit of being a bigger winner in another agreement. In essence, the rationality constraints of the isolated games are relaxed by linking them.

The institutional history of transboundary water management in the US–Mexico context is reviewed by Frisvold and Caswell, using a game theoretic perspective. Of the 12 million people who live within 100 km of the US–Mexico border, 90% inhabit the sister cities that share water resources common to both countries. Resource management and environmental issues have received significant attention under NAFTA and new institutions such as the Border Environmental Cooperation Commission (BECC) and the North American Development Bank (NADBank) have been created. NADBank arranges financing for environmental infrastructure projects that must be certified by BECC. Negotiations between the two nations determine the scope and siting of wastewater collection systems and treatment plants in the border areas and allocate costs between them. Data from these projects reveals that project costs were allocated in proportion to project benefits, suggesting that the solution was consistent with the Nash bargaining concept. The paper discusses how in order to avoid duplicating border sewage treatment facilities, border cities could seek external financing of a jointly developed water project. In this case, negotiations over the terms of the proposal could be modeled as a sequential bargaining game.

Since many of the externalities along the US–Mexico border are unidirectional, most game theoretic solutions tend to have “victim pays” outcomes, which run counter to the “polluter pays” principle. In situations where the above solution concept does not work, negotiation issues can be linked. For example, Mexico can link negotiations in the Colorado River where it is the downstream country with the Lower Rio Grande, where it is located upstream. This interconnected game approach can identify issues for linkage simply by looking for issues with payoffs of the same order of magnitude and where games have asymmetric prisoner’s dilemma structures.

What are the potential costs of ignoring water quality and pollution control issues in the transboundary context? The paper by Bennett points out that most transboundary water agreements deal almost exclusively with allocation issues and ignore quality considerations. An example is the Texas vs. New Mexico suit over Pecos River Compact violations. One reason for the dispute was the failure of the compact to include salinity damages from water flowing through salt beds in New Mexico being used by Texas irrigators. In the case of the Arkansas River, which is shared by Kansas and Colorado, upstream Colorado irrigators divert high quality water and grow salt-sensitive specialty crops. However, the total dissolved solids (TDS) is five times higher just 25 miles downstream of the river, forcing irrigators to plant less salt-sensitive crops such as alfalfa, sorghum and wheat. Salinity also affects the municipal and environmental uses of water, issues not addressed by the prevailing compact. In addition to salinity, the presence of nitrate and other chemicals has emerged as a growing problem in interstate disputes especially in the US.

Even those river compacts that do address water quality issues, such as the Big Blue between Nebraska and Kansas, discuss the issue generally and do not set any quality limits. Without any precise limits, Bennett
points out that there is no recourse for the downstream state in any potential conflict situation. Even in situations where the contract stipulates clearly defined quality limits, as in the case of the Colorado River running between the US and Mexico, expensive salinity reduction projects have been undertaken by the Bureau of Reclamation and cheaper TDS reduction techniques such as adjustments in cropping patterns and acreage reductions were overlooked. Moreover, these compacts do not ensure that upstream users internalize salinity costs, but responsibility is usually borne by the government. The paper suggests that although measurement of water quality and the choice of the most economical treatment methods is difficult, quality issues need to be written into transboundary contracts in order to prevent larger problems in the future.

In conclusion, the accompanying collection of papers deals with some of the most important issues facing water use in agriculture today. They emphasize the need to incorporate both water quality and quantity not only at the level of the individual farmer, but regionally and across jurisdictions. The dynamics of water allocation and optimizing over multiple sources and districts is key to achieving efficient allocation within agriculture. They point out the inadequacy of current water planning methods and their adverse efficiency and equity effects, and suggest avenues for further research in key areas such as dynamics, uncertainty and asymmetric information.

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