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RESEARCH REPORT ABSTRACT 149

MODELING WATER RESOURCES MANAGEMENT AT THE BASIN LEVEL

METHODOLOGY AND APPLICATION TO THE MAIPO RIVER BASIN

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Water demand for agricultural, household, industrial, hydropower, and environmental uses is rapidly increasing in many developing countries, exacerbating water shortages and environmental degradation. The need to reform water allocation policy is pressing, but many questions remain unanswered regarding the feasibility, costs, and likely effects of various policy options. Further, the complex, interdisciplinary nature of water resource issues requires that the technical, economic, environmental, social, and legal aspects of water management be incorporated into a coherent analytical framework. The river basin is the natural unit for such a framework of analysis, and alternative water policy instruments can best be examined at this level.

This report comprises two parts: the development of a prototype for modeling water resource allocation at the river basin level, and the application of the modeling framework to a case study site. The Maipo River basin in central Chile was chosen for the case study because it encompasses both key agricultural areas and a major metropolitan center (the capital city of Santiago). The basin is also a prime example of a mature water economy—one with limited resources and competition for water across many sectors. Moreover, growing concerns about meeting water demand in the face of limited funding for infrastructure development have prompted Chile to introduce innovative allocation policies, including tradable water rights.

The model's main advantage lies in its ability to reflect the interrelationships between essential hydrologic, agronomic, and economic components and to explore both the economic and the environmental consequences of different policy choices. Policymakers and water management authorities can use the model as a decisionmaking tool in selecting water policy reforms and investments in water-saving technologies.

THE MODEL FRAMEWORK

Making use of techniques such as hydrologic modeling, spatial econometrics, and geographical information systems (GIS), the model simulates the balance of flows, salinity, and crop growth throughout the basin, optimizing water allocation, reservoir operation, and irrigation scheduling. The model framework reflects the basin's network of water sources—that is, nodes, such as reservoirs, aquifers, and river reaches—and points of demand, including agricultural, municipal, industrial, and instream water uses. This integrated framework enables different instruments for managing water demand to be evaluated based on their economic benefits.

The model is applied to the Maipo River basin to address site-specific research questions regarding

1. the role of water rights and water rights trading in enhancing allocation efficiency,
2. the role of water-use efficiency in saving irrigation water,
3. the impact of changes in physical irrigation efficiency on basin-level economic and physical efficiency,
4. the effects of hydrologic uncertainty (that is, the amount of water available) on irrigation technology choice, and
5. the potential for substitution among water and other crop production inputs.

Thus, model applications focus on the relative benefits of various water allocation institutions.

BASIN STUDY FINDINGS

The study reveals that under full basin optimization (assuming an omniscient decisionmaker or basin agency) and under the current irrigation system and water supply charges, crop area would increase by 15 percent; total revenues from high-value crops, such as fruits, would increase by 50 percent; and revenues from low-value crops, such as annual forage, would decline by 40 percent. Under this scenario, the use of water for agriculture would be slightly higher, while the water withdrawn for domestic and industrial uses would almost double.

If farmers are allowed to trade water rights, net farm incomes increase substantially, agricultural production declines only slightly, and economic efficiency increases. Benefits could be even larger than under the optimization scenario because farmers can sell their unused water rights—benefiting municipalities and industry—when they are not producing crops. In this case, economic efficiency can be increased without changing the physical distribution of water or existing application systems. Tradable water rights also improve the efficiency of water use by making it more profitable for farmers to invest in advanced irrigation technologies. Higher water charges cause farmers to reduce their water use and shift to higher value crops and more advanced irrigation technologies for some crops. From a basin perspective, however, the potential for water savings from increases in water-use efficiency in irrigation systems is lower than individual system efficiencies might indicate. Where local efficiency is low, improvements can generate significant basinwide profits, but the relative contribution of improvements declines when systems become more efficient.

Water prices and water quality (represented in the model through the salinity of irrigation water) can influence investments in field irrigation technology. In the Maipo River basin, widely planted crops, such as wheat, maize, and annual forage, require large amounts of water and are generally less profitable, but they are also less sensitive to hydrologic uncertainty. Based on an analysis of uncertainty, the annualized capital cost for irrigation technology should be between US$105 and US$130 per hectare. That range maximizes expected profits and minimizes the risk of profit loss under drought conditions.

Under full basin optimization, there are tradeoffs between the additional profits generated and the additional costs—including negative environmental impacts—of using more water and other inputs. For example, the shift from actual to optimized water allocation leads to the use of an additional 301 million cubic liters of scarce water and additional net profits of US$11 million.

When water in the Maipo River basin is substituted with a single alternative input (with other inputs fixed in each case), irrigation investment, labor, machinery use, and pesticide use increase; fertilizer use decreases; and seed use either increases or decreases depending on whether water prices are low or high, respectively.

Although the model presents a useful framework for allocating water among many uses and users, it does not explicitly value the environmental demands of river basins. That complex task remains for future research.

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