Introduction to special section on Groundwater Economics and Policy

Anastasios Xepapadeas

Department of Economics, University of Crete, Rethymno, Crete, Greece

Phoebe Koundouri

Department of Economics, University of Reading, Reading, UK

Department of Economics and Centre for Social and Economic Research on the Global Environment, University College London, London, UK

[1] Historically, surface water has been the main source of water for human consumption, as it was easy and cost-effective to access. However, increased rainfall shortages have resulted in increased use of groundwater to satisfy the ever increasing domestic, agricultural, and environmental/ ecosystem preservation water demands. Thus, during the second half of the 20th century, groundwater withdrawals have increased, up to the point that they now supply one third of the world's population [*United Nations*, 2001]. This extensive use of groundwater in many parts of the world has resulted in water level drawdown, groundwater depletion and related biodiversity loss, and pollution and seawater intrusion in coastal aquifers. As a result, groundwater management and the search for relevant backstop technologies and substitutes has become a practical concern in many arid and semiarid regions throughout the world.

[2] Groundwater is important for sustaining agricultural production patterns and freshwater consumption patterns as well as biodiversity and ecosystems' resilience. Combining this fact with the resource's acute scarcity in many parts of the world makes necessary the development of rules for allocating the resource efficiently among competing uses over time and space. This poses a very interesting economic question that the economics profession has addressed enthusiastically since the mid-1950s. Historically, economists have taken for granted that the divergence between the temporal allocation of groundwater obtained by optimal control methods and the allocation obtained by competitive markets is practically significant for social welfare because of the absence of well-defined groundwater property rights. As a result, they acknowledged the need to study optimal control (or equivalently, dynamic programming) of temporal groundwater allocation. The theory of the intertemporal allocation of groundwater has been developed and studied extensively during the last 45 years. As a result, economists have made and continue to make useful contributions that can be enlightening to water resource managers and policy makers with regard to how one might go about achieving this optimal allocation, that is, the allocation of groundwater that will maximize social welfare. The objective of this special section on ''Groundwater Economics and Policy,'' convened by Anastasios Xepapadeas, is to illustrate the practical usefulness of economics in identifying this allocation, constructing instruments that can be implemented in order to achieve this allocation, and deriving the distributional effects of such an implementation.

[3] The first paper in this section is a survey that examines the potential benefits from groundwater management. In this paper, *Koundouri* [2004] revisits Gisser-Sanchez's effect (GSE), a paradoxical empirical result that has persisted in the groundwater literature since 1980, when Gisser and Sanchez first identified it. In essence, GSE states that the numerical magnitude of benefits of optimally managing groundwater is insignificant. The paper critically reviews both the theoretical and empirical attempts to address GSE and points to the fact that in the theoretical literature, the single most important cause for the presence of GSE is the prevalence of very steep marginal groundwater use benefit curves. However, in a number of circumstances which could be potentially important in real applications, groundwater management is significantly welfare increasing. Some of these cases are dealt with in the papers included in this special issue.

[4] In the second paper, *Koundouri and Xepapadeas* [2004] address the single most important reason for misallocation in groundwater management, the emergence of scarcity rents, or groundwater's shadow or accounting price. The difficulty in establishing clear groundwater ownership rights is closely related to the difficulty of accounting for the scarcity value of groundwater in unregulated competitive equilibrium, and subsequently incorporating it in relevant allocation decisions over space and time. Ignoring scarcity rents leads to underpricing of groundwater, which results in extraction levels above the socially optimal level. Koundouri and Xepapadeas develop a new approach for deriving the in situ shadow prices of groundwater, which can be extended to more general renewable resources problems. By using Shephard's input distance function rather than a cost function, they employ duality to retrieve

accounting or shadow prices that reflect the individual user's valuation of the marginal unit of the resource in situ at each point in time. An empirical application of the method is also included in the paper, where a stochastic input distance function is estimated by using panel microeconomic data from irrigated agriculture in Cyprus. Moreover, the new approach enables derivation of firm-specific inefficiencies and is robust when allocative inefficiency exists, with allocative inefficiency being the norm rather than the exception as far as agriculture is concerned.

[5] As argued in the introductory survey of this special section and by *Koundouri and Xepapadeas* [2004], the scarcity value of groundwater depends on the quantity available, and on its quality. A group of papers which considers quality and quantity focuses on salinity problems [see, e.g., *Dinar*, 1994; *Dinar and Xepapadeas*, 1998; *Tsur*, 1991; *Xepapadeas*, 1996; *Zeitouni and Dinar*, 1997; *Koundouri*, 2000]. The paper by *Moreaux and Reynaud* [2004] extends this literature by studying the specific problems posed by the optimal management of an aquifer under seawater intrusion in the presence of another water source, in a deterministic framework. In such a framework the relation between extraction rate and location of pumping points generates a spatial externality. In the presence of a costly substitute, Moreaux and Reynaud show that the optimal water supply depends on the locations of users. Users located in the coastal zone use exclusively the costly substitute, whereas those located upstream use the aquifer's water supplies. At the optimum, their withdrawals take into account the scarcity value of this resource and the cost externalities they generate on users located downstream. This optimum can be achieved via the use of Pigouvian taxes.

[6] Although the stochastic nature of groundwater recharge and interconnected surface supplies is a fundamental hydraulic feature of aquifers, the biggest part of the literature has been, to a large extent, confined to deterministic recharge models with boundaryless aquifers. Exceptions include a few authors, some of whom contributed to this special issue, who dealt with regulation of stochastic (under uncertainty) groundwater pollution [*Tsur and Zemel*, 1995, 1998] and groundwater management with stochastic surface water [*Tsur and Graham Tomasi*, 1994; *Provencher and Burt*, 1993; *Knapp and Olson*, 1995]. In the fourth paper of this special section, *Zeitouni* [2004] considers the management of an aquifer with stochastic recharge and finite boundaries. For a class of such models, Zeitouni shows that there is a positive threshold of the water stock that the manager should aim at keeping. Thus, under the optimal extraction regime at a time when the water stock is lower than this threshold, there should be no pumping from the aquifer, while at times when the water stock is greater than the threshold, all water in excess of the threshold level should be pumped. The threshold level happens to coincide with the aquifer boundary for sufficiently high cost of pumping, in which case, only the runoff water of excess recharge should be collected.

[7] Another important issue in groundwater management is the concern over the effects of current policy decisions on future generations. This is intensified by the presence of suspected irreversibilities. The uncertainty about future population growth and ecosystem resilience, combined with the exponential discounting process, may result in very low weights being placed on the benefits of protecting the aquifer. *Tsur and Zemel* [2004] first tackled the problem of identifying optimal extraction paths in the presence of uncertainty concerning occurrence of an irreversible event [see, e.g., *Tsur and Zemel*, 1995, 1998]. As Tsur and Zemel argue, unlike other sources of uncertainty (time varying costs and demand, stochastic recharge processes, etc.) under which the extraction policy can be updated during the process to respond to changing conditions, irreversible event uncertainty is resolved only by occurrence, when policy changes can no longer be useful.

[8] Because of the idiosyncratic nature of catastrophic event uncertainty, the expected loss due to the catastrophic threats must be fully accounted for prior to the occurrence, and the resulting policy rules are significantly modified. In their paper in this special section, Tsur and Zemel present an encompassing model that allows the study of optimal groundwater extraction under the threat of events that differ in the damage they inflict and the conditions that trigger occurrence. They demonstrate the sensitivity of the optimal management policy to the details of the hazard and damage specifications. Their analysis, although presented in the context of groundwater resources, has wider application in a variety of resource situations involving event uncertainty.

[9] The development of realistic models for groundwater policy evaluation is another crucial issue in groundwater management. *Burness et al.* [2004] do exactly that by developing an economic-hydraulic model of an idiosyncratic river-aquifer system that is not snowpack fed, but rather the river is generated by the underground supply of rainwater charged aquifer flows. In such a setting, they focus on issues involving the representation of riparian benefits in the context of the hydrology of the basin. In particular, they explore the dynamic and conflicting interaction of incentives for private versus riparian habitat water use, through an application of the model to the upper San Pedro river basin. A novel situation arises wherein private demands are consumptive while riparian habitat demand, although clearly consumptive, is closely related to water stocks. Relevant policy alternatives are discussed, which are mainly driven by the unique hydrology of the mountain front recharge system that is characterized by system lags. This makes it necessary for policy tools to be forward looking and anticipate future demands for and availability of water.

[10] In this special section on groundwater management, issues related to the magnitude of the externality associated with groundwater use, empirical estimates of groundwater scarcity value, impact of spatial externalities due to the groundwater users' locations, uncertainty in recharge or occurrence of irreversibilities and groundwater policy evaluation models were analyzed. Although this list is far from exhaustible, it reflects the state of current research in the economic management of groundwater, and could provide a useful basis for further advances.

References

Burness, S., J. Chermak, and D. S. Brookshire (2004), Water use in a mountain front recharge aquifer, *Water Resour. Res.*, *40*, W06S21, doi:10.1029/2003WR002160.

Dinar, A. (1994), Impact of energy cost and water resource availability on agriculture and groundwater quality in California, *Resour. Energy Econ.*, *16*, 47–66.

Dinar, A., and A. Xepapadeas (1998), Regulating water quantity and quality in irrigated agriculture, *J. Environ. Manage.*, *54*, 273–289.
Knapp, K. C., and L. J. Olson (1995), The economics of conjunctive groundwater management with stochastic surface supplies, *J. Environ. Econ. Manage.*, *28*, 340–356.
Koundouri, P. (2000), Three approaches to measuring natural resource scarcity: Theory and application to groundwater, Ph.D. thesis, Fac. of Econ. and Polit., Univ. of Cambridge, Cambridge, U. K.
Koundouri, P. (2004), Potential for groundwater management: Gisser-Sanchez effect reconsidered, *Water Resour. Res.*, *40*, W06S16, doi:10.1029/2003WR002164.
Koundouri, P., and A. Xepapadeas (2004), Estimating accounting prices for common pool natural resources: A distance function approach, *Water Resour. Res.*, *40*, W06S17, doi:10.1029/2003WR002170, in press.
Moreaux, M., and A. Reynaud (2004), Optimal joint management of a coastal aquifer and a substitute resource, *Water Resour. Res.*, *40*, W06S18, doi:10.1029/2003WR002166, in press.
Provencher, B., and O. Burt (1993), The externalities associated with the common property exploitation of groundwater, *J. Environ. Econ. Manage.*, *24*, 58–139.
Tsur, Y. (1991), Managing drainage problems in a conjunctive ground and suface water system, in *The Economics and Management of Water and Drainage in Agriculture*, edited by A. Dinar and D. Zilberman, pp. 617–636, Kluwer Acad., Norwell, Mass.
Tsur, Y., and T. Graham Tomasi (1994), The buffer value of groundwater with stochastic surface water supplies, *J. Environ. Econ. Manage.*, *21*, 201–224.
Tsur, Y., and A. Zemel (1995), Uncertainty and irreversibility in groundwater resource management, *J. Environ. Econ. Manage.*, *29*, 149–161.
Tsur, Y., and A. Zemel (1998), Pollution control in an uncertain environment, *J. Econ. Dyn. Control*, *22*, 967–975.
Tsur, Y., and A. Zemel (2004), Endangered aquifers: Groundwater management under threats of catastrophic events, *Water Resour. Res.*, *40*, W06S20, doi:10.1029/2003WR002168.
United Nations (2001), *We the Peoples: The Role of the United Nations in the 21st Century*, *The Millenium Report*, Dep. of Public Inf., New York. (Available at http://www.un.org/millennium/sg/report/full.htm)
Xepapadeas, A. P. (1996), Managing common-access resources under production externalities, in ''Economic Policy for the Environment and Natural Resources'' (A. P. Xepapadeas, Ed.) Edward Elgar: Cheltenham.
Zeitouni, N. (2004), Optimal extraction from a renewable groundwater aquifer with stochastic recharge, *Water Resour. Res.*, *40*, W06S19, doi:10.1029/2003WR002162.
Zeitouni, N., and A. Dinar (1997), Mitigating negative water quantity and quality externalities by joint management of adjacent aquifers, *Environmental and Resource Economics*, *9*, 1–20.

P. Koundouri, Department of Economics, University of Reading, Reading RG6 6AA, UK.

A. Xepapadeas, Department of Economics, University of Crete, 74100, Rethymno, Crete, Greece. (xepapad@econ.soc.uoc.gr)