The Economics of Managing Scarce Water Resources

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Introduction

Recent events, news articles in the popular press, and research outside the field of economics have raised alarming questions about the sufficiency of global freshwater supplies and the potentially devastating impacts of current and future water shortages. For example, the 2008 Beijing Olympics drew attention to the problems of pollution and water shortages in China, where massive infrastructure projects are planned to address water scarcity in a country that holds 7 percent of the world's water supply but 20 percent of its people. High-profile droughts in the U.S. Southwest and Southeast, two of the country's fastest-growing regions, have focused attention on the issue of scarce water supplies in the United States. In many parts of the world, annual water use regularly exceeds annual surface water streamflow and is maintained only by depleting groundwater sources, so-called groundwater "mining" (Gibbons 1986). In India, for example, groundwater supplies are being rapidly depleted for agricultural irrigation, drinking water, and industrial use.

Climate change may affect both the long-term availability and the short-term variability of water resources in many regions. Potential regional impacts of climate change could include increased frequency and magnitude of droughts and floods, and long-term changes in mean renewable water supplies through changes in precipitation, temperature, humidity, wind intensity, duration of accumulated snowpack, nature and extent of vegetation, soil moisture, and runoff (Solomon et al. 2007). Behavioral changes associated with climate change, such as changes in demand for heating and cooling, will also affect water scarcity.

While economists have studied water resource management for many decades, they have responded in a nonalarmist fashion to the concerns raised above about water scarcity. Perhaps economists have responded in this way because these concerns remind us of debates in the 1970s about the limits to growth posed by nonrenewable energy and mineral resources, in which economists' disagreement with those in other disciplines boiled down to the failure

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of the “limits” models to incorporate the effects of substitution and technological change. In the “limits to growth” debate, economists had the empirical evidence on their side. Many of the same economic principles can be applied to the problem of water scarcity—for example, as prices rise, demand falls (through conservation in various forms), and desalination is a potential “backstop technology.”

There are, however, some important differences between the issues in the limits-to-growth debate and the problem of water scarcity. First, the barriers to efficient water use and allocation are, in large part, socially constructed. Unlike energy prices, water prices typically are not determined in markets and do not reflect resource scarcity. Allocation mechanisms are highly political, and even when faced with significant scarcity, management institutions are reluctant to raise prices. In contrast, most energy resources are privately owned, and the profit motive provides sufficient incentives for owners to consider scarcity in their dynamic extraction decisions. Second, typical property rights structures for both renewable and nonrenewable water resources ignore important spatial and temporal externalities and public goods. In many arid regions, for example, the marginal value of water left instream to support public goods may exceed its value in agricultural and other uses (Creel and Loomis 1992). In contrast, estimates of the external costs of energy consumption and production are small relative to energy market prices (Parry and Small 2005). In addition, the welfare implications of insufficient access to clean drinking water supplies in terms of human health are demonstrably very large.

This article, the second in a two-part series on the economics of water,[1] surveys selected contributions of economic research to the management of scarce water resources. The next section surveys the literature on the estimation of demand for water in both diverted uses (urban, agricultural, and industrial) and instream (recreation, habitat preservation). This is followed by discussions of efficient water pricing and water allocation and marketing across sectors. Next comes what is known about the economic efficiency and distributional impacts of large-scale water projects such as dams for irrigation and hydroelectric power. This is followed by an examination of water conservation from the perspective of efficiency and cost-effectiveness. Conclusions are offered in the final section.

Estimation of Water Demand

In nearly all markets for goods and services, scarce resources are allocated through prices, which transmit information about relative scarcity and value in use. However, in the case of water, as with many other scarce natural resources, true markets are rare. Prices for water are administratively determined, through mechanisms that are often political and rarely take economic value into account. Water prices, therefore, do not respond automatically to short-term and long-term changes in supply.

Prices set by public officials are one potential lever for managing water demand when resources are scarce. Good estimates of the price elasticity of water demand are critical to any

[1] Water quality and water scarcity are inextricably linked (e.g., abundant water supplies have little value if pollution makes them unsuitable for wildlife, recreation, drinking, irrigation, or industrial use). Although the issues are not easily separated, the first article in this series (Olmstead 2010) surveys the literature on the economics of water quality.

such effort—water managers must understand how demand will respond to changes in price. Thus, much of the economics literature on water demand has focused on the econometric estimation of demand parameters, including price elasticity. Demand estimates can also be used to measure the value of water in both its diverted and instream uses. A substantial literature on the price elasticity of water demand has existed since the 1960s (see, e.g., Howe and Lineweaver 1967), although this literature has been somewhat thin over the last decade. This section summarizes the literature on diverted (residential, agricultural, industrial) and instream demands for water.

Water Demand for Diverted Uses

The water demand function for the residential sector must include marginal prices, income, and proxies for household preferences, including household characteristics. Residential demand functions also typically control for factors such as season and weather. The literature indicates that residential water demand is inelastic at current prices. For example, in a meta-analysis of 124 estimates generated between 1963 and 1993, Espey et al. (1997) obtained an average price elasticity of −0.51, a short-run median estimate of −0.38, and a long-run median estimate of −0.64. Likewise, in a meta-analysis of almost 300 price elasticity studies conducted between 1963 and 1998, Dalhuisen et al. (2003) obtained a mean price elasticity of −0.41. Studies have found that the residential price elasticity may increase when price information is posted on water bills (Gaudin 2006), and that it may be higher under increasing-block prices (IBPs) than under uniform volumetric prices (Olmstead et al. 2007).[2]

Recent work has focused on estimating demand under IBPs, an increasingly common water price structure. The classic problem of endogenous prices in demand estimation arises from the simultaneous shifting of demand and supply, making it difficult to distinguish between price and quantity changes that are due to supply (i.e., cost) shocks and changes due to shifts in demand. IBPs present a different simultaneity concern. When marginal prices rise with consumption, price and quantity demanded are positively correlated. This has often been handled econometrically by using average rather than marginal prices to estimate price elasticities, or in some other way creating a linear approximation to the full price schedule (Nieswiadomy and Cobb 1993; Martínez-Espiñeira 2002). Other common approaches to estimating residential water demand include instrumental variables (IV) models[3] (e.g., Agthe et al. 1986; Deller et al. 1986; Nieswiadomy and Molina 1988, 1989) and discrete/continuous choice (DCC) models[4] (e.g., Hewitt and Hanemann 1995; Pint 1999; Olmstead et al. 2007; Olmstead 2009).

Unlike residential demand, water demand for industry and agriculture must be modeled as part of the general production process for the particular set of outputs generated with water

[2]Under IBPs, the marginal water price increases with consumption, so the price schedule takes the form of a staircase ascending from left to right.

[3]An IV model first estimates observed marginal prices as a function of a set of variables ("instruments") correlated with price, but uncorrelated with the error in the demand equation. Fitted prices from this first stage are regressors in the second-stage demand equation.

[4]The DCC model is a maximum likelihood model in which each observation of water demand is treated as if it could have occurred at any marginal price in the price schedule. The demand parameter estimates maximize the likelihood of observing the data.

and nonwater inputs. In both the agricultural and industrial sectors, water demand data can be difficult to obtain. Water supply in these sectors may or may not be metered, and is often free, especially where firms access raw water sources outside piped networks.

Estimating the value of water in industrial use requires isolating the value of the marginal product of water. Industrial price elasticity estimates for water tend to be higher than residential estimates and vary by industry. The literature contains only a handful of industrial elasticity estimates. Griffin (2006) reports the results of five studies (covering 1969–1992), which have elasticity estimates ranging from −0.15 for some two-digit SIC codes (Renzetti 1992a) to −0.98 for the chemical manufacturing industry (Ziegler and Bell 1984). A study of 51 French industrial facilities estimates an average demand elasticity of −0.29 for piped water, with a range of −0.10 to −0.79, depending on industry type (Reynaud 2003).

Farmers who withdraw water directly from surface sources usually incur an energy cost to convey water for irrigation, but do not typically pay a volumetric charge for the water itself. Many agricultural water demand curves are estimated for groundwater, using energy costs for pumping to construct a water price variable. Prices can also be obtained if farms purchase water from irrigation districts or other water management institutions. While the economics literature contains many estimates of agricultural water demand elasticity, the available data are rarely of sufficient quality to estimate demand functions. Other techniques commonly applied for the agricultural sector include mathematical programming (see Scheierling et al. 2006), field experiments, and hedonic methods[5] (see Colby 1989; Young 2005). A recent meta-analysis of 24 U.S. agricultural water demand studies performed between 1963 and 2004 suggests a mean price elasticity of −0.48 (Scheierling et al. 2006), although estimates vary widely and, unlike in the industrial and residential sectors, often approach zero. Estimates were found to be higher for regions where water is scarce and prices are higher.

Water Demand for Instream Uses

There is a rich economics literature on the value of improvements in water quality.[6] Recently, the value of increasing the *quantity* of water that is left instream, rather than diverted for irrigation, industry, or municipal use, has also received attention from economists.[7] There is now a substantial literature that quantifies the marginal value of surface water left instream for recreation, riparian and wetlands restoration, and other purposes in many different parts of the world. In some cases, economists have compared these values to estimates of the marginal value of water used for irrigation, often the largest competitor for scarce water. Estimating the value of instream water for recreational use or ecosystem maintenance often requires nonmarket methods such as recreational demand models, contingent valuation (CV),[8] and hedonic housing models.

[5]Hedonic methods isolate the portion of agricultural land prices that can be attributed to water supply of a particular quality and quantity.
[6]See Olmstead (2010) for a detailed review of this literature.
[7]The value of increasing instream flow highlights an area where the economics of water quality and water quantity are not easily separated. For example, one obvious direct water quality benefit of increasing streamflow is greater capacity for dilution and assimilation of pollution.
[8]CV is a survey method in which economists elicit respondents' willingness to pay for changes in the status quo (such as an increase in instream flow) by asking carefully structured questions.

Several studies have used CV surveys to estimate the benefits to local populations of resuming or increasing flows in dry or degraded rivers, which may affect several ecosystem services. Overall, these studies have found that local populations may have substantial willingness to pay for restoring these flows. For example, in Sonora, Mexico, where the Yaqui River no longer reaches the Gulf of California, residents of one local city have demonstrated a willingness to pay for restoring flows to the delta, though it is unclear which potential ecosystem service improvements are actually valued by respondents (Ojeda et al. 2008). In the United States, studies estimate a favorable benefit/cost ratio for riparian restoration projects along the Little Tennessee River in North Carolina (Holmes et al. 2004), and net benefits to purchasing water leases and farmland easements to restore a section of the Platte River near Denver, Colorado (Loomis et al. 2000). Another CV analysis suggests that there may be significant benefits to restoring flows in the Ejina River in China, which currently runs dry during the peak irrigation season (Zhongmin et al. 2003). According to a recent study (Dadaser-Celik et al. 2009), restoring flows to the Sultan Marshes in Turkey would generate significant benefits to local residents in terms of animal grazing, plant harvesting, ecotourism, and wastewater treatment. Finally, hedonic housing studies in the United States suggest that homeowners in arid regions have a significant willingness to pay for proximity to healthy riparian systems.[9]

The recreational benefits of increasing instream flow have also been estimated. Spatial and temporal dimensions appear to be particularly important for recreational demand (e.g., the economic value of water instream for recreational fishing varies seasonally and spatially). Estimates for the United States suggest that the marginal value of water for local and downstream fishing exceeds the marginal value of water for irrigation in 51 of the 67 river basins with significant irrigation, but the values are highest in the arid Southwest, where the effects on fishing of marginal changes in streamflow are greatest (Hansen and Hallam 1991). Studies of the marginal value of additional instream flows for whitewater rafting indicate that recreational rafters have significant value for additional units of flow during low-flow periods, but little value for additional increments when flows are adequate to support rafting (Daubert and Young 1979; Leones et al. 1997).

Studies have also estimated comprehensive values for multiple recreational benefits from increasing instream flow. One study found that increasing water supplies to 14 wildlife management areas in California's San Joaquin Valley, which would improve wildlife viewing, fishing, and waterfowl hunting, would have estimated benefits that exceed the marginal value of water for agriculture in the region for the same period (Creel and Loomis 1992).

Unlike the value of water withdrawn for residential, industrial, and agricultural activity, water instream is associated with nonuse value, as well as use value. For example, individuals may hold significant value for the maintenance of flow in surface water systems that support endangered species habitat (Loomis 1987).

While agricultural and urban withdrawals are often the causes of declines in instream flow, deforestation and land development may play a role as well. Economists have estimated the marginal value of alterations in water flows from these activities. For example, Pattanayak and Kramer (2001a, 2001b) demonstrate that the preservation of tropical forests in Manggarai

[9]See Bark et al. (2009) and Bark-Hodgins and Colby (2006) for analyses for Arizona.

province, Indonesia, boosts agricultural production by increasing baseflow,[10] and estimate a positive and significant elasticity of agricultural profits with respect to baseflow (for coffee and rice). In the case of land development, urbanization has negative impacts on groundwater recharge, which reduces urban areas' ability to withstand drought. Thus it may be efficient to tax the increase in impermeable surface area that results from urbanization (Cutter 2007).

Efficient Water Pricing

This section discusses the issue of efficient water pricing in the absence of markets. The literature indicates that urban water prices in many countries lie well below efficient prices (Munasinghe 1992; Renzetti 1999; Brookshire et al. 2002; Timmins 2003; Sibly 2006), with significant economic costs (Renzetti 1992b; Russell and Shin 1996b). In most cases, the efficient piped water price is the long-run marginal cost (LRMC) of supply.[11] LRMC reflects the full economic cost of water supply—the cost of transmission, treatment, and distribution; some portion of the capital cost of current reservoirs and treatment systems, as well as future facilities necessitated by current patterns of use; and the opportunity cost of both the use and nonuse value of water for other potential purposes.

The LRMC may be greater than short-run average cost, because LRMC reflects the cost of new supply acquisition, and new supplies are typically more costly to develop than current supplies (Hanemann 1997). In addition, the efficient price of nonrenewable groundwater supplies must include Hotelling rents, which account for the fact that using up nonrenewable water today will leave less for tomorrow.[12] This means that pricing all units of water at LRMC may cause utility revenues to exceed current expenses, sometimes by a wide margin (Moncur and Pollock 1988; Hall 2000). Since water utilities are usually rate-of-return regulated, the efficient way to address this issue would be to rebate net revenues from a uniform volumetric price in some lump-sum fashion. Instead, water utilities often adopt IBPs, charging something approaching LRMC for "marginal" uses (lawn-watering and the like), while meeting rate-of-return constraints through the manipulation of block cutoffs and inframarginal prices. Even if the highest-tier price in an IBP schedule does reflect LRMC, welfare losses result from subsidies to consumers facing lower-tier prices on the margin.[13]

Pricing by Informal Sector Suppliers

The urban poor in developing countries obtain water service from a wide variety of provider types, including public and private piped water monopolies in the formal sector, and informal sector suppliers such as standpipe operators, water trucks, and households with

[10]Because forests can be either net demanders or net suppliers of water, this analysis is not relevant to all forested watersheds (Pattanayak and Kramer 2001a).

[11]In some cases, charging a short-run marginal cost may be efficient (see Russell and Shin 1996a).

[12]The price of renewable water resources should also include Hotelling rents when allowable withdrawals are limited due to both physical scarcity and legal constraints from sharing with other users (Brookshire et al. 2002).

[13]A uniform marginal price with a rebate has distributional advantages over IBPs in developing countries, where large families and piped water connections shared by multiple households tend to push poor households into the upper tiers of an increasing block tariff (Boland and Whittington 2000).

connections to piped water supply that resell water to unconnected households. In most cities in developing countries, more than half the population obtains basic water service from suppliers other than the official utility (Solo 1998). Yet economists have paid little attention to the subject of informal sector water supply, where volumetric water prices can be many times the volumetric rates of piped systems (Strand and Walker 2005).

Informal sector suppliers may provide water service to households that would otherwise not have access, representing an optimal response to prevailing economic conditions. It is also possible, however, that the high volumetric rates charged by urban informal sector providers results from their exercise of market power. Water sources, such as standpipes and hydrants, may be sufficiently far apart that they give rise to local monopolies, as households are unwilling or unable to travel beyond their closest source. Rents may also arise from corruption or collusion. For example, in Jakarta, significant price–cost margins arose due to a limited number of public taps, as well as rents appropriated by public and private officials (Lovei and Whittington 1993). In Onitsha, Nigeria, tanker truck operators have been observed to be marking up prices by 500 to 1,000 percent over cost (Whittington et al. 1991), and in India, large landowners with tubewells exercise monopoly power in pricing irrigation water for their tenant farmers (Jacoby et al. 2004).

Whatever the source, the exercise of market power raises prices for households in the market and rations some households out of the market, forcing them to resort to raw water sources or other unsafe options. Given the significant welfare implications of expanding access to clean drinking water, analysis of pricing in informal water markets in developing countries is an important area for future research.

Privatization of Water Supply

Recently there has been much discussion in the popular press, as well as academic journals, concerning privatization of drinking water access in developing countries.[14] Economists have analyzed several empirical questions concerning privatization of water supply and its effect on poor households, pricing, and water utility efficiency. Regarding the effect on poor households, significant reductions in child mortality were achieved through the privatization of piped water supply in Buenos Aires, Argentina (Galiani et al. 2005). Although the causal mechanism by which this welfare improvement was achieved is unclear, the number of poor households connected to piped supplies increased post-privatization. Following the introduction of private sector participation, the share of households connected to piped water and sewerage increased in Argentina, Bolivia, and Brazil, but similar improvements were observed in control regions where public management was retained, so the improvements cannot be causally attributed to privatization (Clarke et al. 2009). Private water supply corporations in the Texas/Mexico border region that are not subject to price regulation by municipalities or state agencies appear to be more likely to connect poor communities than are public suppliers (Olmstead 2004). Thus far, the empirical evidence does not support the argument commonly made outside the economics literature that private water suppliers are less likely than public suppliers to serve poor households.

[14]For reviews of the popular and noneconomics academic literature on social conflicts over privatization, see Finnegan (2002) and Perreault (2005).

Efficiency and Pricing: Private versus Public Monopolies

Recent reviews of the literature provide support for the hypothesis that private infrastructure owners operate more efficiently than public ones across a variety of sectors (Megginson and Netter 2001). However, the provision of piped water and sanitation is one of only a few remaining natural monopolies—are private monopolies really more efficient than public ones?

Recent studies provide conflicting answers to this question. For example, estimates for the United Kingdom suggest little improvement in productivity when public management was replaced by privatized water and sewerage providers (Saal and Parker 2001). In the United States, an efficiency advantage has been estimated for private providers, but only among operators of small water utilities; large utilities appear to be run more efficiently by public providers (Bhattacharyya et al. 1995). Estache and Rossi (2002) find no difference in the efficiency of public and private water utilities among 50 firms in 29 Asian countries.

In theory, the prices of private water suppliers could be either higher or lower than those of public suppliers, depending on the cost savings (if any) achieved by private operators, profits earned, and the interaction of private operators' cost savings and profit-taking with water price regulation. Empirical evidence suggests that in both France (Chong et al. 2006) and Spain (Martínez-Espiñeira et al. 2009) prices are higher, on average, when utilities are managed in whole or in part by private investors. Prices also increased in the United Kingdom after water sector privatization (Saal and Parker 2001).

Water Allocation and Marketing Across Sectors

To the extent that prices do not accurately reflect the economic value of water in various uses (and water instream, like many public goods, lacks an observable measure of social value), allocation of scarce water across sectors is likely inefficient. In theory, the development of markets (i.e., permitting voluntary, mutually beneficial trades) can result in water moving to its highest-valued uses, and the potential gains from water trading have attracted the attention of economists for many decades (Hartman and Seastone 1970; Vaux and Howitt 1984; Saliba and Bush 1987).[15]

Informal water markets are common. For example, in India and Pakistan, farmers who can afford large groundwater wells with diesel or electric pumps sell water to smaller farmers who cannot afford such infrastructure, with payment taking the form of cash, labor, or share farming (Bjornlund and McKay 2002). However, given the potential gains from trade, formal, intersectoral water markets have been slow to develop (Easter et al. 1998). This may be because the transaction costs for water marketing can be quite high. These costs include the costs of physical infrastructure necessary for transporting water from sellers to buyers, search costs (i.e., identifying willing buyers and sellers), and the legal costs of creating and enforcing

[15]Water marketing is not the only way that water can be reallocated across sectors to address inefficiencies in the current allocation of supplies. Other potential allocation mechanisms include: administrative transfers, forfeiture and abandonment proceedings under state law, public agency exercise of eminent domain, legal challenges to existing water allocation, legislative settlements of conflicting claims (at the federal and state levels), and redesign of large-scale water projects to favor different sets of users (Colby 1990).

contracts and obtaining regulatory permission. Carey et al. (2002) find that transaction costs reduce trading and favor trades among closely affiliated farms, that trades external to local networks are, on average, larger than local trades in the presence of transaction costs, and that the gains from trade decrease with transaction costs, especially for smaller networks of farms. Nonetheless, many studies have demonstrated potential and realized net benefits from trading, in areas as diverse as south Texas (Chang and Griffin 1992), southern Italy and Spain (Pujol et al. 2006), north-central Chile (Hearne and Easter 1997), Morocco (Diao and Roe 2003), and southeast Australia (Bjornlund and McKay 2002).

The Largest Markets

The largest intra- and inter-sectoral water markets have developed in Chile, Australia, and the American West. Chile's 1981 National Water Code established freely tradable water rights separate from land rights. Significant trading has taken place in north-central Chile, but transactions have been quite rare in other parts of Chile (though more common in arid regions and during droughts), perhaps due to constraints posed by physical geography, infrastructure, legal and administrative complications, and cultural resistance by farmers (Bauer 2004). Chile's water code deals inadequately with externalities. Consumptive rights are rights to full use of the water, with no return flows required.

Australia's Murray-Darling river basin covers 14 percent of the total Australian land area and supports major agricultural production. Until 1980, withdrawal rights for irrigation in the basin were essentially unlimited. Water trading was introduced in South Australia in 1983, in New South Wales in 1989, and in Victoria in 1991. Permanent interstate transfers are not allowed, and there are significant limitations on inter-regional sales, but intra-regional trading is active. A cap on water use in the basin was enacted in 1997. Trade appears to have led to both higher-value agricultural production and more efficient irrigation technologies (Bjornlund and McKay 2002).

In the American West, relative prices provide signals of the potential for gains from water trading. Farmers in Arizona's Pima County pay $27 per acre-foot, and water customers in the nearby city of Tucson pay $479–$3267 per acre-foot (Brewer et al. 2008). In Texas' Rio Grande Valley, the value of water in agriculture has been estimated at $300–$2,300 per acre-foot, and in urban uses at $6,500–$21,000 per acre-foot (Griffin and Boadu 1992). While these prices and values are for different commodities (raw water versus treated, piped water), the sharp differences in marginal water values across sectors are also products of inefficient pricing, historic water rights allocations, and subsidized irrigation projects (Wahl 1989).

A recent study of water marketing in twelve western states between 1987 and 2005 suggests that prices are higher, on average, for agricultural to urban transfers than for transfers between agricultural producers, and that this difference is growing over time (Brewer et al. 2008). Water right sales are increasingly more common than short- and long-term leases, and states with the most urban growth appear to engage in the most water trading.

An economic analysis of water market prices suggests that the significant price dispersion apparent in U.S. western markets may be due to the fact that water is a complex, multidimensional commodity (both legally and hydrologically); there are few potential traders in many markets, and they may be of disparate size; and the information flows and linkages in such markets may be insufficient to allow prices to converge (Colby et al. 1993). Statistical estimates of the relationship between water market transaction prices and the characteristics of individual transactions in New Mexico support these hypotheses. For example, water rights of higher seniority (which are more likely to be honored in dry years than junior rights) tend to trade at higher prices, higher volume trades result in lower per-unit prices (suggesting economies of scale), and rights allowing more flexibility in the place and purpose of use command higher prices (Colby et al. 1993). A more recent study of trades in Arizona, Colorado, and New Mexico water markets suggests that water prices are lower in wetter periods (supply shifting out) and that income growth (demand shifting out) drives up prices, findings that are consistent with standard economic theory (Brookshire et al. 2004). In addition, areas with higher-valued agricultural productivity tend to have a lower quantity of water traded (Brookshire et al. 2004).

Many of the low observed prices for agricultural irrigation water in the United States result from federal subsidies. It is interesting to examine the interaction of these subsidies with water markets. If the benefits of historical irrigation projects were capitalized into the land prices prevailing at that time, historical landowners reaped windfall profits from federal projects if they sold their land (Sax 1965). This means that current landowners, while they may have paid for water rights when they purchased their properties, essentially receive a "second wave" of windfall profits when they sell water to U.S. cities today. This raises interesting distributional questions for future research.

Externalities and Water Markets

One of the biggest challenges to welfare improvement from water marketing is dealing adequately with externalities and public goods. The externalities to nonrenewable groundwater extraction in common property settings are well-studied (Provencher and Burt 1993), and these externalities complicate water marketing in regions where groundwater is an important resource (Hanak 2005). Return flows present another important externality. For example, irrigation water not lost to evapotranspiration either recharges groundwater aquifers or augments surface water flows; water transferred to coastal cities may be returned to the ocean through offshore wastewater outfall systems (and urban uses, in general, have a higher consumptive component). The spatial component of water withdrawals and return flows is, therefore, an important consideration in water trading, just as the location of emissions is an important consideration in market-based approaches to water quality regulation. When instream flows have value, water market outcomes can be Pareto optimal only when transferable diversion and consumption rights are established, return flow coefficients are established to identify the location of each diverter's return, and institutional mechanisms are established to create a market presence for instream flow values (Griffin and Hsu 1993).

There may also be important positive externalities to water trading. Agricultural drainage may be highly polluted, particularly in arid regions where salinity and drainage problems arise from long-term irrigation. Water marketing in such regions allows farmers to sell water to other users, thus reducing farmers' incentives to apply irrigation water in excess of crop requirements (to leach accumulated salts out of the soil) and producing external water quality benefits (Dinar and Letey 1991; Weinberg et al. 1993).

Efficiency of Large-Scale Water Projects

The effects of inefficient pricing have been exacerbated in many countries by large-scale, publicly subsidized water projects for irrigation, flood control, hydropower, and urban and rural water supply.

Water Projects in the United States

Water development projects in the American West were among the earliest formal subjects of benefit–cost analysis by economists. In the numerous case studies of federal irrigation projects examined by Wahl (1989), historical and current subsidies exceed 85 percent of construction costs. These subsidies take many forms, including interest-free repayment by farmers, below-market interest rates, deferral of payments without interest, and the basing of irrigators' repayment requirements on federal estimates of ability to pay rather than willingness to pay. Disregard for important externalities, such as effects on instream flow and water quality (particularly salinity), and risks related to dam safety, represent additional implicit subsidies.

Although new federal water projects are less common today, recent research suggests that newer projects may also be inefficient. For example, an economic analysis of the Central Arizona Project, which was completed in 1987 and provides water to the city of Phoenix, suggests that the project was built 86 years too early, with a deadweight loss of more than $2.6 billion, and that exploiting groundwater sources to delay its construction would have been more efficient (Holland and Moore 2003). Further research suggests that the national welfare losses might have been reduced very significantly had the project been constructed by a private, rather than a public, institution (Holland 2006). While these types of projects generally have significant net costs at the national level, they result in significant net benefits locally. For example, the Central Arizona Project's net benefit to Arizona was almost $1 billion, and the timing was almost optimal from the state's perspective (Holland and Moore 2003).

Water Projects in Developing Countries

Developing countries, particularly India, China, and Brazil, have increasingly pursued large-scale water projects as tools for development and poverty reduction. By 2000, at least 45,000 large dams had been constructed worldwide for the purposes of water development or energy supply, and nearly one-half of the world's rivers had at least one large dam (World Commission on Dams 2000). Until recently, the welfare impacts of such projects received little formal attention from economists. Designing studies to assess the development impacts of large-scale infrastructure projects is complicated by several statistical issues, most importantly the possibility of endogenous placement of such projects.

The benefits typically cited for large-scale water projects include agricultural development and rural poverty alleviation, through reduced influence of weather shocks for farmers and the introduction of hydropower. In a study of India, Duflo and Pande (2007) show that dam construction leads to significant increases in irrigated area and agricultural production in downstream districts. But dams do not significantly impact agricultural production in the districts in which they are constructed, and they appear to increase the vulnerability of farmers in these districts to rainfall shocks. Duflo and Pande (2007) also find that dams increase rural poverty in the districts where they are located and decrease poverty downstream, and that the effects of upstream poverty increases outweigh the downstream benefits, offering evidence that the projects are not, on average, welfare-improving. However, their analysis does not measure the benefits of electricity generation from dams. Lipscomb et al. (2008) assess the impacts in Brazil of electrification through the construction of hydropower dams, and find that electrification in a county raises the value of the housing stock, increases employment, raises average incomes, reduces the poverty head count ratio (i.e., the fraction of a population with incomes below the official poverty threshold set by the national government), and raises the county's UNDP Human Development Index score (which is an index comprising measures of life expectancy, education, and GDP). Given the amount spent worldwide on such projects (by countries as well as multilateral lending institutions), developing a better understanding of the welfare impacts of large water projects in developing countries is a critical area for future research.

Impacts of Dam Removal

With increasing values for instream water (for recreational use; habitat for fish, birds, and other wildlife), some industrialized countries have been considering the welfare impacts of dam removal. A study of the removal of the Edwards dam and alteration of two other dams on Maine's Kennebec River in 1999 (undertaken largely to encourage the return of anadromous fish to the river above the dam sites) finds that the project may have increased property values (Lewis et al. 2008). There is also some evidence that local property values may be more favorably affected by frontage along free-flowing rivers than by frontage along the lakes created by small dams along those rivers, suggesting that the removal of small dams may improve property values (Provencher et al. 2008).

Recreational use of rivers may also increase after dams are removed. A study of recreational use of the Lower Snake River by Pacific Northwest households (Loomis 2002) suggests that the gain in river recreation after the removal of four dams exceeds the loss in reservoir recreation (since removing dams eliminates the reservoirs created behind them). However, the study also found that in this case recreational benefits alone are not sufficient to justify the costs of dam removal. Another study found that a federal requirement that two hydroelectric dams on the Manistee River in Michigan switch from peak-flow to run-of-river flow operation had net benefits when electricity production costs, air quality benefits, and recreational fishing benefits due to habitat improvements are taken into account (Kotchen et al. 2006). Households may also have substantial nonuse value for dam removal when it benefits endangered species populations, as demonstrated for salmon and steelhead runs in the Pacific Northwest (Loomis 1996). While economic models may be sufficient to estimate the impacts of dam removal on recreational uses, property values, and other implicit market effects, understanding whether dam removal is a cost-effective strategy for habitat recovery or species preservation requires close cooperation between economists and natural scientists (Halsing and Moore 2008).

Economics of Water Conservation

Water conservation generally refers to the *technical* water savings that can be achieved through a particular technology or policy intervention. An economic definition of water conservation, however, requires that the benefits of a technology or policy exceed its costs (Bauman et al. 1984). Even when water prices and allocation across sectors are inefficient, water managers can choose policy instruments to reduce water consumption that minimize the cost of achieving such reductions. Decades of theoretical and empirical economic analysis suggest that market-based environmental policies are more cost-effective than prescriptive policies. Cost-effective water conservation policies would typically require raising water prices in some form or another, rather than implementing technology standards or rationing policies, the two most common prescriptive, or command-and-control (CAC), approaches (Olmstead and Stavins 2009). This section discusses what the literature shows about the effectiveness of CAC and price-based approaches for reducing water consumption.

Technology Standards

Technology standards are common policy instruments for long-run water conservation. However, estimates of the actual water savings from technology standards have often been smaller than expected due to behavioral changes that partially offset the benefit of greater technical efficiency—the well-known "rebound effect" from studies of energy efficiency standards (Greening et al. 2000). For example, in a recent field trial, when randomly selected households had their top-loading clothes-washers replaced by front-loading models, their average clothes-washing increased by 5.6 percent, perhaps due to the cost savings associated with increased efficiency (Davis 2008). The U.S. federal plumbing fixture standards, passed as part of the National Energy Policy Act of 1992, may also have seen a significant rebound effect (Wallander 2009).

Few empirical economic analyses have estimated the welfare losses from water conservation technology standards. However, using data from 13 groundwater-dependent California cities, Timmins (2003) compared a mandatory low-flow appliance regulation with a modest water price increase and found that under all but the least realistic of assumptions, prices were more cost-effective than technology standards in reducing groundwater aquifer lift-height in the long run.

Rationing Policies

Rationing policies for short-run water conservation are ubiquitous. For example, during a 1987–1992 drought in California, 65–80 percent of urban water utilities implemented outdoor watering restrictions (Dixon et al. 1996). In 2008, 75 percent of Australians lived in communities with some form of mandatory water use restrictions (Grafton and Ward 2008). However, rationing policies are not efficient. Grafton and Ward (2008) find that mandatory water restrictions in Sydney, Australia, in 2004–2005, resulted in economic losses of $235 million, about $150 per household, or one-half the average household water bill in Sydney in that year. Brennan et al. (2007) also demonstrate that outdoor watering restrictions generate efficiency losses. An experimental study simulating water consumption from a common pool predicts that consumer heterogeneity generates economic losses from CAC water conservation policies (Krause et al. 2003).[16]

[16] A CV study suggests that Colorado towns with a high probability of water supply shortages are not willing to pay to reduce the probability of water restrictions, and that a city with a low probability of water restrictions

Other studies demonstrate that replacing rationing policies with price increases can substantially reduce the economic cost of achieving short-run water consumption reductions. For example, Collinge (1994) shows that a municipal water trading system can reduce costs significantly over a CAC approach. Empirical studies provide additional evidence supporting price-based policies. For example, a study of 11 urban areas in the United States and Canada compared residential outdoor watering restrictions with drought pricing in the short run (Mansur and Olmstead 2007). The study found that for an aggregate demand reduction equivalent to a two-day-per-week outdoor watering restriction, a market-clearing price would result in gains of about $92 per household per summer, about 30 percent of what the average household in the study sample spent each year on water. Brennan et al. (2007) arrived at similar short-run conclusions: the economic costs of a two-day-per-week sprinkling restriction in Perth, Australia (relative to a price-based approach), are just under $100 per household per season, while the costs of a complete outdoor watering ban range from $347–$870 per household per season. Although nonprice conservation programs can reduce water consumption,[17] both economic theory and the emerging empirical estimates suggest that using price increases to reduce demand, and allowing consumers to adjust their end-uses of water, is more cost-effective than implementing nonprice demand management programs.

Conclusion

This article has reviewed the contributions of economics to the literature on managing scarce water resources. In assessing this literature, we have considered the estimation of water demand in diverted uses and instream uses, water pricing, water allocation and marketing across sectors, the efficiency of large-scale water infrastructure projects, and water conservation.

Since water is not commonly exchanged in markets, and prices are set by water managers and, in some cases, politicians, research on the economics of water demand and the estimation of price elasticities have made price a more useful potential lever for managing water demand. The welfare gains from water marketing across sectors and the significant potential welfare losses from large-scale water infrastructure projects have also been highlighted by economic research over the past three decades. Unfortunately, the results of this research do not appear to have had a strong effect on water policy, as there are many examples of inefficient water allocation and water projects that have been constructed at net social loss. The influence of standard economic principles on the choice of water conservation policies also appears to have been relatively weak, since technology standards and water rationing remain the most common approaches.

Should economists be more actively involved in the debate about the sufficiency and quality of global water supplies to support growing populations and increasing water demand? As mentioned in the introduction, in some ways the debate reflects principles similar to those

may be willing to accept compensation, through reduced water bills, for an increased probability of water restrictions (Howe et al. 1994).

[17] For example, public information campaigns, retrofit subsidies, water rationing, and mandatory water use restrictions had negative and statistically significant impacts on average monthly residential water use in California during the 1990s, and the more stringent policies had stronger effects than voluntary policies and education programs (Renwick and Green 2000).

in earlier debates over the limits posed by natural resource scarcity (i.e., that substitution possibilities and technological change mitigate scarcity). Moreover, there is an important additional factor supporting the economic optimists in the water debate that was lacking in the earlier energy resources debate. That is, since water prices have historically been far below efficient prices, water price increases in the agricultural, municipal, and industrial sectors may go a long way toward ameliorating the problem of water shortages.

However, as competing demands for water exceed supply in more and more regions of the world, economics clearly has much to contribute to the design of water policy. The significant potential welfare gains from providing clean drinking water to the 1.1 billion people worldwide who currently lack it suggest the need for economists to strengthen both their research focus and their engagement in domestic and international policy decisions regarding water supply, pricing in the formal and informal sectors, and privatization. As water resources are increasingly diverted for municipal and agricultural purposes, the marginal value of water left instream rises. Although over the last decade economists have increasingly focused on estimating values for instream public goods, additional estimates of instream values and methods for reliable benefits transfer will be critical inputs to public policy decisions regarding future water allocation. Further economic research on water market structures, externalities, and distributional impacts may also help reduce the significant legal and institutional constraints on trading and improve the welfare impacts of trading where it is already taking place. Given the prevalence of current and planned large-scale water projects worldwide, which are being justified on development grounds, there is also a need for further work by economists to examine these projects' costs, benefits, and distributional impacts.

References

Agthe, Donald E., R. Bruce Billings, John L. Dobra, and Kambiz Raffiee. 1986. A simultaneous equation demand model for block rates. *Water Resources Research* 22:1–4.

Antwander, Lars, and Teofilo J. R. Ozuna. 2002. Can public sector reforms improve the efficiency of public water utilities? *Environment and Development Economics* 7:687–700.

Bark, R. H., D. E. Osgood, B. G. Colby, G. Katz, and J. Stromberg. 2009. Habitat preservation and restoration: Do homebuyers have preferences for quality habitat? *Ecological Economics* 68:1465–75.

Bark-Hodgins, Rosalind, and Bonnie G. Colby. 2006. An economic assessment of the Sonoran Desert Conservation Plan. *Natural Resources Journal* 46:709–25.

Bauer, Carl J. 2004. Results of Chilean water markets: Empirical research since 1990. *Water Resources Research* doi:10.1029/2003WR002838.

Baumann, Duane D., John J. Boland, and John H. Sims. 1984. Water conservation: The struggle over definition. *Water Resources Research* 20:428–34.

Bhattacharyya, Arunava, Thomas R. Harris, Rangesan Narayanan, and Kambiz Raffiee. 1995. Specification and estimation of the effect of ownership on the economic efficiency of the water utilities. *Regional Science and Urban Economics* 25:759–84.

Bjornlund, Henning, and Jennifer McKay. 2002. Aspects of water markets for developing countries: Experiences from Australia, Chile, and the US. *Environment and Development Economics* 7:769–95.

Boland, John J., and Dale Whittington. 2000. The political economy of water tariff design in developing countries: Increasing block tariffs versus uniform price with rebate. In *The Political Economy of Water Pricing Reforms*, ed. Ariel Dinar, 215–35. New York: Oxford University Press.

Brennan, Donna, Sorada Tapsuwan, and Gordon Ingram. 2007. The welfare costs of urban outdoor water restrictions. *Australian Journal of Agricultural and Resource Economics* 51:243–61.

Brewer, Jedidiah, Robert Glennon, Alan Ker, and Gary Libecap. 2008. Water markets in the West:

Prices, trading, and contractual forms. *Economic Inquiry* 46:91–112.

Brookshire, David S., Bonnie Colby, Mary Ewers, and Philip T. Ganderton. 2004. Market prices for water in the semiarid West of the United States. *Water Resources Research* doi:10.1029/2003WR002846.

Brookshire, David S., H. Stuart Burness, Janie M. Chermak, and Kate Krause. 2002. Western urban water demand. *Natural Resources Journal* 42:873–98.

Carey, Janis, David L. Sunding, and David Zilberman. 2002. Transaction costs and trading behavior in an immature water market. *Environment and Development Economics* 7:733–50.

Chang, Chan, and Ronald C. Griffin. 1992. Water marketing as a reallocative institution in Texas. *Water Resources Research* 28:879–90.

Chong, Eshien, Freddy Huet, Stéphane Saussier, and Faye Steiner. 2006. Public-private partnerships and prices: Evidence from water distribution in France. *Review of Industrial Organization* 29:149–69.

Clarke, George R. G., Katrina Kosec, and Scott Wallsten. 2009. Has private participation in water and sewerage improved coverage? Empirical evidence from Latin America. *Journal of International Development* 21:327–61.

Colby, Bonnie G. 1989. Estimating the value of water in alternative uses. *Natural Resources Journal* 29:511–27.

———. 1990. Enhancing instream flow benefits in an era of water marketing. *Water Resources Research* 26:1113–20.

Colby, Bonnie G., Kristine Crandall, and David B. Bush. 1993. Water right transactions: Market values and price dispersion. *Water Resources Research* 29:1565–72.

Collinge, Robert A. 1994. Transferable rate entitlements: The overlooked opportunity in municipal water pricing. *Public Finance Quarterly* 22:46–64.

Creel, Michael, and John Loomis. 1992. Recreation value of water to wetlands in the San Joaquin Valley: Linked multinomial logit and count data trip frequency models. *Water Resources Research* 28:2597–606.

Cutter, W. Bowman. 2007. Valuing groundwater recharge in an urban context. *Land Economics* 83:234–52.

Dadaser-Celik, Filiz, Jay S. Coggins, Patrick L. Brezonik, and Heinz G. Stefan. 2009. The projected costs and benefits of water diversion from and to the Sultan Marshes (Turkey). *Ecological Economics* 68:1496–506.

Dalhuisen, Jasper M., Raymond J. G. M. Florax, Henri L. F. de Groot, and Peter Nijkamp. 2003. Price and income elasticities of residential water demand: A meta-analysis. *Land Economics* 79:292–308.

Daubert, John T., and Robert A. Young. 1979. Economic benefits from instream flow in a Colorado mountain stream. Colorado Water Resources Research Institute Completion Report No. 91.

Davis, Lucas W. 2008. Durable goods and residential demand for energy and water: Evidence from a field trial. *RAND Journal of Economics* 39:530–46.

Deller, Steven C., David L. Chicoine, and Ganapathi Ramamurthy. 1986. Instrumental variables approach to rural water service demand. *Southern Economic Journal* 53:333–46.

Diao, Xinshen, and Terry Roe. 2003. Can a water market avert the "double-whammy" of trade reform and lead to a "win-win" outcome? *Journal of Environmental Economics and Management* 45:708–23.

Dinar, Ariel, and J. Letey. 1991. Agricultural water marketing, allocative efficiency, and drainage reduction. *Journal of Environmental Economics and Management* 20:210–23.

Dixon, Lloyd S., Nancy Y. Moore, and Ellen M. Pint. 1996. *Drought Management Policies and Economic Effects in Urban Areas of California, 1987–1992.* Santa Monica, CA: RAND Corporation.

Duflo, Esther, and Rohini Pande. 2007. Dams. *Quarterly Journal of Economics* 122:601–46.

Easter, K. William, Mark W. Rosegrant, and Ariel Dinar, eds. 1998. *Markets for water: Potential and performance.* Dordrecht: Kluwer Academic.

Espey, Molly, James Espey, and W. Douglass Shaw. 1997. Price elasticity of residential demand for water: A meta-analysis. *Water Resources Research* 33:1369–74.

Estache, Antonio, and Martín A. Rossi. 2002. How different is the efficiency of public and private water companies in Asia? *World Bank Economic Review* 16:139–48.

Finnegan, William. 2002. Leasing the rain. *The New Yorker*, 8 April.

Galiani, Sebastian, P. Gertler, and E. Schargrodsky. 2005. Water for life: The impact of the privatization of water supply on child mortality. *Journal of Political Economy* 113:83–120.

Gaudin, Sylvestre. 2006. Effect of price information on residential water demand. *Applied Economics* 38:383–93.

Gibbons, Diana C. 1986. *The Economic Value of Water*. Washington, DC: Resources for the Future.

Grafton, R. Quentin, and Michael Ward 2008. Prices versus rationing: Marshallian surplus and mandatory water restrictions. *Economic Record* 84:S57–65.

Greening, Lorna A., David L. Greene, and Carmen Difiglio. 2000. Energy efficiency and consumption—The rebound effect—A survey. *Energy Policy* 28:389–401.

Griffin, Ronald C. 2006. *Water Resource Economics: The Analysis of Scarcity, Policies, and Projects*. Cambridge, MA: MIT Press.

Griffin, Ronald C., and Shih-Hsun Hsu. 1993. The potential for water market efficiency when instream flows have value. *American Journal of Agricultural Economics* 75:292–303.

Griffin, Ronald C., and Fred O. Boadu. 1992. Water marketing in Texas: Opportunities for reform. *Natural Resources Journal* 32:265–88.

Hall, Darwin C. 2000. Public choice and water rate design. In *The political economy of water pricing implementation*, ed. Ariel Dinar, 189–212. New York: Oxford University Press.

Halsing, David L., and Michael R. Moore. 2008. Cost-effective management alternatives for Snake River Chinook salmon: A biological-economic synthesis. *Conservation Biology* 22:338–50.

Hanak, Ellen. 2005. Stopping the drain: Third-party responses to California's water market. *Contemporary Economic Policy* 23:59–77.

Hanemann, W. Michael. 1997. Prices and rate structures. In *Urban water demand management and planning*, ed. D. Baumann, J. Boland, and W. M. Hanemann, 137–79. New York: McGraw-Hill.

Hansen, LeRoy T., and Arne Hallam. 1991. National estimates of the recreational value of streamflow. *Water Resources Research* 27:167–75.

Hartman, L. M., and D. Seastone. 1970. *Water transfers: Economic efficiency and alternative institutions*. Baltimore, MD: Johns Hopkins University Press.

Hearne, Robert R., and K. William Easter. 1997. The economic and financial gains from water markets in Chile. *Agricultural Economics* 15:187–99.

Hewitt, Julie A., and W. Michael Hanemann. 1995. A discrete/continuous choice approach to residential water demand under block rate pricing. *Land Economics* 71:173–92.

Holland, Stephen P. 2006. Privatization of water-resource development. *Environmental and Resource Economics* 34:291–315.

Holland, Stephen P., and Michael R. Moore. 2003. *Cadillac Desert* revisited: Property rights, public policy and water-resource depletion. *Journal of Environmental Economics and Management* 46:131–55.

Holmes, Thomas P., John C. Bergstrom, Eric Huszar, Susan B. Kask, and Fritz Orr III. 2004. Contingent valuation, net marginal benefits, and the scale of riparian ecosystem restoration. *Ecological Economics* 49:19–30.

Howe, Charles W., and F. P. Lineweaver. 1967. The impact of price on residential water demand and its relation to system demand and price structure. *Water Resources Research* 3:13–32.

Howe, Charles W., Mark Griffin Smith, Lynne Bennet, Charles M. Brendecke, J. Ernest Flack, Robert M. Hamm, Roger Mann, Lee Rozaklis, and Karl Wunderlich. 1994. The value of water supply reliability in urban water systems. *Journal of Environmental Economics and Management* 26:19–30.

Jacoby, Hanan G., Rinku Murgai, and Saeed Ur Rehman. 2004. Monopoly power and distribution in fragmented markets: The case of groundwater. *Review of Economic Studies* 71:783–808.

Kotchen, Matthew J., Michael R. Moore, Frank Lupi, and Edward S. Rutherford. 2006. Environmental constraints on hydropower: An ex-post benefit–cost analysis of dam relicensing in Michigan. *Land Economics* 82:384–403.

Krause, Kate, Janie M. Chermak, and David S. Brookshire. 2003. The demand for water: Consumer response to scarcity. *Journal of Regulatory Economics* 23:167–91.

Leones, Julie, Bonnie Colby, Dennis Cory, and Liz Ryan. 1997. Measuring regional economic impacts of streamflow depletions. *Water Resources Research* 33:831–38.

Lewis, Lynne Y., Curtis Bohlen, and Sarah Wilson. 2008. Dams, dam removal, and river restoration: A hedonic property value analysis. *Contemporary Economic Policy* 26:175–86.

Lipscomb, Molly, A. Mushfiq Mobarak, and Tania Barham. 2008. Returns to electricity: Evidence from the quasi-random placement of hydropower plants in Brazil. Working Paper, Yale School of Management.

Loomis, John B. 1987. The economic value of instream flow: Methodology and benefit estimates for optimum flows. *Journal of Environmental Management* 24:169–79.

———. 1996. Measuring the economic benefits of removing dams and restoring the Elwha River: Results of a contingent valuation survey. *Water Resources Research* 32:441–47.

———. 2002. Quantifying recreation use values from removing dams and restoring free-flowing rivers: A contingent behavior travel cost demand model for the Lower Snake River. *Water Resources Research* doi:10.1029/2000WR000136.

Loomis, John, Paula Kent, Liz Strange, Kurt Fausch, and Alan Covich. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: Results from a contingent valuation survey. *Ecological Economics* 33:103–17.

Lovei, Laszlo, and Dale Whittington. 1993. Rent-extracting behavior by multiple agents in the provision of municipal water supply: A study of Jakarta, Indonesia. *Water Resources Research* 29:1965–74.

Mansur, Erin T., and Sheila M. Olmstead. 2007. The value of scarce water: Measuring the inefficiency of municipal regulations. NBER Working Paper No. 13513.

Martínez-Espiñeira, Roberto, Maria A. García-Valiñas, and Francisco González-Gómez. 2009. Does private management of water supply services really increase prices? An empirical analysis in Spain. *Urban Studies* 46:923–45.

Martínez-Espiñeira, Roberto. 2002. Residential water demand in the northwest of Spain. *Environmental and Resource Economics* 21:161–87.

Megginson, William L., and Jeffrey M. Netter. 2001. From state to market: A survey of empirical studies on privatization. *Journal of Economic Literature* 39:321–89.

Moncur, James E. T., and Richard L. Pollock. 1988. Scarcity rents for water: A valuation and pricing model. *Land Economics* 64:62–72.

Munasinghe, Mohan.1992. *Water supply and environmental management: Developing world applications.* Boulder, CO: Westview Press.

Nieswiadomy, Michael L., and David J. Molina. 1988. Urban water demand estimates under increasing block rates. *Growth and Change* 19: 1–12.

———. 1989. Comparing residential water demand estimates under decreasing and increasing block rates using household data. *Land Economics* 65:280–89.

Nieswiadomy, Michael L., and S. L. Cobb. 1993. Impact of pricing structure selectivity on urban water demand. *Contemporary Policy Issues* 11:101–13.

Ojeda, Monica Ilija, Alex S. Mayer, and Barry D. Solomon. 2008. Economic valuation of environmental services sustained by water flows in the Yaqui River Delta. *Ecological Economics* 65:155–66.

Olmstead, Sheila M. 2004. Thirsty *colonias*: Rate regulation and the provision of water service. *Land Economics* 80:36–150.

———. 2009. Reduced-form vs. structural models of water demand under non-linear prices. *Journal of Business and Economic Statistics* 27:84–94.

———. 2010. The economics of water quality. *Review of Environmental Economics and Policy* 4(1): 44–62.

Olmstead, Sheila M., and Robert N. Stavins. 2009. Comparing price and non-price approaches to urban water conservation. *Water Resources Research* doi:10.1029/2008WR007227.

Olmstead, Sheila M., W. Michael Hanemann, and Robert N. Stavins. 2007. Water demand under alternative price structures. *Journal of Environmental Economics and Management* 54:181–98.

Parry, Ian, and Kenneth A. Small. 2005. Does Britain or the United States have the right gasoline tax? *American Economic Review* 95:1276–89.

Pattanayak, Subhrendu K., and Randall A. Kramer. 2001a. Pricing ecological services: Willingness to pay for drought mitigation from watershed protection in eastern Indonesia. *Water Resources Research* 37:771–78.

———. 2001b. Worth of watersheds: A producer surplus approach for valuing drought mitigation in Eastern Indonesia. *Environment and Development Economics* 6:123–46.

Perreault, Thomas. 2005. State restructuring and the scale politics of rural water governance in Bolivia. *Environment and Planning A* 37:263–84.

Pint, Ellen M. 1999. Household responses to increased water rates during the California drought. *Land Economics* 75:246–66.

Provencher, Bill, and Oscar Burt. 1993. The externalities associated with the common property exploitation of groundwater. *Journal of Environmental Economics and Management* 24:139–58.

Provencher, Bill, Helen Sarakinos, and Tanya Meyer. 2008. Does small dam removal affect local property values? An empirical analysis. *Contemporary Economic Policy* 26:187–97.

Pujol, Joan, Meri Raggi, and Davide Viaggi. 2006. The potential impact of markets for irrigation water in Italy and Spain: A comparison of two study areas. *Australian Journal of Agricultural and Resource Economics* 50:361–80.

Renwick, Mary E., and Richard D. Green. 2000. Do residential water demand side management policies measure up? An analysis of eight California water agencies. *Journal of Environmental Economics and Management* 40:37–55.

Renzetti, Steven. 1992a. Estimating the structure of industrial water demands: The case of Canadian manufacturing. *Land Economics* 68:396–404.

———. 1992b. Evaluating the welfare effects of reforming municipal water prices. *Journal of Environmental Economics and Management* 22:147–63.

———. 1999. Municipal water supply and sewage treatment: Costs, prices, and distortions. *Canadian Journal of Economics* 32:688–704.

Reynaud, Arnaud. 2003. An econometric estimation of industrial water demand in France. *Environmental and Resource Economics* 25: 213–32.

Russell, Clifford, and Boo-Shig Shin. 1996a. An application and evaluation of competing marginal cost pricing approximations. In *Marginal cost rate design and wholesale water markets, advances in the economics of environmental resources*, vol. 1, ed. Darwin C. Hall. Greenwich, CT: JAI Press.

———. 1996b. Public utility pricing: Theory and practical limitations. In *Marginal cost rate design and wholesale water markets, advances in the economics of environmental resources*, vol. 1, ed. Darwin C. Hall, 123–39. Greenwich, CT: JAI Press.

Saal, David S., and David Parker. 2001. Productivity and price performance in the privatized water and sewerage companies of England and Wales. *Journal of Regulatory Economics* 20:61–90.

Saliba, Bonnie Colby, and David B. Bush. 1987. *Water markets in theory and practice*. Boulder, CO: Westview Press.

Sax, Joseph L. 1965. Selling reclamation water rights: A case study in federal subsidy policy. *Michigan Law Review* 64:13–46.

Scheierling, Susanne M., John B. Loomis, and Robert A. Young. 2006. Irrigation water demand: A meta-analysis of price elasticities. *Water Resources Research* doi:10.1029/2005WR004009.

Sibly, Hugh 2006. Efficient urban water pricing. *Australian Economic Review* 39:227–37.

Solo, T. M. 1998. *Water and sanitation services for the urban poor: Small–scale providers, typology, and profiles*. Washington, DC: UNDP–World Bank Water and Sanitation Program.

Solomon, Susan, Dahe Qin, Martin Manning, Melinda Marquis, Kristen Averyt, Melinda M. B. Tignor, Henry LeRoy, Miller, and Zhenlin Chen, eds. 2007 *Climate change 2007: The physical science basis*. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge, UK: Cambridge University Press.

Strand, Jon, and Ian Walker. 2005. Water markets and demand in Central American cities. *Environment and Development Economics* 10:313–35.

Timmins, Christopher. 2003. Demand-side technology standards under inefficient pricing regimes: Are they effective water conservation tools in the long run? *Environmental and Resource Economics* 26:107–24.

Vaux, H. J., and Richard E. Howitt. 1984. Managing water scarcity: An evaluation of interregional transfers. *Water Resources Research* 20:785–92.

Wahl, Richard W. 1989. *Markets for federal water: Subsidies, property rights, and the Bureau of Reclamation*. Washington, DC: Resources for the Future.

Wallander, Steven. 2009. The water conservation potential of the federal plumbing fixture efficiency standards. Working Paper, Yale School of Forestry and Environmental Studies.

Weinberg, Marca, Catherine L. Kling, and James E. Wilen. 1993. Water markets and water quality. *American Journal of Agricultural Economics* 75:278–91.

Whittington, Dale, Donald T. Lauria, and Xinming Mu. 1991. A study of water vending and willingness to pay for water in Onitsha, Nigeria. *World Development* 19:179–98.

World Commission on Dams. 2000. *Dams and development: A new framework for decision-making.* London: Earthscan Publications.

Young, Robert A. 2005. *Determining the economic value of water: Concepts and methods.* Washington, DC: Resources for the Future.

Zhongmin, Xu, Cheng Guodong, Zhang Zhiqiang, Su Zhiyong, and John Loomis. 2003. Applying contingent valuation in China to measure the total economic value of restoring ecosystem services in Ejina region. *Ecological Economics* 44: 345–58.

Ziegler, Joseph A., and Stephen E. Bell. 1984. Estimating demand for intake water by self-supplied firms. *Water Resources Research* 20: 4–8.