Managing Water Demand: Price vs. Non-Price Conservation Programs

Sheila M. Olmstead
School of Forestry and Environmental Studies
Yale University

Robert N. Stavins
John F. Kennedy School of Government
Harvard University

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Executive Summary

Water management has typically been approached as an engineering problem, rather than an economic one. Water supply managers are often reluctant to use price increases as water conservation tools, instead relying on non-price demand management techniques. These include requirements for the adoption of specific technologies (such as low-flow fixtures) and restrictions on particular uses (such as lawn watering).

This paper offers an analysis of the relative merits of price and non-price approaches to water conservation. As economists, we emphasize the strong empirical evidence that using prices to manage water demand is more cost-effective than implementing non-price conservation programs. Price-based approaches also have advantages in terms of monitoring and enforcement. In terms of predictability and equity, neither policy instrument has an inherent advantage over the other. As in any policy context, political considerations are also important.

Despite empirical evidence regarding their higher costs, constituencies that prefer non-price approaches have succeeded in implementing them and preventing management through prices. We hope this report provides an impetus for change in this regard, and that public officials can demonstrate the potential for cost savings in market-based approaches to water conservation. Below, we summarize some of the important conclusions of the analysis, and we also address some common misconceptions.

Key Conclusions of This Analysis

1. Conclusions regarding the sensitivity of water demand to water prices

- On average, in the United States, a ten percent increase in the marginal price of water can be expected to diminish demand in the urban residential sector by about 3 to 4 percent. (This is equivalent to saying that U.S. residential water *price elasticity* is in the range of –0.3 to –0.4).

- The price elasticity of residential water demand is similar to that of residential electricity and gasoline demand in the United States.

- Price elasticity can be expected to be greater under higher prices, all else equal.

2. Conclusions regarding the effects of non-price conservation policies on water demand

- Estimates of the water savings attributable to non-price demand management policies such as watering restrictions and low-flow fixture subsidies vary from zero to significant savings.

- More stringent mandatory policies (when well-enforced) tend to have stronger effects than voluntary policies and education programs.

- Where water savings have been estimated from non-price approaches, they are usually smaller than expected, due to behavioral responses. For example, customers may take longer showers with low-flow showerheads, flush twice with low-flow toilets, and water lawns longer under day-of-the-week or time-of-day restrictions.

3. Conclusions regarding the comparison of price v. non-price water conservation policies

Cost-effectiveness

- Price-based approaches to water conservation are more cost-effective than non-price approaches.

- The gains from using prices as an incentive for conservation come from allowing households to respond to increased water prices in the manner of their choice, rather than by installing a particular technology or reducing particular uses, as prescribed by non-price approaches.

- A recent study of 12 cities in the United States and Canada suggests that replacing two-day-per-week outdoor watering restrictions with drought pricing could achieve the same level of aggregate water savings, along with welfare gains of approximately $81 per household per summer drought.

Impacts on utility revenues

- Utilities implementing non-price demand management programs will experience increases in total costs (from implementation, monitoring, and enforcement of the programs), and decreases in total revenues, if water demand reductions ensue.

- Utilities implementing price increases to reduce demand, at current estimates of price elasticity, will experience increases in total revenues.

Monitoring and enforcement

- Non-price demand management policies require monitoring and enforcement, since they are easy to violate (one reason for the prevalence of outdoor watering restrictions). In a study of 85 urban water utilities in California during a prolonged drought in the 1990s, more than half of customers violated quantity-of-use restrictions, where these were implemented, and compliance rates with type-of-use restrictions were also very low.

- Non-compliance in the context of pricing requires that households consume water "off-meter". Higher prices may create a greater incentive to do this, but even at substantial increases in current prices, the monitoring and enforcement requirements of a price increase are far less than those of non-price approaches.

Predictability in achieving water conservation goals

- A price elasticity estimate for a water supplier's service area will provide a very good measure of the demand response that can be expected from a price increase in that service area.

- A statistical evaluation of the water savings attributable to a non-price conservation policy will provide a very good measure of the demand response that can be expected from implementing a similar policy in the same water service area.

- In the absence of statistical estimates of either price elasticity, or the impacts of a particular non-price conservation program, neither policy has an advantage over the other in terms of predictability.

Equity and distributional concerns

- Economic analyses have demonstrated that under price-based approaches, low-income households contribute a greater share of a city's resulting aggregate water consumption reduction than they do under certain types of non-price demand management policies.

- The fact that price-based approaches are regressive in *water consumption* does not mean that they must be regressive in *income*. Progressive price-based approaches to water demand management can be designed by returning utility profits from higher prices in the form of a rebate.

- Returning profits from higher prices through a rebate mechanism will not significantly dampen the effects of the price increase on water demand, as long as the rebate is not tied to current water consumption.

- Water suppliers can use a rebate system to achieve distributional goals, if this is desired, by offering rebates inversely related to household income, or some other measure.

- The fact that non-price programs are progressive in *water consumption* does not mean that they are progressive in *income*. The impact of non-price programs on distributional equity will depend largely on how the non-price program is financed.

Political considerations

- Raising water prices (like the elimination of any subsidy) can be politically very difficult; perhaps as a result, water demand management through non-price techniques is the overwhelmingly dominant paradigm in the United States.

- The cost-effectiveness advantage of price-based approaches is now very clear. Thus, it would be useful to generate discussion of the political advantage to be gained by demonstrating this potential cost savings.

- Where communities are willing to continue to bear excessive costs from non-price demand management approaches, in exchange for the political popularity of low water prices, the tradeoffs involved in this choice should be measured and made explicit.

- Where water rate-setting officials are constrained by law from raising water prices, during droughts or in general, a discussion of the real costs of these constraints would be useful.

Clearing Up Common Misconceptions

1. Water prices are low, thus price cannot be used to manage demand.

The estimates of price elasticity offered in this study are based on current *low* water prices across the United States. The misconception that low prices obviate the use of price as an incentive for water conservation may stem from economists' definition of a price response in the range observed for water demand as "inelastic." There is a critical distinction between the technical term "inelastic demand" and the phrase "unresponsive to price". Inelastic demand will decrease by less than one percent for every one percent increase in price. In contrast, if demand is truly unresponsive to price, the same quantity of water will be demanded at any price. This may be true in theory for a subsistence quantity of drinking water, but it has not been observed for water demand in general in 50 years of published empirical analysis.

2. Water customers are unaware of prices, thus price cannot be used to manage demand.

If this common misconception were true, the hundreds of statistical studies estimating the price elasticity of water demand would have found that effect to be zero. This is not the case – water consumers behave as if they are aware of water prices. There is mixed evidence regarding the role of customer awareness of water prices in determining price responsiveness, however. Billing frequency has been shown in statistical analyses to have no effect on water customers' responsiveness to price. On the other hand, improvements in the presentation of water price and consumption information on water bills may increase customers' price responsiveness. The estimates offered in this paper are based on many decades of water demand research in cities that bill water customers monthly, every two months, quarterly, or annually; and in which bills provide everything from no information about prices, to very detailed information. In general, water suppliers need not change billing frequency or format to achieve water demand reductions from price increases, but providing more information may boost the impact of price increases.

3. Increasing-block pricing provides an incentive for water conservation.

Under increasing-block prices (IBPs), the price of one unit of water increases with the quantity consumed, based on a quantity threshold or set of thresholds. Many water utilities that have implemented IBPs consider them part of their approach to water conservation; many state agencies and other entities recommend them as water conservation tools. A study of 85 Massachusetts communities suggests that increasing-block prices, *per se*, have no impact on the quantity of water demanded, controlling for price levels.

High prices provide an incentive for water conservation. If water suppliers can only implement high prices on some consumption, perhaps because they are constrained in their rate of return, it is better to have high prices on some consumption, than low prices on all consumption. In this sense, because they involve raising prices on some water consumption, increasing-block prices can provide an incentive for water conservation. For this to be true, the quantity thresholds at which prices increase must be "relevant" for the class and type of consumption a water supplier hopes to diminish. For example, if a water supplier is concerned with reducing peak summer demand due to residential lawn-watering, then the quantity threshold at which the price jumps must be a quantity of consumption generally achieved by households watering lawns in the summer in that community.

4. Where water price increases are implemented, water demand will always fall.

Price elasticity estimates measure the reduction in demand we can expect from a one percent increase in the marginal price of water, *all else constant*. Individual water utilities may increase prices and see demand rise subsequently due to population growth, changes in weather or climate, increases in average household income, or other factors. In these cases, a price increase can reduce the rate of growth in water demand to a level below what would have been observed if prices had remained constant.

A Recommendation

The costs of non-price conservation programs are often calculated. The theoretical and empirical evidence for the cost-effectiveness of price-based approaches, in general, is strong. But specific non-price water conservation approaches can only be compared to price increases if water suppliers have a measure of the benefits of non-price conservation programs.

In this report, we summarize the available evidence on the water savings attributable to non-price water demand management policies. More important than the raw water savings induced by these programs, however, is the cost per gallon saved, in comparison with the alternative price-based approach. For example, New York City spent $290 million in the mid-1990s to replace 1.3 million household toilets with low-flow models. Is this cost, and any cost to households associated with dissatisfaction from the change, less than the cost of a price increase that would have achieved the same aggregate water savings? We cannot answer this question, and this is not uncommon, despite the vast number of non-price water conservation programs in place across the United States. We strongly recommend the increased application of benefit-cost analysis to water demand management policies.

Managing Water Demand: Price vs. Non-Price Conservation Programs

Sheila M. Olmstead and Robert N. Stavins*

While water scarcity is less severe in New England than in the arid states of the American West, cities and towns throughout Massachusetts have long struggled to manage water resources in the face of population increases, consumer demand for water-intensive landscaping and other services, and increasing costs (including environmental costs) of developing new supplies. We provide an economic perspective on water demand management through pricing and non-price conservation programs. We focus on the municipal residential sector, in large part because this sector is the primary (and often exclusive) target of demand management policies, and we supplement this with some consideration of industrial and agricultural water demand management.

In Section 1, we introduce the economic approach to water management, and in Section 2, we review the fundamental economic concepts of economic efficiency and cost-effectiveness. We define efficient water pricing, and we examine the short-run and long-run consequences of inefficient pricing. In Section 3, we review various types of water tariffs that suppliers can implement, discussing the relative prevalence as well as the strengths and weaknesses of each. Section 4 introduces the important concept of price elasticity of demand – the response of water demand to a change in price – and assesses empirical measurements of price elasticity. Section 5 summarizes the results of published studies assessing the impact of non-price water demand management programs. In Section 6, we compare price and non-price approaches, and we conclude in Section 7.

1. Introduction

Economics is the study of the allocation of scarce resources. In Massachusetts and elsewhere, there are competing demands for water, and a limited supply. In municipal settings, water is used by households for diverse activities, including drinking, bathing, and landscape maintenance. Water is also a key input to industrial processes, including cooling in electricity generation and petroleum production. And when water augments instream flows, it provides ecosystem services, such as waste assimilation and maintenance of species habitat, as well as recreational opportunities, such as fishing and rafting. During periods of scarcity, when there is insufficient supply to satisfy all potential users without limit, how should water resources be allocated?

* Olmstead is an Assistant Professor of Environmental Economics, Yale University, School of Forestry and Environmental Studies. Stavins is the Albert Pratt Professor of Business and Government, John F. Kennedy School of Government, Harvard University, and a University Fellow of Resources for the Future. The authors are grateful to the Pioneer Institute for financial support, and to Amy Dain for research assistance.

In nearly all markets for goods and services in the United States and the vast majority of other nations in the world, scarce resources are allocated through prices, which transmit important information about the relative scarcity of products and their value in use. One need only think of the recent increase in the market prices of petroleum products such as heating oil and gasoline to understand how prices transmit this valuable information. Fifty years of empirical economic analysis have demonstrated that water demand, too, is responsive to price changes, both in the short run and the long run.

True markets for water are rare, however. Prices for water are administratively determined, through price-setting mechanisms that are often political and that rarely take economic value into account. Since water prices are not set by markets, they cannot respond naturally to short-term and long-term changes in supply.

Water management has typically been approached as an engineering problem, rather than an economic one. Water supply managers are reluctant to use price increases as water conservation tools, instead relying on non-price demand management techniques. These include requirements for the adoption of specific technologies (such as low-flow fixtures) and restrictions on particular uses (such as lawn maintenance).

In the summer of 1999, hundreds of New England towns and cities implemented drought restrictions, and public officials asked citizens to water their lawns less frequently and turn off their faucets while brushing their teeth. Both theory and empirical analyses indicate that such approaches are unlikely to be effective, and when they are, they are likely to be excessively costly for what they accomplish. Along a wide variety of dimensions, prices emerge as a better tool than prescriptive approaches for managing water demand.

While allowing prices to transmit information about water scarcity would have significant social benefits, the development of truly competitive water markets, such as those for heating oil or soft drinks, is neither likely, nor is it desirable from an economic perspective. Water resources have a number of characteristics that make them particularly problematic to manage through ordinary markets.

Water resources are mobile – they flow, seep, and evaporate – making it difficult to establish and enforce exclusive property rights, the basis of an exchange economy. The same river can be tapped by many communities, firms, and recreational users as it moves through a landscape. In addition, water is a bulky commodity; its per unit value is low, making the costs of transportation and storage high relative to its overall value in use. Extensive transportation infrastructure, such as that established for oil and natural gas, is found only where water scarcity is a recurring, long-term problem and the economic value of water is very high. Also, because of the particular cost structure of piped, treated water supply, the cheapest way to serve a given population is to have one firm serve the entire market – a condition known as "natural monopoly." It would be wasteful for competing firms to establish separate treatment facilities and distribution networks to supply the same population with drinking water.

Furthermore, water supply is highly variable in time, space, and quality. Storage reservoirs are often necessary to smooth supplies. Reservoirs to mitigate periods of shortage, as well as infrastructure to manage flooding, provide public benefits, often shared by multiple communities. In addition, drinking water reservoirs can also be used for other purposes, such as recreation, irrigation, and power generation. These and other aspects of water resources provide public goods, benefits that are shared by all and whose enjoyment by one party does not diminish the ability of others to enjoy them as well.

For all of these as well as other reasons, water is a special commodity, and if it were traded on simple markets, some aspects of the economic value of water would not be captured, and it would be under-supplied in some public uses. As a result, unlike the vast stocks of fossil fuels owned by private firms producing energy products, the stocks of water that supply ecological, municipal, industrial, and agricultural functions are often publicly owned and managed. Finally, the history of public water supply and concerns about equity indicate that water is often considered a good to which people have a basic right to use (for free or at least at very low cost). Having recognized all of this, what can economic thinking in general, and the concepts of efficiency and cost-effectiveness, in particular, bring to the effective management of water resources?

2. Fundamental Economic Concepts: Efficiency and Cost-Effectiveness

In *The Wealth of Nations*, published in 1776, Adam Smith pointed out a well-known paradox regarding the usefulness of water and its price: "Nothing is more useful than water, but it will purchase scarce anything; scarce anything can be had in exchange for it." During the 1999 summer drought on the U.S. East Coast, one could "refill an 8-ounce glass with tap water 2,500 times for less than the cost of a can of soda" (Stavins 1999). Although U.S. residential water prices increased almost 10 percent faster than the rate of inflation between 1980 and 1994 (Ernst and Young 1994), U.S. water prices typically lie far below what economists consider efficient levels. This is true in urban settings, as well as in the case of agriculture.[1]

Since water is not traded in markets, we would not expect prices to adjust automatically to reflect periods of scarcity, as they do for other goods and services. Instead, most water pricing is regulated by public institutions – city councils, public utility commissions, water boards, and other entities. Given the public benefits provided by many aspects of water supply and management, this could be a good thing from an economic perspective, if these price-setting public institutions had some way to measure the true economic value of water supply and to use this information to establish economically rational water tariffs. Below, we describe the components of an efficient water price, as well as the consequences of inefficient pricing. We then turn to cost-effectiveness, a goal less difficult than efficiency to achieve.

[1] Subsidies for irrigation water in the American West approached 90 percent, on average, during the 1980s (Wahl 1989).

2.1 Efficient Water Pricing

Economics is fundamentally anthropocentric; if a change matters to any person — now or in the future — then it should, in principle, show up in an economic assessment. The economic concept of benefit is considerably broader than most non-economists seem to think.[2] From an economic perspective, water resources can be viewed as a form of natural asset that provides service flows used by people in the production of goods and services, such as agricultural output, human health, recreation, and more amorphous goods such as quality of life. This is analogous to the manner in which real physical capital assets (for example, factories and equipment) provide service flows used in manufacturing. As with real physical capital, a deterioration in the natural environment (as a productive asset) reduces the flow of services the environment is capable of providing. Ecological benefits are very much part of this picture.

Providing or protecting water resources involves active employment of capital, labor, and other scarce resources. Using these resources to provide water supplies means that they are not available to be used for other purposes. The economic concept of the "value" of water is thus couched in terms of society's willingness to make trade-offs between competing uses of limited resources, and in terms of aggregating over individuals' willingness to make these trade-offs.[3] Economists' tools of valuation were originally developed in a more limited context, one in which policy changes mostly cause changes in individuals' incomes and/or prices faced in the market. Over the last thirty years, however, these ideas have been extended to accommodate changes in the qualities of goods, to public goods that are shared by individuals, and to other non-market services such as environmental quality and human health.

The economist's task of estimating the benefits or loss of benefits resulting from a policy intervention is easiest when the benefits and costs are revealed explicitly through prices in established markets. When it comes to measuring environmental and some other impacts, however, valuing benefits is more difficult, and requires indirect methods. With markets, consumers' decisions about how much of a good to purchase at different prices reveal useful information regarding the surplus consumers gain. With non-market environmental goods, it is necessary to infer this willingness to trade off other goods or monetary amounts for additional quantities of environmental services using other techniques. Economists have developed a repertoire of techniques that fall broadly into two categories: indirect measurement and direct questioning. Both sets of valuation methods are relevant for assessing the anticipated benefits of policies regarding water resources.[4]

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[2]For a summary of myths that non-economists seem to have regarding economics, and a set of responses thereto, see: Fullerton and Stavins (1998).

[3]Reference is typically made to *willingness-to-pay* for protecting/providing water supplies or *willingness-to-accept* compensation for degradation /loss of such water resources.

[4] Economists prefer to measure trade-offs by observing the actual decisions of consumers in real markets, using so-called *revealed preference* methods. These estimation techniques are well established for measuring the conceptual trade-offs that are the basis of valuation. However, they are applicable only in limited cases. In many other situations, it is simply not possible to observe behavior that reveals people's valuations of changes in environmental goods and services. This is particularly true when the value is a passive or *non-use value*. For example, an individual may value a change in an environmental good because she wants to preserve the option of consuming it in

Thus, every environmental amenity, ecosystem service, and natural resource has multiple benefits or values to people. The sum of these economic benefits are essentially captured by people's total willingness to pay, including *use value,* the value of water in its many uses, including drinking, energy production, recreation, irrigation, and species habitat, and *non-use value,* the value of a water resource beyond that associated with particular uses. For example, some people may obtain some value from the knowledge that portions of the Colorado River are free-flowing in or near the Grand Canyon, or that wetlands fed by the Ipswich River in Massachusetts support endangered species habitat. This may be true, even if one never intends to visit these rivers. Non-use value can be associated with the mere existence of a water resource in some unspoiled form, or with a desire to leave such a resource to future generations. As water, or any other good or service, becomes more scarce, people are willing to pay more for incremental units. This inverse relationship between marginal willingness to pay, on the one hand, and quantity, on the other hand, is captured by a downward sloping demand curve.

Turning from the benefit side to the cost side, the task of estimating the costs of providing water supplies may seem straightforward, compared with the conceptual problems and empirical difficulties associated with estimating the benefits. In a relative sense, this may be true, but as one moves towards developing more precise and reliable cost estimates, significant conceptual and empirical issues arise.

The economist's notion of cost, or more precisely, *opportunity cost*, is linked with — but distinct from — everyday usage of the word. Opportunity cost is an indication of what must be sacrificed in order to obtain something. In the water resources context, it is a measure of the value of whatever must be sacrificed to make those resources available. These costs typically do not coincide with monetary outlays, the accountant's measure of costs. This may be because out-of-pocket costs fail to capture all of the explicit and implicit costs that are incurred, or it may be because some prices may themselves provide inaccurate indications of opportunity costs. Hence, the costs of providing water are the forgone social benefits due to employing scarce resources for water provision purposes, instead of putting those resources to their next best use.[5]

It has been observed over and over again in diverse markets for goods and services of various kinds that the incremental costs of providing an additional unit increase as the total quantity supplied increases. In the language of economics, there are increasing (or upward sloping) marginal costs. The costs of a gallon of water flowing out of a kitchen faucet include the costs of transmission, treatment and distribution; some portion of the capital cost of reservoirs and treatment systems, both those in existence today and those future facilities

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the future (*option value*) or because she desires to preserve the good for her heirs (*bequest value*). Still other people may envision no current or future use by themselves or their heirs, but still wish to protect the good because they believe it should be protected or because they derive satisfaction from simply knowing it exists (*existence value*). With no standard market trade-offs to observe, economists must resort to surveys in which they construct hypothetical markets, employing *stated preference*, as opposed to revealed preference methods. In the best known stated preference method, commonly known as *contingent valuation*, survey respondents are presented with scenarios that require them to trade-off, hypothetically, something for a change in the environmental good or service in question. For a comprehensive treatment of the theory and methods of environmental benefit estimation, see: Freeman (2003).

[5] Costs and benefits are thus two sides of the same coin (Cropper and Oates 1992).

necessitated by current patterns of use; and the opportunity cost in both use and non-use value of that gallon of water in other potential functions.[6] This is the *long-run marginal cost* of supplying water.

In a competitive market – which, as we have explained above, is not the context for most water resources – the quantity of a good or service provided and its price are jointly determined by the forces of supply and demand, which are closely linked with costs and benefits, as described here. In fact, the downward-sloping marginal benefit curve is the demand curve, and the upward-sloping marginal cost curve is the supply curve. Where these intersect, where demand and supply balance one another, markets achieve an equilibrium, determining quantity provided and price in the process. And that particular combination of price and quantity maximizes the difference between benefits and costs, that is, it maximizes what economists call net benefits (the sum of consumer surplus and producer surplus). This is the definition of economic efficiency, and the efficient quantity and the efficient price of any good or service.

Although this free-market interaction of supply and demand does not take place in the context of water resources, it is nevertheless the equivalency of downward-sloping marginal benefits and upward-sloping long-run marginal costs that defines the efficient quantity and price of specific water resources. This is because at this level of consumption, consumers would use water until the marginal benefits from consumption were just equal to the long-run marginal costs. Net benefits would be maximized. If water were efficiently priced, then price would – in effect – be equal to long-run marginal cost (LRMC), and consumers would face an appropriate choice from the perspective of society: consume this unit of water only if the private benefits you obtain from doing so exceed its full social cost. Thus, efficient pricing maximizes the net benefits to society of a particular water resource or set of water resources.

2.2 Contrasting Typical Water Prices with Efficient Ones

Water prices in North America typically lie below LRMC (Hanemann 1997a, Timmins 2003). This is true, in general, because water suppliers tend to price water at the short-run *average* cost of supply. The practice of average-cost pricing has arisen principally due to the fact that most U.S. water suppliers are required to cover costs, but are not permitted to earn a profit (or are permitted a low, regulated rate of return on capital investments). Thus, it is typical for a per-unit water price to recoup the average cost of supplying that unit in the short run, resulting in total revenues approximately equal to total costs.

While short-run average cost is approximately constant, LRMC is typically increasing, because cities and agricultural regions have typically tapped the cheapest water sources to develop first. Later additions to water supply are either more distant geographically in the case of surface water, deeper in underground aquifers in the case of ground water, of diminished quality, or otherwise more expensive to develop (Hanemann 1997a). LRMC is greater than short-run average cost because it reflects this higher cost of new supply acquisition. A water

[6] The use of non-renewable groundwater resources imposes another important economic cost – the value of foregone future consumption. An extensive treatment of this issue is beyond the scope of this paper. See Moncur and Pollock (1988) and National Research Council (1997) for thorough discussions of groundwater valuation and pricing.

supplier charging LRMC for all units of water sold would earn total revenues in excess of total costs, that is, a profit. In Section 3, we discuss alternative water pricing structures that can achieve greater efficiency than average-cost pricing, while still complying with regulated rates of return. In the meantime, we examine the consequences of pricing water below LRMC.

2.3 Consequences of Inefficient Water Pricing

With water prices below LRMC, water consumption is excessive relative to the economic optimum, in that some consumption that takes place is worth less in its current use than the economic cost of its supply.[7] This has severe consequences.

In the short run, without price increases acting as a signal, water consumption proceeds during periods of scarcity at a faster-than efficient pace. Water conservation takes place only under "moral suasion or direct regulation" (Howe 1997). In contrast, if water prices rose as reservoir levels fell during periods of limited rainfall, consumers would respond by using less water, reducing or eliminating uses according to households' particular preferences. During an extended drought in California from 1987 to 1992, for example, a handful of municipal water utilities implemented price increases to reduce water demand, achieving aggregate demand reductions of 20 to 33 percent (Pint 1999).

In the long run, inefficient prices alter land-use patters, industrial location decisions, and other important factors. The sum of all these individual decisions determines the sustainability of local and regional water resources.[8] Efficient water prices would result in land-use patterns and patterns of industrial, commercial and agricultural activity that account for water scarcity. Some households would be expected to plant fewer green lawns or install front-loading clothes washing machines, for example, in areas where water prices are relatively high. Agricultural producers might install drip irrigation systems, and industrial facilities would have an incentive to adopt wastewater reuse systems. Water-intensive production processes, such as oil refining and semi-conductor manufacturing, would tend to locate in regions where water is relatively more plentiful.

In contrast, under today's water prices, Texas and California are major rice producers, requiring flood irrigation in very arid regions. In Phoenix, Arizona, the marginal price of residential water consumption is zero for the first 4,900 gallons used per household per month. A number of analysts have estimated the welfare costs of pricing water resources below the long-run marginal cost of their provision, and the costs are very significant, even for individual cities (Renzetti 1992b; Russell and Shin 1996).[9]

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[7] The opposite is also true – higher-than-efficient prices would result in "too little" water consumption. We do not discuss this possibility in detail, since we know of no real-world example, in New England or elsewhere.

[8] As in the case of market-based policies to reduce air and water pollution, prices also provide a strong incentive for technological change that brings down the marginal cost of water conservation in the long run. We discuss this advantage of price-based approaches to water conservation in Section 6.

[9] For example, Renzetti (1992b) estimates welfare benefits of $2 to $2.5 billion (in 1986 dollars) for a move from inefficient to efficient pricing in Vancouver, British Columbia.

2.4 Applying Cost-Effectiveness to Water Management

Implementation of efficient water prices would be challenging, to say the least. Some of the opportunity costs are exceedingly difficult to quantify. What is the value of a gallon of water left instream to support endangered species habitat, for example? While economists have developed a variety of useful methods for estimating such values, any expectation that every water supplier will develop full individual measures of the LRMC of water supply is not realistic. If LRMC represents an ultimate water pricing goal, there are many smaller, less ambitious steps toward efficiency that can be accomplished more readily.

Even with inefficient prices, injecting stronger price signals into the processes of water use and allocation can result in important improvements. For example, given a particular public goal, such as the conservation of a particular quantity of water or percentage of current consumption, various policies can be employed, some more costly than others. Seeking to choose the least costly method of achieving some water-provision goal would be an application of the economic concept of *cost-effectiveness* to water management. Even if the water conservation goal is, itself, inefficient, society can benefit from the minimization of costs to achieve it. Many decades of theoretical and empirical economic analysis suggest that market-based environmental policies are more cost-effective than non-market policies, often characterized as command-and-control approaches. We consider this aspect of the economics of water demand management in Section 6, where we compare price and non-price approaches.

3. Water Pricing Options

Water suppliers have many options for structuring water prices, because a variety of rate structures can generate the same amount of revenue for the same total quantity sold. First, water consumption can be metered or unmetered. From an economic perspective, water use should be metered, and a volumetric rate charged for consumption. When water consumption is not metered, suppliers charge a flat fee, often monthly or bimonthly, for the privilege of connection to piped water supply.[10] The fee may be based on the size of the pipe delivering water to a home or business, but it does not otherwise vary with the quantity of water consumed.

Flat water fees are equivalent to imposing a zero marginal water price. When monthly charges for water consumption are not linked to the quantity consumed, households have an incentive to use the resource until their own marginal benefit of water consumption is driven to zero. This provides no incentive for conservation, and unless the marginal cost of water supply is equal to zero, it will be inefficient.

Significant water savings have been reported for U.S. communities switching from unmetered to metered consumption (OECD 1999).[11] For example, the city of Leavenworth,

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[10] Hanemann (1997b, pp. 137-138) notes that even in the early 20th century, when most urban water agencies charged flat fees, these fees often varied by customer characteristic used to classify customers into groups by relative water consumption. For example, in Phoenix, Arizona in 1907, households were charged for each head of livestock, and barber shops for each chair on the premises.

[11] See, especially, the results of studies listed in Table 15 (OECD 1999, p. 46).

Washington began metered billing in 1990, observing a 40-60 percent reduction in peak summer demand over the first metered summer (Anonymous 1993). A federal government study suggests an average 20 percent reduction in total water use due to metering (Maddaus 1984). But flat fees are exceedingly easy to administer, and moving to a metered system can be controversial (Vossler *et al*. 1998).

If water use is metered, volumetric rates can take many forms, and they are usually accompanied by a fixed water service fee for each billing period. Under a constant or uniform volumetric price, households are charged the same unit price at all levels of consumption. An economically efficient constant marginal price would be equal to the LRMC of water supply, as explained in Section 2. Two somewhat more sophisticated price structures are block pricing and seasonal pricing.

3.1 Block Pricing and Seasonal Pricing

Under block pricing, the marginal price depends on the quantity of water consumed. Increasing block price (IBP) structures charge higher marginal prices for higher quantities consumed, resembling a staircase ascending from left to right; decreasing block prices (DBPs) are stacked in the opposite direction (Figure 1). DBPs offer the equivalent of a volume discount. Large water consumers, often industrial facilities, pay less per unit to purchase water as their consumption rises. Obviously, this does not provide a conservation incentive. DBPs have been used by communities in an effort to attract large manufacturing industries. For water-intensive industries, this may be an appealing feature, but the economic tradeoff generated by such a subsidy is unlikely to be positive. The long-run consequences of pricing below the economic cost of water supply can be severe: communities taking this path may attract water-intensive industries that would better be located in areas in which water resources are cheap. Massachusetts public water utilities cannot implement DBPs, according to state law, although private water suppliers are exempt from this rule.

In contrast, IBPs can be a useful water pricing tool from an economic perspective. While all units of water, ideally, should be sold at the LRMC of water supply, implying a constant marginal price, utilities' adoption of IBPs may help them increase the fraction of consumption priced at LRMC (or something approaching this efficient price), while avoiding the difficult problem inherent in the efficient approach, namely the generation of profits, not permitted for most public water agencies. LRMC is likely to be greater than short-run average cost. Hence, in the short run, utilities charging LRMC for all units produced will acquire revenues that exceed their actual expenses (including capital depreciation) for each unit sold. This is because they are essentially collecting the economic cost of eventual system expansion, necessitated by the rate and pattern of current use. Thus, pricing all units at LRMC would cause utilities to earn profits, and sometimes substantial ones (Moncur and Pollock 1988; Hall 2000).

In the United States, water utility profits are heavily regulated, and non-profit status is common. IBPs provide one way around this conflict between efficient pricing and a zero- or low-profit constraint. The most efficient way to deal with this problem would be to charge the LRMC of water supply as a constant marginal price, and then rebate any profits back to consumers. This can be done in many ways, as long as the rebate is not tied to current consumption (otherwise, consumers will simply face an "adjusted" marginal price, lower than the billed price, that accounts for the rebate, effectively a per-unit subsidy). For example, the rebate of utility profit shares could be based on household income, to meet an income redistribution goal. While such a system has been proposed for developing countries (Boland and Whittington 2000), we know of no U.S. water supplier currently implementing such a rebate system.

Under IBPs, water suppliers can charge something approaching LRMC for the "marginal" uses (lawn-watering and the like), while meeting zero-profit constraints through the manipulation of block cutoffs and lower-tier prices. From an economic perspective, it is certainly desirable to increase the fraction of consumption that faces efficient prices. But even if the highest-tier price in an IBP schedule reflects LRMC, some welfare losses result from infra-marginal "subsidies" – the lower prices offered on the earlier units of water purchased. Thus, the relative efficiency of uniform and IBP structures depends on a variety of factors. In general, an IBP structure in which the upper tiers approach efficient prices may compare very favorably, on efficiency grounds and in terms of conservation incentives, with a uniform marginal price that is well below the LRMC of supply.

Water suppliers may also change water rates seasonally. Seasonal rates are typically higher during the months of peak demand, usually the summer, and lower in the off-peak season. It makes economic sense to charge more at these times – the opportunity cost of water consumption is higher. For example, if a utility's withdrawals from a reservoir to supply households with water for green lawns competes with instream flow in rivers and streams, summer may be a time during which this flow is already low due to low rainfall or, occasionally, pronounced drought. The opportunity cost of watering a lawn during this season would be equivalent to the marginal benefit of leaving this water instream instead. The marginal benefit of instream flow is typically higher during periods of low flow (Daubert and Young 1981; Duffield *et al*. 1992; Loomis 1998), justifying a higher price for residential water consumption and other uses where they compete with instream flow.

Seasonal rates can be used in combination with IBPs. In the mid-1990s, for example, Seattle Public Utilities charged a uniform marginal price for residential consumption during the off-peak season, and a two-tier IBP in the summer. Suppliers with IBPs year-round may raise all prices or only upper-tier prices during the peak season.

3.2 Relative Prevalence of Water Price Structures in the United States and the State of Massachusetts

In 1996, fully 96 percent of surveyed residential water customers were metered, according to a study of 827 U.S. water utilities by the American Water Works Association (Figure 2). From 1996 to 2002, the prevalence of various rate structures in the residential sector changed little, although there was substantial growth in the fraction of U.S. residential consumers facing IBPs after 1980, according to a biennial survey of 167 U.S. urban residential water providers (Table 1). By one estimate, only 4 percent of U.S. customers faced IBPs in 1982 (OECD 1999). Price structure shares vary significantly by sector (Figure 3). IBPs are relatively more common in the residential sector, and DBPs in the industrial sector. In Massachusetts, 46 percent of municipalities use a constant marginal water price, 48 percent use IBPs, 5 percent use flat fees that do not vary with water consumption, and the remaining small fraction use decreasing block rates (Tighe and Bond 2004).

In addition to the rate types discussed above, water suppliers often implement connection charges, in part to recover capital expenditures for new facilities required to meet new customers' expected demand. Suppliers may also differentiate rates by income, providing a basic level of service at very low cost to low-income households, based on some kind of simple means-testing. In some cases, suppliers may also provide special low rates to elderly customers – the Boston Water and Sewer Commission is one example.

There are many criteria water suppliers use when selecting a water rate structure. Economic efficiency is not necessarily one of these. Rather, suppliers tend to focus on revenue generation, cost allocation (including, potentially, cross-subsidies from one class of customer to another), equity, and the provision of incentives for water conservation. A full discussion of these criteria and issues is beyond the scope of this study, the focus of which is on the last item, water conservation incentives.[12]

4. Effects of Price on Water Demand

If policymakers are to use prices to manage demand, the key variable of interest is the price elasticity of water demand, the percent decrease in demand that can be expected to occur when price is raised by one percent. In shorthand, we can think of price elasticity as represented by the reciprocal of the steepness of the slope of a demand curve.[13] A very steep demand curve implies that even a very large price increase may not diminish demand very much. This would be true, for example, for the portion of water demand used for drinking, a basic need. In contrast, a relatively flat demand curve implies that even a small price increase is likely to decrease quantity demanded substantially. This might occur in an industrial process in which there are readily available substitutes for treated water, such as raw or recycled water (see Figure 4).

Consumers are relatively more sensitive to water prices in the long run than they are in the short run because over longer time periods, capital investments are not fixed. For example, households might change appliance stocks, retrofit water-using fixtures, or alter landscaping from lawns to drought-tolerant plants; firms can be expected to change water-consuming technologies, increase recycling, or relocate to areas in which water is more plentiful; and farmers may install technically efficient irrigation systems. The height and shape of the demand curve, itself, may shift due to these changes. In the short run, water users have a much smaller menu of options to reduce water consumption, thus measured price responses tend to be smaller.

[12] Hanemann (1997b) provides an excellent treatment of these and many other issues in water rate structure design.

[13] For all but one specific class of demand function, price elasticity varies along the demand curve, thus while we can speak broadly about comparisons across demand curves, there may be points on a relatively steep demand curve at which price elasticity exceeds that on some parts of a flat demand curve.

Because price and demand are inversely correlated (an increase in the price of water means that consumers will want less of it, all else equal), price elasticity is a negative number.[14] An important benchmark in elasticity estimation is –1.0; this figure divides demand curves into the categories of *elastic* and *inelastic*. Elastic demand is demand for which a one percent increase in price leads to a greater than one percent decrease in demand (represented by an elasticity "more negative than" –1.0). If demand is inelastic, a one percent increase in price leads to less than a one percent decrease in demand; in this case, elasticity lies between zero and –1.0.

There is a critical distinction between the technical term "inelastic demand" and the phrase "unresponsive to price". If demand is truly unresponsive to price, price elasticity is equal to zero, and the demand curve is a vertical line – the same quantity of water will be demanded at any price. This may be true in theory for a subsistence quantity of drinking water, but it has not been observed for water demand in general in fifty years of empirical economic analysis.

4.1 Methods for Obtaining Price Elasticity Estimates

To obtain price elasticity, economists estimate demand curves for water in particular sectors (and in a few cases, for particular end-uses of water). A demand curve explains water consumption as a function of marginal prices and a set of other important variables that influence consumption. For example, an urban residential water demand curve might explain demand as a function of price, household income, family size, home and lot size, weather, and possibly other variables. Many of these non-price variables may have a stronger influence on consumption than price.

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 and non-water inputs. This makes estimation of demand functions in these sectors much more challenging.[15] In addition, in both the agricultural and industrial sectors, water demand data can be difficult to obtain. Water demand data in the industrial sector is proprietary, and competitive firms have strong incentives to avoid making these data public; this is true for any information on input costs and other aspects of production. In addition, even when consumption data for industrial facilities can be obtained from water utilities, many plants have additional raw water sources outside of piped networks. These sources may or may not be metered, and are often unpriced. For these reasons, industrial water demand elasticities are estimated infrequently.[16]

The metering issue is even more severe for agricultural water consumers, making it difficult and in many cases impossible to measure accurately the quantity of water used for irrigation. Farmers who withdraw water directly from surface sources usually face a price of zero. Without some kind of price, a demand curve cannot be estimated. Farmers who withdraw from groundwater sources usually pay no price for the water, itself, but must pay for the energy

[14] Elasticity figures may also be reported in absolute value, and the negative sign is then implicit. We use the more conventional negative sign throughout this paper.
[15] See a useful explanation of this problem with respect to industrial demand in Griffin (2006), p. 24; and with respect to agricultural demand in Scheierling *et al*. (2006), p. 2.
[16] See Renzetti (2002) for a detailed treatment of the economics of industrial water demand.

required to pump water to the surface. Many agricultural water demand curves are estimated for groundwater, often using energy costs to construct a water price variable. Prices can also be obtained where farms purchase water from irrigation districts or other water management institutions. While the economics literature contains many agricultural water demand elasticity estimates, the availability of data of sufficient quality for statistical estimation of demand functions is uncommon (Griffin 2006).[17] Other techniques commonly applied are mathematical programming, field experiments, and hedonic (non-market valuation) methods.[18]

Once a demand function is obtained using statistical or other techniques that depend on the particular model and sector, the function can be used to estimate the impact on demand of a small change in price, conditional on all other demand determinants remaining unchanged.

4.2 A Summary of Water Price Elasticity Estimates

4.2.1 Residential Demand

Water demand in the residential sector is sensitive to price, but the magnitude of the sensitivity is small (i.e., demand is inelastic) at current prices. In their meta-analysis of 124 estimates generated between 1963 and 1993, accounting for the precision of estimates, Espey *et al*. (1997) obtain an average price elasticity of –0.51, a short-run median estimate of –0.38, and a long-run median estimate of –0.64. Dalhuisen *et al*. (2003) obtain a mean price elasticity of -0.41 in a meta-analysis of almost 300 price elasticity studies, 1963-1998.[19] A recent, comprehensive residential demand estimate for households in eleven urban areas in the United States and Canada, suggests that the price elasticity of water demand is approximately –0.33 (Olmstead *et al*. 2006). In short, the price elasticity of residential demand varies substantially across place and time, but on average, in the United States, a ten percent increase in the marginal price of water in the urban residential sector can be expected to diminish demand by about three to four percent.

4.2.2 Industrial Demand

In general, price elasticity estimates in the industrial sector tend to be somewhat higher than residential elasticities, and they vary substantially by industry. Not surprisingly, estimated elasticities tend to be higher in industries where the cost share of water inputs is relatively larger (Reynaud 2003).[20] With merely a handful of estimates, measures of the central tendency of

[17] One could ask why, given these problems with data and estimation, agricultural water demand has been so heavily studied. The answer is that agricultural demand, even in "service economies" such as that of the United States, remains the largest component of total water demand, even in many water-scarce regions. Thus, analysts are particularly interested in the response of agricultural demand to price and other variables.

[18] The mathematical programming (often linear programming) models maximize net returns to water for a representative farm, subject to constraints on land, a total quantity of available water, and other inputs; analysts then obtain the net revenue-maximizing quantity of water use at alternative water prices (Scheierling *et al*. 2006).

[19] Hanemann (1997) lists 99 water demand studies for urban areas in North American between 1951 and 1991 in his Table 2-5 on pp. 67-72. A simple average of those estimates, using midpoints of ranges where ranges are reported, is equal to –0.47. The process of averaging estimates without accounting for the precision of those estimates is at best imprecise; however, the rough average is included here for an additional point of reference.

[20] Industrial facilities using a significant quantity of water tend to recycle it – for example, the same gallon of water can run through a cooling process at an oil refinery many times – resulting in additional degradation of water quality

industrial elasticity estimates would be meaningless. One study of 120 U.S. municipalities estimated industrial elasticities in the range of –0.44 to –0.97 (Williams and Suh 1986). The results of five studies between 1969 and 1992 are reported in Griffin (2006). These estimates vary from –0.15 for some two-digit Standard Industrial Classification (SIC) codes (Renzetti 1992a), to –0.98 for the chemical manufacturing industry (Ziegler and Bell 1984). A recent comprehensive study of 51 French industrial facilities estimates an average demand elasticity of –0.29 for water purchased from utilities, with a range of –0.10 to –0.79, depending on the type of industry (Reynaud 2003).

4.2.3 Agricultural Demand

A recent meta-analysis of 24 U.S. agricultural water demand studies performed between 1963 and 2004 suggests a mean price elasticity estimate of –0.48 (Scheierling *et al*. 2006), although estimates vary widely and, unlike in the industrial and residential sectors, often approach zero. Estimates are higher in water-scarce regions and where prices are higher. Unlike residential consumers who can be expected to demand some water for essential functions even at very high prices, farmers will simply cease production at some price (Griffin 2006). This is the "choke price" – the price at which demand is driven to zero.

An example of the variation in price elasticity with the price of water is provided by Nieswiadomy (1985), who uses energy prices (during a period of rapid energy price increases) to estimate the demand for groundwater; when energy is relatively cheap in 1973, he estimates a water price elasticity of –0.29, but by 1980 when energy is relatively expensive, the estimated elasticity rises to –1.24.

4.2.4 Elasticity Estimates in New England

There are few studies of water demand in New England. Most recently, a broad study of residential water consumption in Massachusetts cities estimated price elasticities ranging from –0.10 to –0.69 (Stevens *et al*. 1992). These results were similar to those of earlier regional analyses. Table 2 summarizes New England elasticity estimates. Given these results, there is no reason to believe that regional responses of water demand to price increases should differ significantly from the national averages reported above.

4.2.5 Comparisons and Caveats

Interpreting elasticity estimates is difficult without information that allows them to be compared with those for other goods and services. A comprehensive survey of price elasticity estimates for residential electricity demand suggests that price elasticity is, on average, -0.20 in the short run and –0.70 in the long run (Bohi and Zimmerman 1984).[21] Literature surveys

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with each use. In this case, water demand and water pollution control standards are closely linked, as firms can choose either to withdraw more water (resulting in less recycling and thus, cleaner effluent) or to recycle more water (resulting in dirtier effluent). These tradeoffs have been demonstrated empirically (Reynaud 2003, Féres and Reynaud 2005).

[21] A more recent study suggests that the price elasticity of residential energy demand has changed very little over time (Bernstein and Griffin 2005).

suggest similar responsiveness to price for residential water and electricity demand. A survey of the literature on gasoline demand reports an average short-run price elasticity of –0.24, and an average long-run elasticity of –0.80 – again, quite similar to average water demand estimates (Dahl and Sterner 1991). While it is commonly asserted that water demand does not respond to changes in water prices, the same is rarely said of electricity and gasoline demand. Yet empirical estimates of demand curves for each of these commodities suggest similar price responsiveness, in both the short run and the long run.

There are some important caveats worth mentioning. First, an elasticity estimate is essentially a derivative or a measure of the slope of the demand curve – the instantaneous change in demand for a very small change in price. The impact of very large price changes can, therefore, not be determined from a price elasticity estimate in which the sample that generated the estimate does not include some high prices. Thus, the summary estimates should be taken as elasticities *at current prices* – were prices to approach the efficient levels discussed in Section 2, water demand would likely be much more sensitive to price increases.

In addition, price elasticities vary with many factors. For example, in the residential sector, high-income households tend to be much less sensitive to water price increases than low-income households. And price elasticity may increase by 30 percent or more when price information is posted on water bills (Gaudin 2006).[22] Thus, price elasticities must be interpreted in the context in which they have been derived. Municipalities or other water suppliers considering price as a demand management tool would, ideally, estimate demand curves for water using *current* data (capturing sufficient price variation) from *their own* customers; transferring historical estimates or those calculated for other areas is not recommended if suppliers require a high degree of certainty over the magnitude of the anticipated demand reduction from a price increase.

Finally, we mentioned earlier that water demand is driven by many factors, all of which are included in good estimates of demand and price elasticity. A price elasticity estimate tells us the effect of price on water demand, *all else held constant*. Thus, even if prices go up, if changes in the other drivers of water demand are occurring at the same time, water demand may still rise. For example, a one percent increase in income can be expected to raise demand by 0.2 to 0.6 percent (Hanemann 1997), with a mean income elasticity estimate of 0.43 among 160 studies completed between 1960 and 1998 (Dalhuisen *et al*. 2003). Increasing incomes and increasing prices, thus, work in opposite directions at the household level (rising income increasing demand for water, and rising prices diminishing it). At the utility level, growth in the number of service connections due to population increases and new construction may increase aggregate water demand, even if price increases reduce per-connection demand. In order to determine whether price increases will diminish aggregate demand, or simply slow its rate of growth, individual water utilities must obtain demand curve estimates for their own service areas, and use them to simulate the effects of expected changes in demographic and other conditions, as well as price.

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[22] Some have suggested that billing frequency may affect price elasticity (Arbués *et al*. 2003). Two recent analyses have failed to find any significant effect of billing frequency on price elasticity (Gaudin 2006, Kulshreshtha 1996). In one case, more frequent billing in Massachusetts cities may have actually *decreased* price elasticity (Stevens *et al*. 1992).

4.3 The Possible Role of Price Structure

In Section 3, we described the various price structures faced by water consumers in the residential, industrial, and agricultural sectors. Those price structures in which marginal water prices depend on the quantity consumed (IBPs and DBPs) introduce some difficult challenges for the statistical estimation of demand functions (Hewitt and Hanemann 1995; Pint 1999; Olmstead 2006).

Does the structure of water prices affect consumers' price sensitivity? Meta-analyses of residential water demand suggest that price elasticity is higher under IBPs than under uniform marginal prices (Espey *et al*. 1997, Dalhuisen *et al*. 2003).[23] If this were true, a one percent price increase under IBPs would result in a greater reduction in water consumption than a one percent price increase under a uniform marginal price, all else equal. This would imply that the structure of water prices, in addition to the magnitude of marginal price, itself, may affect price elasticity.

This hypothesis is difficult to test empirically, since price elasticity varies geographically and over time for many different reasons. Thus, simple statistical analyses that compare price elasticities among consumers facing IBPs with those facing uniform prices may suggest a correlation between price structure and elasticity, but causation is difficult to determine. For example, it may be that communities that regularly experience arid conditions and in which water shortage is a relatively more frequent occurrence tend to have higher water prices, on average, than communities in which water is plentiful. Higher prices tend to result in higher price elasticities, all else equal. If arid communities are also more likely to implement IBPs than wet communities, then statistical analysis that does not control for this innate tendency of arid communities toward a specific type of price structure may offer results implying that IBPs increase price elasticities. The meta-analytical approach is insufficient to sort out this statistical problem.

A recent study has examined this question empirically (Olmstead *et al*. 2006). The authors estimate a full-sample price elasticity for a sample of households in 11 North American cities facing heterogeneous price structures and then explore how elasticity varies between linear and non-linear pricing regimes. Models that split their sample by price structure suggest that demand is more price-elastic under IBPs, implying either a demand response to price structure, or underlying heterogeneity among the particular cities choosing these different types of price structures. Further tests suggest that the observed difference in price elasticity by price structure may result from the underlying tendency of cities to adopt IBPs, rather than IBPs, themselves, but the authors cannot rule out a behavioral response to price structure. Further research in this area is needed to settle this important question.

4.4 Implications of Price Elasticity for Water Utility Revenues

Water managers should be interested in the price elasticity of water demand apart from its usefulness in conservation efforts, because it also provides information about likely revenue

[23] There has also been some discussion in the literature as to whether the particular type of price structure chosen by a water supplier affects the *quantity* of water demanded. A study of 85 Massachusetts cities suggests that it does not (Stevens *et al*. 1992).

impacts of price changes. If demand is *elastic*, a price increase will drive demand down to such an extent that a water supplier's total revenues will actually decrease. When demand is inelastic, as it is for most residential and agricultural demand, and much industrial demand in the United States, a price increase will increase a water supplier's total revenues. The extra per-unit revenues from the price increase will outweigh the lost revenues from the resulting decrease in demand.

This is a critical distinction, and it forms one basis for the comparison of price and non-price conservation policies in Section 6. When a water supplier implements a non-price water conservation program, it incurs costs to do so (for advertising, billing inserts, monitoring, enforcement, etc.). If this non-price conservation program reduces demand, revenues decline. Thus, total costs increase and total revenues decrease, an undesirable result from the perspective of fiscal management. During prolonged droughts, this can result in the necessity for substantial price increases following "successful" non-price conservation programs, simply to prevent water utilities from unsustainable financial losses (Hall 2000).

5. Effects of Non-price Conservation Programs on Water Demand

In addition to the common, but erroneous assumption that consumers do not respond to water price changes, pricing policies are also constrained by law and by politics. As a result, water suppliers tend to rely on non-price conservation programs to induce demand reductions during shortages. Most such programs are applied exclusively in the urban residential sector, and so we focus most heavily on this sector in our examination. We divide non-price programs into three categories: (1) required or voluntary adoption of water-conserving technologies; (2) mandatory water use restrictions; and (3) mixed non-price conservation programs.

5.1 Required or Voluntary Adoption of Water-Conserving Technologies

Many urban water utilities have experimented with required or voluntary adoption of low-flow technologies.[24] When water savings from these programs have been estimated, they have often been smaller than expected, due to behavioral changes that partially offset the benefit of greater technical efficiency. For example, households with low-flow showerheads may take longer showers than they would without these fixtures. The necessity of the "double flush" was a notorious difficulty with early models of low-flow toilets. In a recent demonstration of similar compensating behavior, randomly-selected households had their top-loading clotheswashers replaced with more water efficient, front-loading washers. In this field trial, the average front-loading household increased clothes-washing by 5.6 percent, perhaps due to the cost savings associated with the appliances' increased efficiency (Davis 2006).

Several engineering studies have observed a small number of households in a single region to estimate the water savings associated with low-flow fixtures. But most of these studies used intrusive data collection mechanisms, attaching equipment to faucets and other fixtures in

[24] Since the 1992 Energy Policy Act, national law has required the installation of low-flow toilets and showerheads in all new residential construction, but some cities have also mandated or encouraged retrofitting.

homes (Brown and Caldwell 1984). Study participants were aware they were being monitored as they used water, which may have led to confounding behavioral changes.

One comprehensive study that was not characterized by this monitoring problem indicates that households fully constructed or retrofitted with low-flow toilets used about 20 percent less water than households with no low-flow toilets. The equivalent savings reported for low-flow showerheads was 9 percent (Mayer *et al*. 1998). Careful studies of low-flow showerhead retrofit programs in the East Bay Municipal Utility District, California, and Tampa, Florida estimate water savings of 1.7 and 3.6 gallons per capita per day (gpcpd), respectively (Aher *et al*. 1991; Anderson *et al*. 1993). In contrast, showerhead replacement had no statistically significant effect in Boulder, Colorado (Aquacraft 1996). Savings reported for low-flow toilet installation and rebate programs range from 6.1 gpcpd in Tampa, Florida to 10.6 gpcpd in Seattle, Washington (U.S. General Accounting Office 2000). Renwick and Green (2000) estimate no significant effect of ultra low-flush toilet rebates in Santa Barbara, California.

It is not surprising that studies of the water savings induced by such policies vary widely, from zero to significant water savings – the scope and nature of policies implemented in these cities varies widely, as well. Some have larger retrofitting incentives but reach few customers; others reach many customers with small incentives.

5.2 Mandatory Water-Use Restrictions

Non-price management tools also include utility implementation of mandatory water use restrictions, much like the traditional command-and-control approach to pollution regulation. These may include both restrictions on the total quantity of water that can be used, as well as restrictions on particular water uses, usually outdoors, such as lawn-watering and car-washing. Empirical evidence is mixed regarding the aggregate effects of these programs. Summer 1996 water consumption restrictions in Corpus Christi, Texas, including prohibitions on landscape irrigation and car-washing, did not prompt statistically significant water savings in the residential sector (Schultz *et al*. 1997). A longer-term program in Pasadena, California, the LITEBILL water and energy conservation program, did result in aggregate water savings (Kiefer *et al*. 1993), while mandatory water use restrictions in Santa Barbara, California induced a demand reduction of 29 percent (Renwick and Green 2000).

A comprehensive study of drought management policies in California during a prolonged drought in the late 1980s and early 1990s found that many water utilities implemented mandatory water use restrictions along with price surcharges for excess use (Dixon *et al*. 1996).[25] Restrictions on the total quantity of water used were widely violated by residential users, and industrial users were largely exempt from these restrictions. Type-of-use restrictions were also common, but weakly enforced.

5.3 Mixed Non-Price Conservation Programs

[25] If violation of the total quantity restriction simply triggers a high price for continued consumption, with no threat that water supply will be cut off, this is equivalent to an increasing-block price structure.

Water utilities typically implement a variety of non-price conservation programs simultaneously, making it difficult to determine the effects of individual policies. A number of studies have analyzed these mixed approaches to conservation policy. One analysis of the effect of conservation programs on aggregate water district consumption in California found small but significant reductions in total water use attributable to landscape education programs and watering restrictions, but no effect due to non-landscape conservation education programs, low-flow fixture distribution, or the presentation of drought and conservation information on customer bills (Corral 1997). Another study of southern California cities found that the number of conservation programs in place in a city had a small negative impact on total residential water demand (Michelsen *et al*. 1998). An aggregate demand study in California found that public information campaigns, retrofit subsidies, water rationing, and water use restrictions had negative and statistically significant impacts on average monthly residential water use, and the more stringent policies had stronger effects than voluntary policies and education programs (Renwick and Green 2000).[26]

6. Comparing Price and Non-price Approaches to Water Conservation

Two critical economic questions remain regarding water demand management. The first has to do with efficiency, and the second with cost-effectiveness. The efficiency question revolves around the definition of "water conservation." A water supplier might expend significant resources to generate water savings, such as by upgrading its transmission and distribution infrastructure. But such actions would not be economically efficient unless the value of the resources used in this process is less than the value of the water conserved.

In Corpus Christi, Texas, during an extreme drought in the summer of 1996, industrial water users were surveyed regarding water conservation practices they had implemented (Schultz *et al*. 1997). A paint manufacturer had substantially reduced its fraction of water-based products, and increased its fraction of solvent-based products. Construction firms and oil refineries had ceased hosing down dusty work areas, increasing the amount of material carried by wind from these areas. In each of these cases, the costs to local residents and those downwind of the resulting increase in air pollution may have been greater than the benefits of reduced water consumption. Is it better to have less water consumption and more industrial water pollution, or vice-versa? Economic analysis focuses on these kinds of tradeoffs, offering a broader view from the perspective of society. Thus, the first question that should be asked of any water conservation effort is whether it is worth the devotion of resources, broadly defined, necessary to achieve a particular quantity of water savings. Answering this efficiency question requires a benefit-cost analysis.

A second-order question refers to cost-effectiveness, identifying a means – a policy instrument – that will achieve some particular water savings goal at least cost. In subsequent sections, we address the issue of least-cost water conservation policies, comparing price and non-

[26] The price elasticity estimated in this study is –0.20.

price approaches, and consider other key issues in water conservation policy instrument choice: the ability to achieve water conservation goals, distributional equity, and political considerations.

6.1 Economic Losses from Non-Price Approaches

The general theoretical advantages of price-based approaches to water demand management are clear, as explained previously in Section 2, namely substantial reductions in the economic cost of achieving water consumption reductions with prices, rather than non-price approaches (Collinge 1994; Krause *et al*. 2003).[27]

How large are the losses from non-price demand management approaches in reality? During droughts, U.S. municipalities typically implement voluntary and mandatory quantity-based water consumption restrictions, primarily in the residential sector. Analyses of the impact of these demand management programs on aggregate demand, discussed in Section 5, occasionally also estimate price elasticities (Michelsen *et al*. 1998, Renwick and Green 2000), but in general do not facilitate a full comparison of the cost of implemented non-price programs with that of price increases that would have achieved the same level of water savings.

We know of only two cases in which such a comparison has been made. Timmins (2003) compares a mandatory low-flow appliance regulation with a modest water tax (a price increase), using aggregate consumption data from 13 groundwater-dependent California cities. Under all but the least realistic of assumptions, he finds the tax to be more cost-effective than the technology standard in reducing groundwater aquifer lift-height in the long run.

Another study of 11 urban areas in the United States and Canada compares residential outdoor watering restrictions with the establishment of drought pricing (Mansur and Olmstead 2006). For the same level of aggregate demand reduction as that implied by a regulation limiting households to outdoor water use (for lawn-watering and car-washing) two days per week, the establishment of a market-clearing drought price in these cities would result in welfare gains of approximately $81 per household per summer drought. This gain relative to the current command-and-control approach represents about one-quarter of the average household's total annual water bill in their sample. The savings from the market-based approach are driven by two factors: (1) the ability of households facing drought prices rather than quantity restrictions to decide which uses to reduce according to their own preferences; and (2) allowing heterogeneous responses to the regulation across households, resulting in substitution of scarce water from those households who value it less, to those who value it more.

We previously summarized evidence on water savings attributable to low-flow fixture and appliance policies. More important than the raw water savings induced by these programs, however, is the cost per gallon saved, in comparison with alternative policies. The costs of toilet retrofit policies implemented in U.S. cities range from less than $100,000 to replace 1,226 toilets in Phoenix, Arizona to $290 million for 1.3 million toilets in New York City (U.S. General

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[27] Collinge (1994) proposes a theoretical water entitlement transfer system in the residential sector, which would allow households to buy and sell permits for water consumption. Krause *et al*. (2003) simulate water consumption from a common pool, and predict that customer heterogeneity will generate welfare losses from command-and-control water conservation policies.

Accounting Office 2000). These can be expensive programs, but there has been only one benefit-cost analysis (Timmins 2003), and little discussion of the magnitude of price increases that would have been necessary to induce demand reductions equivalent to those observed with technology standards. Only with such information can price and non-price demand management programs be effectively compared as policy options.

Based on both economic theory and empirical estimates, using price increases to reduce demand, allowing households, industrial facilities, and other consumers to adjust their particular end-uses of water as they see fit, is more cost-effective than implementing non-price demand management programs.

6.2 Predictability in Achieving Water Conservation Goals

Predictability of the effects of a water conservation policy may be of considerable importance to government agencies, although in most cases the objective of water conservation policies is water savings, without any specific target in mind. In this case, an estimate of the reduction expected from policy implementation is necessary, but precision is less important.

If near absolute certainty is required, economic theory would suggest that the quantity restrictions typical of traditional, prescriptive approaches to water demand management would be preferred to price increases, particularly if water suppliers could be sure of near-total compliance, or at least be able to adjust their water savings target upward to account for a reliable estimate of the noncompliance rate (Weitzman 1973). But suppliers generally cannot rely on substantial compliance with quantity-based restrictions. In a comprehensive study of drought management policies among 85 urban water utilities during a prolonged drought in Southern California, analysts report that 40 agencies adopted mandatory quantity restrictions (in the form of "limits" on the total quantity of water to be used per billing period), but also found that more than half of the customers violated the restrictions (Dixon *et al*. 1999). Customers in violation paid penalties and surcharges, on average, $40 per violation. Such non-binding quantity constraints (with a high price as a "safety valve") are common, but how are utilities to predict the water savings achievable through quantity restrictions when less than half of consumers typically comply? In the same study, about three-quarters of participating urban water agencies implemented type-of-use restrictions (most of them mandatory). Few penalties were reported, and enforcement was weak, again raising questions regarding compliance.

With such low rates of compliance with traditional quantity-based regulations, neither price nor non-price demand management programs have an advantage in terms of predictability, unless a price elasticity has been estimated for a water supplier's service area, and the price increase is within the range of price variation exploited to estimate the elasticity. Alternatively, the water supplier may implement a non-price program similar to a past program that has been evaluated for effectiveness in the same service area. In these cases, the effect of either policy change on demand may be relatively predictable.

6.3 Equity and Distributional Considerations

The main distributional concern with a market-based approach to urban water management arises from the central feature of a market – allocation of a scarce good by willingness to pay (WTP). Under some conditions, WTP may be considered an unjust allocation criterion. Think, for example, about the negative reaction to selling food and water to the highest bidder in the aftermath of a natural disaster. This sense that there are some goods and services that should not be distributed by markets in particular contexts is behind the practice of rationing during wartime. A portion of water in residential consumption is used for basic needs, such as drinking and bathing. "Lifeline" rates and other accommodations ensuring that water bills are not unduly burdensome for low-income households are common. Thus, policymakers considering market-based approaches to water management must be concerned about equity in policy design.

What does the empirical evidence tell us about the equity implications of water pricing as a conservation tool? Renwick and Archibald (1998) estimate water demand elasticities by income quartile in two Southern California communities, using data collected over a six-year period, and use these estimates to compare the distributional implications of price and non-price water conservation policies. They find that low-income households are more price-responsive than high-income households, as we would expect, reflecting water expenditures' larger share of the household budget. Thus, if water demand management occurs solely through price increases, low-income households will contribute a greater fraction of the cities' aggregate water savings than high-income households. Importantly, the distributional implications of non-price policies vary by policy type (Renwick and Archibald 1998). For example, requiring particular landscape irrigation technologies results in demand reduction mainly among higher-income households.[28]

Mansur and Olmstead (2006) examined the distributional impacts of various demand management policies in a study of 11 North American cities. They used residential water consumption data to generate demand curve estimates for residential water, both indoors and outdoors. They then simulated the effects of a two-day per week outdoor watering restriction, and the effects of a price increase that would result in the same aggregate water consumption reduction as the prescriptive policy. Under drought pricing, relative to the prescriptive approach, the consumption share of households above both the sample median income and lot size would rise from 35 to 48 percent; the consumption share for households below both median income and median lot size would fall from 23 to 16 percent. Thus, raising prices to reduce consumption would cause a greater consumption reduction for low-income than for high-income households.

The fact that price-based approaches are regressive in *water consumption* does not mean that they must be regressive in *cost*. Likewise, the fact that non-price programs are progressive in water consumption does not mean that they are necessarily progressive in cost. The impact of non-price programs on distributional equity will depend largely on how the non-price program is financed. And progressive price-based approaches to water demand management can be designed by returning utility profits from higher prices in the form of a rebate. In the case of residential water users, this could occur through the utility billing process. Drought pricing, like LRMC pricing, would cause utilities to earn substantial profits (Mansur and Olmstead 2006). These profits would have to be returned to consumers in some form, as utilities usually are

[28] Agthe and Billings (1987) find that low-income households exhibit a larger demand response to price increases in Tucson, Arizona, but the study does not compare the distributional effects of price and non-price approaches.

required to earn zero or very low profits. Profits could be re-allocated based upon income, in order to achieve equity goals. Any rebate scheme that is not tied to current consumption can retain the strong economic-incentive benefits of drought pricing, without imposing excessive burdens on low-income households, relative to traditional approaches.

Conventional wisdom suggests that IBPs are particularly "equitable" pricing structures, since households with low water consumption pay a smaller marginal price than households with high water consumption. Thus, there is a perception that water for "basic needs" is priced at reasonable levels, with the upper-tier prices acting, essentially, as surcharges on less vital water uses within households, particularly lawn-watering. In some cases, IBPs may indeed be progressive policy tools. For example, one study of block pricing of electricity in Medellín, Colombia, found that the rate structure does redistribute income in favor of the poor (Maddock and Castaño 1991).[29] In other cases, however, economists have shown that poor households are actually hurt by these price structures, because such structures raise the average cost of water paid by households living in high-density areas in which a single water connection may be shared by many families (Whittington 1992; Pashardes and Soteroula 2002). Shared connections (as in some apartment houses) – or even very large families – drive per-connection consumption into the higher-priced upper blocks of the tiered system, so that even some of the water consumed for basic needs such as drinking, cooking, and washing may be charged at the highest prices. While they may very well be progressive, water suppliers introducing IBPs to achieve equity goals should be wary of the lack of evidence for their effectiveness in this regard.

6.4 Monitoring and Enforcement

Evaluations of any kind of regulation must consider the potential administrative costs for monitoring and enforcement. Price-based approaches to water demand management hold a very substantial advantage over non-price approaches in this regard. Non-price demand management policies require that water suppliers monitor and enforce restrictions on particular fixtures, appliances, and other technologies that customers use indoors and out, the particular days of the week or times of the day that customers use water for specific purposes, and in some cases, the quantity used for each purpose.

The great difficulty in monitoring and enforcing these types of command-and-control approaches is one reason for the prevalence of outdoor watering restrictions in the residential sector – outdoor uses are often (but not always) visible, and it is easier to cruise residential streets looking for violators than it is to observe what happens in industrial facilities. Monitoring and enforcement problems also explain the very low rates of compliance with many non-price demand management programs. In some cases, urban water utilities rely on neighbors to report illegal watering activities. Where low-flow fixtures are encouraged or required, they are often replaced with their higher-flow alternatives if consumers are dissatisfied with their performance.[30]

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[29] In general, the very poorest households do not have sufficient incomes to consume enough electricity to place them in the higher marginal price brackets, and so they benefit, on net, from the tiered prices.

[30] Consumers were so dissatisfied with early models of low-flow toilets that a black market arose in the older, 3.5-gallon models. Even in June 2006, a search on E-bay turns up dozens of 3.5-gallon toilets, technically illegal to install in new U.S. construction since the 1992 Energy Policy Act (see www.ebay.com, and search "3.5 toilet").

In contrast, "cheating" in the context of pricing requires that households consume water "off meter" – water consumption is already metered and billed volumetrically in most U.S. cities. This is not to say that no households will find it worth their while to do this. The nature of a higher price is that it generates an incentive not only for conservation, but also for avoidance. But at current prices and even very substantial percentage increases over current prices, the monitoring and enforcement requirements of a price increase are likely far less significant than those of a non-price approach.

6.5 Political Considerations

Price and non-price conservation programs also differ in terms of their political feasibility. Water demand management through non-price techniques is the overwhelmingly dominant paradigm in the United States. Raising prices, particularly for what people perceive to be a "public service" (though water is supplied by both public and private entities, in Massachusetts and elsewhere in the United States), can be politically very difficult. After a two-year drought in the late 1970s, the city of Tucson, Arizona was the first U.S. city to adopt marginal-cost water prices, which involved a very substantial price increase. One year later, the entire Tucson city council was voted out of office due to the water rate increase (Hall 2000). This is, perhaps, an extreme example, but it is cited often in the literature on water pricing and water conservation. Few elected officials relish the prospect of raising taxes; likewise, few relish the prospect of raising water prices.

Ironically, as we have demonstrated, non-price programs are more expensive to society than water price increases, once the costs of programs and associated welfare losses are considered, including the relative cost of reducing water consumption in specific uses, rather than reducing those uses most cost-effective for each customer. A parallel can be drawn in this case to market-based approaches to environmental pollution control, including taxes and tradable permit systems. Cost-effectiveness has only recently been considered an important criterion for the choice of policies to control pollution (Keohane *et al*. 1998). The persistence of non-price approaches in water demand management sends a strong message. Despite empirical evidence regarding their higher costs, political constituencies that prefer non-price approaches have succeeded in implementing these approaches and preventing management through prices. Some of this resistance to using prices may be due to misinformation – it may be that policymakers and water customers simply are not aware of the cost-effectiveness advantage of the price-based approach. For example, a common misconception in this regard is that price elasticity is "too low to make a difference".

Non-price demand management techniques can also create political liabilities in the form of water utility budget deficits. As we have discussed in Section 4.4, non-price conservation programs are costly. In addition, if these policies actually reduce demand, water utility revenues decline. During prolonged droughts, these combined effects can result in the necessity for substantial price increases following "successful" non-price conservation programs, simply to prevent water utilities from unsustainable financial losses. This situation occurred in 1991 in southern California. During a prolonged drought, Los Angeles water consumers responded to the Department of Water and Power's request for voluntary water use reductions. Total use and total revenues each fell by more than 20 percent. As a result, the Department requested a rate increase to cover its growing losses. Customers' perception that water conservation, instead of being rewarded, was penalized by a price increase, created intense political pressure for the city's elected officials (Hall 2000).

Is there political advantage to be gained by public officials who can demonstrate the potential for cost savings in water conservation, and the possibility of averting revenue crises of the type described above? The costs of inefficient water pricing and the relative cost advantages of price over non-price water demand management programs are well understood. But like other subsidies, low water prices (on a day-to-day basis, as well as during periods of drought) are popular and politically difficult to remove. Some communities may be willing to continue to bear excessive costs from inefficient water pricing, in exchange for the political popularity of low prices. In other cases, rate-setting officials may be constrained by law, unable to increase water prices by a percentage that exceeds some statutory maximum. In these cases, the tradeoffs involved should be measured and made explicit to water customers.

7. Conclusion

Water management in the United States has typically been approached as an engineering problem, not an economic one. Water supply managers are often reluctant to use price increases as water conservation tools, instead relying on non-price demand management techniques. These include requirements for the adoption of specific technologies (such as low-flow fixtures) and restrictions on particular uses (such as lawn watering).

This paper has offered an analysis of the relative merits of price and non-price approaches to water conservation. On average, in the United States, a ten percent increase in the marginal price of water can be expected to diminish demand in the urban residential sector by about 3 to 4 percent. For the purpose of comparison, this average of hundreds of published water demand studies since 1960 is similar to averages reported for residential electricity and gasoline demand. Estimates of the water savings attributable to non-price demand management policies such as watering restrictions and low-flow fixture subsidies vary from zero to significant savings. These programs vary tremendously in nature and scope. More stringent mandatory policies (when well-enforced) tend to have stronger effects than voluntary policies and education programs.

In a general comparison of the two approaches, we emphasize the strong empirical evidence that using prices to manage water demand is more cost-effective than implementing non-price conservation programs. Price-based approaches also have advantages in terms of compliance, monitoring and enforcement. In terms of predictability and equity, neither policy instrument has an inherent advantage over the other.

In specific cases, non-price water conservation programs can only be compared with price increases if water suppliers have a measure of the benefits of non-price conservation programs. In compiling this report, we were unable to find any estimates of the impacts of these types of water conservation policies in New England, and few such estimates exist, even for very expensive programs, across the United States. We strongly recommend the increased application of benefit-cost analysis in comparing price increases with non-price water conservation programs by cities considering implementing such policies.

As in any policy context, political considerations are important. Raising water prices (like the elimination of any subsidy) is politically difficult. Nonetheless, there may be political capital to be earned by elected officials who can demonstrate the cost-effectiveness advantage of the price-based approach. At a minimum, communities choosing politically popular low water prices over cost-effectiveness should quantify this tradeoff and make it explicit.

We are reminded in this discussion of the debate, beginning in the late 1980s, over market-based approaches to pollution control. While opponents of environmental taxes and tradable permit systems still resist these approaches, policymakers have succeeded in implementing them in many cases, achieving impressive pollution reductions at great cost savings over more prescriptive approaches. We hope that this work provides an impetus for a similar shift in the area of water conservation, where the principles are essentially the same.

8. References

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Table 1. Shares of U.S. Residential Water Price Structures, 1996-2002

	Percent of U.S. water utilities applying rate structure, by year			
Price Structure	**1996**	**1998**	**2000**	**2002**
Decreasing Block	36%	35%	35%	30%
Uniform Price	32	34	36	36
Increasing Block	32	31	29	30

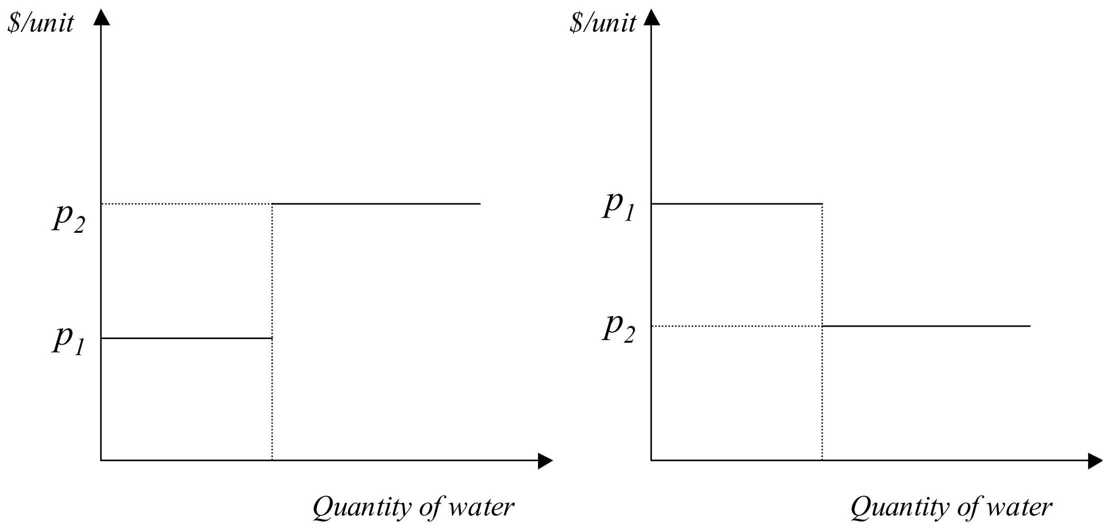
Source: Raftelis Financial Consulting (2002), PA, *Raftelis Financial Consulting 2002 Water and Wastewater Rate Survey*, Charlotte, NC, Raftelis Financial Consulting, PA: 6.

Table 2. Price Elasticity Estimates in New England

Water demand study	**Price elasticity estimate(s)**
Stevens *et al*. (1992)	-0.10 to –0.69
Stevens and Kesisoglou (1984)	-0.10 (short run), -0.38 (long run)
Male *et al*. (1979)	-0.32
Turnovsky (1969)	
Estimates for 1962	-0.05 to –0.40
Estimates for 1965	-0.29 to –0.41

Sources: Stevens, T. H., Jonathan Miller and Cleve Willis (1992), "Effect of Price Structure on Residential Water Demand," *Water Resources Bulletin* 28(4): 681-685; Stevens, Thomas H. and Eleni Kesisoglu (1984), "The Effect of Price on the Demand for Water in Massachusetts: A Case Study," Research Bulletin 698, Massachusetts Agricultural Experiment Station; Male, James W., Cleve E. Willis, Frederick J. Babin and Charles J. Shillito (1979), Analysis of the Water Rate Structure as a Management Option for Water Conservation, Water Resources Research Center, University of Massachusetts, Amherst, MA; and Turnovsky, W. D. (1969), "The Demand for Water: Some Empirical Evidence of Consumers' Responses to a Commodity Uncertain in Supply," *Water Resources Research* 5: 350-361.

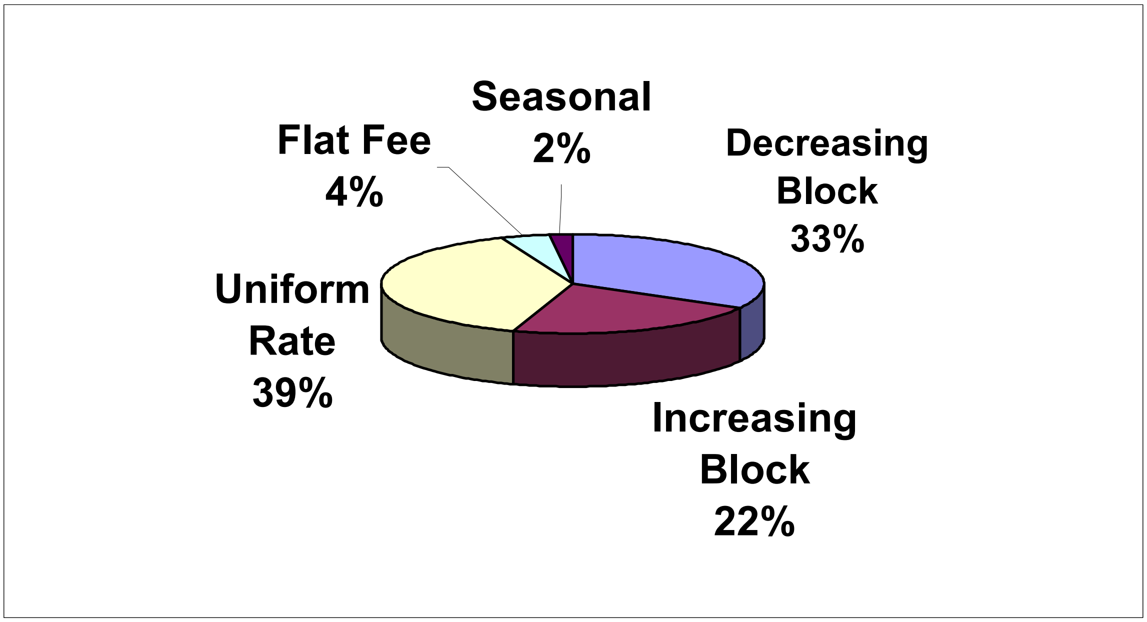
Figure 1. Increasing and Decreasing Block Price Structures



Two-tier increasing block price structure

Two-tier decreasing block price structure

Figure 2. U.S. Residential Water Rate Structures, 1996



Source: American Water Works Association (1998), WATER:\STATS 1996 Survey data.

Figure 3. U.S. Water Rates by Sector, 1996

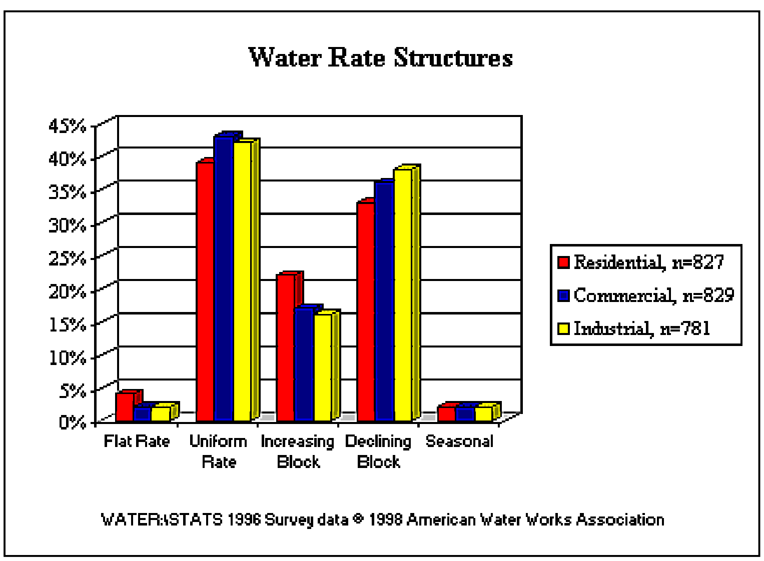
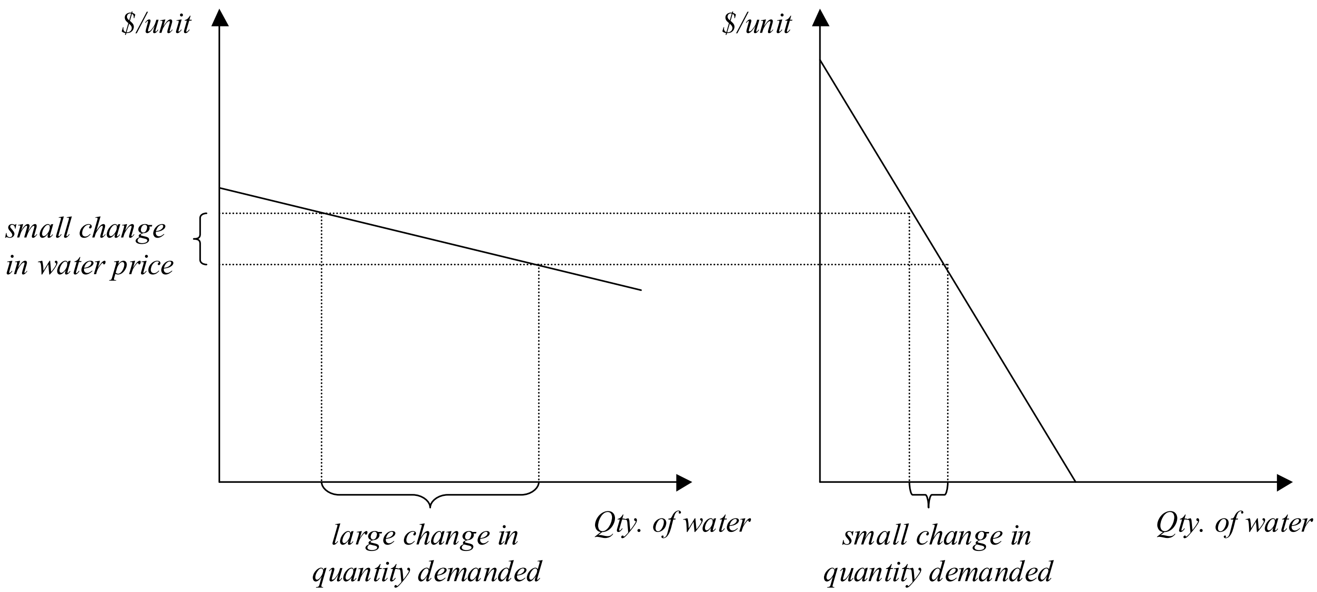


Figure 4. Price Elasticity and the Slope of Water Demand Curves



Relatively ***elastic*** demand

Relatively ***inelastic*** demand