UNBUNDLING WATER MARKETS:
INSTITUTIONS AND MARKET POWER

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Abstract

The supply of water is characterized by significant investments in distribution, which has public good characteristics. Losses in distribution are typically a large fraction of the water carried, often as high as 65-70%. Economic models of water have mostly ignored distribution. Prescriptions for water reform and privatization are not meaningful without a microstructural model of the water market that separates the market for generation, distribution and end-use. Alternative institutions with market power in generation, distribution or the end-use are compared with benchmark cases – social planning and a business-as-usual regime with distribution failure. The empirical results show that the status quo with market failure in distribution may be preferred to a distribution monopoly, while both are dominated by monopoly power in the input or output markets.

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1. Introduction

Water management has been called one of the most significant challenges of the 21st century. The then Vice-President of the World Bank, Ismail Serageldin, famously predicted in 1995 that "if the wars of this century were fought over oil, the wars of the next century will be fought over water." The distribution of water has public good characteristics. Water markets, in general, will not be efficient because individual users of water are unlikely to make optimal investments in the distribution of water. This source of market failure justifies government intervention in managing and supplying water resources. In the past, the generation and distribution of water has mostly been vertically integrated and operated as a state-owned utility. However, as numerous studies have shown, public ownership and management of water projects have led to serious inefficiencies including "weak incentives to reduce costs, implement marginal cost pricing or maintain water systems" (Cowan and Cowan, 1998).[2]

There is a sizeable literature on the need to privatize the management of water resources.[3] Privatization has often meant the creation of water markets at the retail end where water users (especially in agriculture) may buy and sell water that they receive from the distribution system.[4] However, market behavior at the downstream (retail) end is closely linked to the upstream generation and distribution of water. The analysis of privatization options is not meaningful without an explicit modeling of the microstructure of the water market so that the effect of market power in one segment of the market can be traced through the entire supply chain.[5]

A strong central authority will lead to the optimal provision of the service. However, when the providing

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[2] They suggest that the record of governmental provision in the water sector is "extremely poor." In developing countries, tariffs are routinely set well below cost recovery levels, often less than half the water supplied is paid for by beneficiaries, and large segments of the population are not connected to the grid.

[3] Holland (2002) provides an overview of the literature on privatization of water resources. Several studies have done comparative analyses of the performance of water utilities pre- and post-privatization.

[4] Water privatization has occurred sporadically in the urban sector in Europe and in Latin America and in a few water districts in California. In general, privatization efforts beginning with the Thatcher government's efforts in Great Britain and the large scale sale of state owned enterprises to the private sector in the Former Soviet Union have mostly focused on energy, telecommunications and transport industries (Stanislaw and Yergin, 1998). Consequently, the privatization of water resources has received almost no attention in recent surveys (see Megginson and Netter, 2001). Only about 15% of U.S. water systems are privatized compared with about 40% in Europe.

[5] Recent studies of the architecture of power markets (especially after the California power crisis of 2000-01) recognize that "market design is tightly controlled by technology" (Wilson (2002) leading to the development of economic models that "unbundle" electricity generation from transmission (see Joskow and Tirole (2003)).

authority is weak, privatization may lead to institutions that have market power in generation, distribution and end-use. We compare these institutions to the social planning solution and the *business-as-usual* case with sub-optimal investment in distribution.[6] They are compared in terms of social welfare, equilibrium output and price, volume of service (aggregate water use and area coverage) and its spatial distribution.

The analytical model suggests that with imperfect competition in generation, distribution or the end-use market, the cost of producing water is likely to be higher than optimal. The business-as-usual regime as well as end-use monopoly are likely to generate less water in the aggregate. Both these regimes result in a higher end-use price, lower output and a smaller service area relative to the optimal. To produce the same aggregate output, the cartel uses less water than the business-as-usual regime. If the cost of water generation is highly elastic, a water users association will have limited monopoly power in the input market and therefore may perform closer to the optimal solution. On the other hand, if the end-use market is characterized by high demand elasticity, deadweight losses under a producer cartel are likely to be lower, so that this institutional regime may be the preferred choice for reform. If both generation and end-use markets are characterized by high elasticity, and the returns from distribution investment are low, then it may be preferable to forego reform and maintain the low-efficiency business-as-usual regime.

The empirical model with stylized data suggests that institutions with market power in generation and end-use perform consistently better than the distribution monopoly and the business-as-usual regime. However, the distribution monopoly maximizes service area coverage, even though social welfare is relatively low. Thus if the policy goal focuses on maximizing the service area, the distribution monopoly may be the best candidate. It charges monopoly water prices, hence can distribute the service over a larger grid. Higher prices may also lead to increased conservation.[7,8]

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[6] Holland (2002) develops a dynamic groundwater extraction model to study how privatization may affect the timing of project development for importing additional water supplies, such as in the Central Arizona Project. In this case privatization may cause a delay in building import capacity since the private entity does not benefit from return flow externalities of groundwater use.

[7] The literature on water distribution is scant, but the problem is somewhat similar to transmission of electricity over high voltage networks. As pointed out by Joskow and Tirole (2003), most studies of electricity networks take the transmission network to be given, its capacity fixed and unaffected by decisions made by the transmission owner and the system operator. However the specific modeling of water distribution and electricity transmission technology is somewhat different. Water flows only in one direction while electricity can be transmitted in both directions so that there is no spatial asymmetry in the latter. Moreover, electrical network capacity varies with demand and supply fluctuations often within the same day so that capacity constraints under stochastic demand often lead to localized market power. Short-run capacity issues are less important in water distribution, since demand is not highly time sensitive. However, both problems share a common feature that needs to be addressed – the effect of unbundling generation and distribution on output and investment decisions.

For ease of exposition, we develop the model for water distribution in farming, which is by far the largest user of water.[9] The insights, however, are also relevant for urban and industrial water use, [10] as well as for any other commodity that is distributed over space.

In general, our analysis suggests that blanket proposals for privatization of infrastructure delivery services (e.g., water, sanitation and electricity) must be informed by the choice of an appropriate institutional delivery system. Which institution performs better depends upon the conditions in each of the micro-markets and their interlinkages through technology. A regime that delivers the highest (second-best) social welfare may not maximize service coverage. Privatization need not always be Pareto-improving. Under some conditions, a status quo regime with market failure may actually be preferred to privatization. The failure to recognize these technology linkages may result in failure of privatization efforts.[11]

There is a uniform consensus among experts that the supply of new water resources has become increasingly scarce and with increases in global population, the rising demand for water must be met only from reallocating existing supplies.[12] By 2025, more than 4 billion people – half of the world's population, could live under severe water stress, especially in Africa, Middle East and South Asia. In a recent State of the Planet review in the journal *Science*, Gleick (2003) makes the argument that while 20th century water policy relied on construction of massive infrastructure in the form of dams, aquaducts and pipelines, the focus in the 21st century must shift toward "soft" approaches that improve the efficiency of

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[8] Joskow and Tirole (2000) examine the welfare effects of financial and physical property rights in electricity transmission and market power of the transmission company.

[9] About 70% of global water use is in the farming sector (International Year of Freshwater (2003). In the Western United States, 76% of all surface water is diverted for agriculture (Congressional Budget Office, (1997)). Distribution losses in farming are especially severe, sometimes of the order of 50% of the water carried.

[10] Water supply for the production of export goods especially in manufacturing and high technology is a critical problem in the free trade zones of developing countries. Semiconductor manufacturing, for instance requires large amounts of de-ionized freshwater, often as much as an entire town. In the export-oriented *maquiladora* region of Mexico, it is claimed that clean water is so scarce that babies and children drink Coke and Pepsi instead (Barlow, 2001). Later in the paper we discuss urban and industrial applications.

[11] The failure of electricity privatization in California largely resulted from an inadequate appreciation of the technological features of electricity transmission and the consequent failure of privatized markets to induce investment in increasing transmission capacity (Wilson, 2002).

[12] New dams are not only prohibitively expensive to build but almost inevitably run into opposition on environmental grounds.

water use and reallocation of water use among different users.[13, 14]

Section 2 describes a vertically integrated water allocation model with distribution. In section 3, we model the specific institutional alternatives and compare their characteristics. Section 4 provides an illustration. Section 5 concludes the paper.

2. The Model

We extend a spatial framework developed by Chakravorty, Hochman and Zilberman (1995), henceforth referred to as CHZ. In order to facilitate institutional comparisons, we simplify their model and extend their analysis by imposing imperfect competition in the generation, distribution and end-use markets.[15] We consider a simple one-period model in which water is generated at a point source, e.g., a dam or a diversion in a river or a groundwater source. There may be multiple generating firms, provided all the water is delivered at one common location. Let $z(0)$ denote the amount of water generated at this location, determined endogenously. The cost of supplying $z(0)$ units of water is $g(z(0))$, assumed to be an increasing, differentiable, convex function, $g'(z(0))>0, g''(z(0))>0$. If the water is generated by multiple sources, then the cheapest source is selected for each marginal unit generated.[16] Water at the source is sold to the canal authority which manages the distribution system.[17] In what follows, we will make alternative assumptions about ownership of water generation and distribution. These operations may be owned by one vertically integrated firm or distinct firms may be involved in generation and distribution.

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[13] For instance, urban water may be conserved by using more efficient flush toilets – the largest indoor user of water in the U.S. (Gleick 2003). New efficiency standards have led to reduction of water use by about 75%, and further conservation is possible. In farming, drip irrigation and microsprinklers can achieve efficiencies in excess of 95%, compared to 60% or less in flood irrigation. Only about 1% of all irrigated land is under micro-irrigation.

[14] The need for improved management through institutional reform has also been highlighted in a recent Ministerial Conference on Global Water Security (Soussan and Harrison, 2000).

[15] They deal with water use and technology choice by firms located spatially under alternative water pricing mechanisms. They do not consider market power in water generation, distribution or in the end-use market which is the focus of the current paper. We simplify their framework by abstracting from endogenous choice of conservation technology by firms, which unnecessarily complicates the analytics without yielding any radically new insights.

[16] The sources are ranked according to "least cost first." They may be located at different distances from the source provided transportation costs are included in the cost of generation.

[17] Water may be generated at another source and transported through barges or supertanker. Transport of water over large distances is common. Japan, Korea and Taiwan import freshwater and Turkey is emerging as a major exporter. Both Alaska and Canada are rich in freshwater resources (often called the future "OPEC" of water) and have signed agreements to ship water to countries as remotely located as China (Barlow (2001)).

The canal company supplies water to identical users located over a continuum on either side of a canal. Firms at location x draw water from the canal, where x is the distance measured from the source. Let r be the opportunity rent per unit area of land. Without loss of generality, let the constant width of land be unity. For simplicity let us assume that each firm occupies a unit of land, so that the number of producers is proportional to the length of the canal.

Let the price of water charged by the canal company at any location x be given by $p_w(x)$. Then the quantity of water delivered by the canal company to a firm at location x is $q(x)$. The fraction of water lost in distribution per unit length of canal is given by the function $a(x)$. Let $z(x)$ be the residual quantity of water flowing in the canal through location x. Then

$$z'(x) = - q(x) - a(x)z(x) \tag{1}$$

where the right-hand side terms indicate, respectively, water delivered and water lost in distribution at location x. It suggests that the residual flow of water in the canal decreases away from the source ($z'(x) \leq 0$). Let X be the length of the canal determined endogenously. Then

$$z(0) = \int_0^X [q(x) + a(x)z(x)]dx. \tag{2}$$

From (1) and (2), the flow of water in the canal reduces to zero at the boundary ($z(X)=0$). The loss function $a(x)$ depends on $k(x)$, defined as the annualized capital and operation and maintenance expenditure in distribution, which varies with location. If there is no investment ($k=0$), then the fraction of water lost $a(x)$ equals the base loss rate $a(0)$, where $0 \leq a(0) \leq 1$. If $k(x)$ is strictly positive, then $a(x) < a(0)$. Let the reduction in the distribution loss rate obtained by investing $k(x)$ be given by $m(k(x))$. Then

$$a(x) = a(0) - m(k(x)). \tag{3}$$

Assume $m(\bullet)$ to be increasing, and exhibiting decreasing returns to scale in k.[18] Firms located along the canal use water $q(x)$ to produce output $y=f(q)$ where $f(\bullet)$ is concave, i.e., $f'(q)>0, f''(q)<0,$ and

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[18] Let $m(0)=0$ and $\lim_{k \to 0} m'(k) = \infty$, which suggests that marginal returns to distribution investments approach infinity as k goes to zero and $a(x)=a(0)$ when $k=0$. Then $0 \leq a(x) \leq a(0)$.

$\lim_{q \to 0} f'(q) = \infty$.[19] The production technology for each firm is assumed to exhibit constant returns to scale with respect to all other inputs.[20]

Let Y denote aggregate output. It is then given by

$$Y = \int_0^X f(q(x))dx. \tag{4}$$

Resource Allocation by an Integrated Water Utility

For the social planner, let the total cost of producing a given output level Y be given by $C(Y)$, which can then be expressed as

$$C(Y) = g(z(0)) + \int_0^X [k(x) + r]dx. \tag{5}$$

In (5) the cost of producing output Y is the sum of the cost of water generation, distribution and the opportunity rent to land. We use duality to determine resource allocation by minimizing the cost of producing a given level of output Y. The utility chooses functions $q(x)$, $k(x)$, and values for X and $z(0)$ that minimize total costs as follows:

$$\underset{q(x),k(x),z(0),X}{Minimize}\ g(z(0)) + \int_0^X [k(x) + r]dx \tag{6(a)}$$

subject to

$$z'(x) = - q(x) - a(x)z(x) \tag{6(b)}$$

$$Y'(x) = f(q) \tag{6(c)}$$

$$z(0)\ free,\ z(X) = 0,\ X\ free. \tag{6(d)}$$

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[19] We depart from the CHZ model by assuming that firm level conservation is fixed. In CHZ, firms choose conservation technology, so that a higher price of water leads to a greater investment in conservation. All our results go through with this modification. We discuss this issue later.

[20] In the case of urban water supply, *f(q)* may be the household demand function for water.

The corresponding Lagrangian is given by

$$L = k + r + \lambda_w(q + az) - \lambda_y f(q) - \lambda_z z \tag{7}$$

where $\lambda_w(x)$ and $\lambda_y(x)$ are the respective shadow prices of water and output, associated with 6(b,c).[21] The necessary conditions are

$$\lambda_y f'(q)) - \lambda_w = 0 \tag{8}$$

$$\lambda_w z m'(k) - 1 = 0 \tag{9}$$

$$\lambda_w'(x) = \lambda_w(x) a(x) \tag{10}$$

$$\lambda_y'(x) = 0 \tag{11}$$

$$\lambda_y = C'(Y) \tag{12}$$

$$\lambda_w(0) = g'(z(0)), \tag{13}$$

and

$$L(X) = 0 \tag{14}$$

where β is a constant.[22] From the maximum principle, $\lambda_w(x)$ is continuous on $[0,X)$, and $q(x)$ and $k(x)$ are continuous except at $x=X$.[23] In the above, $\lambda_w(x)$ is interpreted as the shadow price of delivered water at location x and (10) is the familiar condition analogous to Hotelling. The shadow price of delivered water increases away from the source because of the cost of distribution. The spatial allocation of resources is characterized as follows:

PROPOSITION 1**:** *Water supply, output and investment in distribution decrease away from the water source.*

Proof: see CHZ. □

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[21] We avoid unnecessary complications by avoiding attaching a multiplier to the state constraint $z(x) \geq 0$. From (1), if $z(x)=0$ at any $x \in [0,X)$, it could not increase from that value. Then the state constraint is never tight except possibly at $x=X$.

[22] At the boundary, $\lambda_w(X^-) - \lambda_y(X) = \beta$.

[23] The assumed limiting values of $f'(0)$ and $m'(0)$ suggest that $q(x)>0$ and $k(x)>0$ and thus (8) and (9) hold with equality.

An increase in the shadow price of water from head (upstream) to tail (downstream) causes a decrease in the amount of water used by each firm. So firms situated downstream of the project receive less water. The marginal product of water $(\lambda_y f'(q(x)) = \lambda_w(x))$ increases with distance leading to a decrease in its use, and a fall in output over distance. Of particular interest is the result that distribution investments decrease with distance. Although the shadow price of water increases away from the source, the volume of water being carried by the distribution system decreases at a higher rate because of water withdrawals by firms and distribution losses. The net effect is a decrease in the "value" of the residual water flowing in the system, causing a decrease in distribution investment.

At the boundary X of the distribution system, (14) gives
$L(X) = k(X) - r + \lambda_w(X)[q(X) + az(X)] - \lambda_y f(q(X)) - \lambda_z(X)z(X) = 0$. Substituting $z(X)=0$ and $k(X)=0$ and rearranging, yields

$$\lambda_y f(q(X)) - \lambda_w q(X) = r \tag{15}$$

which implies that net benefits from expanding service by one unit must equal the opportunity rent of land, r. Thus the equilibrium value of X is inversely related to r. If $r=0$ (land is in infinite supply), that would imply a greater service area. If r increased exogenously with x because the downstream locations were closer to an urban center, then X would be smaller. On the other hand if an urban area were closer to the upstream section, then the function $r(x)$ would be negatively sloping and various cases may arise depending on the relative magnitude of the land rent function and $r(x)$. For instance, in regions where $r(x)$ is larger than quasi-rents to land, land is better allocated for alternative uses such as residential or commercial use.

3. Alternative Institutional Choices

If government intervention is prohibitively costly or infeasible (e.g., when the government is weak) then the socially optimal allocation of resources may not be achieved. Empirical observation suggests that wherever privatization of water systems has taken place, it has "occurred not for ideological reasons but because the public system was so inefficient, its infrastructure so decrepit, and the state of its finances so precarious" (Orwin (1999)). In that case, privatization of water may be done through a variety of mechanisms. A polar extreme may entail total decentralization in which a utility may supply water but the distribution of water is delegated to the producing firms. There may then be sub-optimal provision of the public good since each firm will attempt to free-ride by failing to consider the benefits from its investment in distribution on other firms. Alternatively, the management of the distribution system may be transferred to a water-users association, which has market power in water generation and maintains the distribution system and charges each firm the true marginal cost of supplying water (Dosi and Easter (2003)). Yet another arrangement may involve a vertically integrated utility that buys water competitively or owns the water generation facility, supplies the public good competitively to firms and manages production. The utility may have market power in the output market.[24] Another institutional arrangement may be a system operator or a canal company which owns the generation facility (or buys water competitively) but is a monopoly seller of water to individual firms. While the institutional arrangements considered here are stylized, and there may not be an exact one-to-one correspondence between the institutions considered here and those in actual operation, the purpose is to examine how market power in water generation, distribution and in the output market individually may affect resource allocation. In Table 1 we provide a taxonomy of the different institutional arrangements for water generation, distribution, and the market for the end-use. For example, the business-as-usual regime with sub-optimal distribution may involve average cost pricing of water at each location or marginal cost pricing. Privatization may mean different combinations of market microstructures (competition and monopoly) in the generation, distribution and end-use markets. Below we model a subset of the various institutions summarized in the table.

a. "Business-As-Usual" Water Distribution

This is the benchmark model that aims to capture the situation when there is no centralized distribution of the public good and there is a general failure in operation and maintenance of distribution facilities.[25]

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[24] We thus consider the polar cases of a monopoly in the output market and a monopsony in the input market. This is mainly to tease out the relative effects of market power in the two markets on the spatial organization of production. In reality, these various forms of organization may have some degree of market power in both factor and output markets. An alternative model may involve an oligopolistic structure in the input and output markets, although the qualitative results may not be very different from the ones discussed here.

[25] Wade (1987) gives a graphic first-hand account of the gradual breakdown of an irrigation system in South India because of corruption and rent-seeking. Canals are not maintained regularly, so that losses from leakage as well as theft are common. In addition, often the more powerful among the beneficiaries steal water from the distribution system, depriving downstream users of their entitlements. In these low performance management regimes, water prices are generally not related to the amount delivered at any location. A water charge in the form of an output tax or land tax is common, if at all. Also see Ray and Williams (2002) for a discussion of water theft and cooperation along a canal. In our analysis, the price of water at each location equals marginal cost, but the results are qualitatively similar to any sub-optimal pricing scheme such as a land tax. The key feature of the "no frills" regime is the lack of optimal investments in distribution. In general, the stylized institutional arrangements modeled in this paper are based upon normative criteria relating to the performance of alternative management systems that can achieve second-best outcomes and not those that are already in place.

Firms withdraw water from a rudimentary distribution system and may individually invest in distribution taking investment by other firms as given. As we show below, this causes the usual free-rider problems associated with public goods. Water losses in distribution will be higher than under social planning. For convenience we assume that individual water users can engage in trade in water rights and thus pay spot shadow prices for water at each location.[26] Equivalently the water agency charges firms the marginal cost of water at each location and uses the proceeds to maintain a basic distribution system. Both of these arrangements yield the same outcome. Each firm is atomistic in the end-use market, which is modeled as a competitive industry.

Let the corresponding cost function under this decentralized *status quo* model be given by $C^d(Y)$. Individual firms act competitively by buying water from the water utility at its marginal cost at source.[27] Their investment in distribution $k(x)$ is chosen assuming other firms' investment as given. Let firm i be located at distance x. It receives its allocation of water $q_i(x)$ at the water source. If the price of water at source for the firm at location x is $\lambda(x)$ and the exponential loss rate of water is $a(x)$, then the value of water at any location in the interval $l \in [0,x]$ is given by $a(l)z_i(l)\lambda(l)$ where $z_i(l)$ is the water carried at location l for delivery to firm i. Firm i invests $k_i(l)$ and takes investment by all other firms $k_{-i}(l)$ as given. The choice of investment $k_i(l)$ is then given by

$$\underset{k_i(l)}{Maximize}\quad a(l)z_i(l)\lambda(l) - k_i(l)$$

where $a(l)=a(0) - m(k_i(l)+ k_{-i}(l))$. The necessary condition yields $m'(k_i(l)+ k_{-i}(l))z_i(l)\lambda(l)=1$. Each firm i chooses k_i to satisfy the above condition. Adding over all firms i, we obtain the condition for investment in the public good at any location $x \in [0,X]$ as $m'(\sum k_i(x))z(x)\lambda(x)=X$. Compare this condition to socially optimal investment in distribution given by (9), rewritten as $\lambda_w z m'(k)=1$. When $\lambda_w \geq \lambda$, $m'(\sum k_i(x)) > m'(k)$ so that $\sum k_i(x) < k(x)$ since $m''(k)<0$. That is, there is sub-optimal investment in water distribution at every location in the decentralized model, because of the free-rider problem.[28]

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[26] An alternative model with uniform pricing over space, e.g., a water charge in the form of a land or output tax, has been examined by CHZ.

[27] Since distribution investments are firm-specific, each firm buys water at cost at the source and chooses investment in distribution.

[28] CHZ assume that the benefits from individual firm investment in distribution are negligible, so that equilibrium investments under decentralization in their case is zero.

Each firm at location x chooses water as follows:

$$\underset{q(x)}{Maximize}\ \Pi^d(x) = pf(q(x)) - \lambda_w q(x) \tag{16}$$

where $\Pi^d(x)$ represents competitive profits at $'x'$. This yields $pf'(q(x)) = \lambda_w(x)$. Let us denote the cost function for aggregate output in this decentralized model as $C^d(Y)$. Equilibrium aggregate output Y^d and price p^d are then obtained as:

$$\underset{Y}{Max} \int_0^Y D^{-1}(\theta) d\theta - C^d(Y) \tag{17}$$

which yields

$$D^{-1}(Y) - C^{d\prime}(Y) = 0 \tag{18}$$

and

$$D^{-1\prime}(Y) - C^{d\prime\prime}(Y) < 0. \tag{19}$$

That is, price equals the marginal cost of producing output.

b. The Producer Cartel – An Output Monopoly

The producer cartel internalizes the public good nature of distribution investment by investing in water distribution and organizing production. It may either own the generation facility or equivalently, buy aggregate water needed for production at marginal cost. It supplies water at each location through a water trading or rationing scheme. It has market power in the end-use market where it operates as a monopoly. Examples of such market power include large plantation style agribusiness firms such as Archer Daniels Midland, Dole Pineapple, Tyson Chicken, ConAgra and Cargill and the scandal-plagued European dairy giant Parmalat, as well as producer cooperatives.[29] Historically under the Capper-Volstead Act of 1922, producer cooperatives in the United States have been given exemption from the nation's anti-trust laws so that they could overcome what was then viewed as destructive competition among independent farmers.[30]

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[29] Total net business volume of U.S. producer cooperatives in the year 2000 was a whopping $100 billion (USDA (2002)).

[30] A recent anti-trust analysis of dairy cooperatives suggests "we now see a small number of huge cooperatives, that

Let the consumers' inverse demand function for aggregate output Y be given by $D^{-1}(Y)$ which is assumed to be downward sloping, $D^{-1}{}'(Y)<0$.[31] We can now derive equilibrium price and output for the cartel. For any given level of output Y, both the social planner and the plantation must solve problem 6(a)-6(d). Their total cost of producing a given Y would be identical assuming that the program 6(a)-6(d) has a unique solution, since both a social planner and an output monopolist would allocate resources efficiently over space, including investment in distribution of water. However, aggregate output, water use and output prices will in general not be the same. Denote this common cost function by $C^{*}(Y)$, where the superscript '*' denotes the least cost for producing a given output Y.

Cartel output Y^{p} is chosen to maximize profits Π^{p} as follows:

$$Maximize\ \Pi^{p} = D^{-1}(Y)Y - C^{*}(Y) \tag{20}$$

so that Y^{p} solves

$$MR(Y) - C^{*}{}'(Y) = 0 \tag{21}$$

and

$$MR'(Y) - C^{*}{}''(Y) < 0. \tag{22}$$

Let p^{p} be the output price for the plantation. Then $p^{p} = D^{-1}{}'(Y^{p})$.

c. The Water Users Association – an Input Monopoly

The Water Users Association is assumed to be similar to the monopolist except that its market power lies in the market for water generation and it is a competitive price-taker in the output market. This may happen if for instance, there is only one buyer of generated water, and represents a setting in which the number of buyers of water may be relatively small. The point behind modeling the Water Users Association as an input monopoly is to contrast it with the plantation and thus show how market power in

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have extended their power beyond the assemblage of farmers, stretching vertically by ownership and alliances through the chain of production and distribution, all the way to the retail level….we are finding higher and higher levels of concentration in a spiral of countervailing strategies that increasingly present a model quite different from market competition," (Miyakawa, 2004).

[31] This may be a derived demand function for output from a more general consumer utility maximization problem.

the input and the output markets may affect resource allocation.[32] An example of this type of an "input cooperative" are the water districts in California which acquire, store and conserve water and allocate it to users. "These quasi-governmental entities can appropriate water, construct reservoirs and distribution systems, and enter into contracts with federal or state local suppliers" (Congressional Budget Office, 1997). The biggest one serves more than half a million acres. These districts contract to buy surface water supplies from either the State of California or the Bureau of Reclamation. "Water is allocated in large blocks controlled by strong local districts. They influence the terms under which virtually all of the water in California's Central Valley is used" (National Research Council (1992)). In other states, the most common type of water supply organization is a mutual water (or ditch) company. Mutuals are non-profit cooperative organizations that generally sell stocks or shares to members. These districts determine retail water prices. They recover their costs by charging prices that may or may not be independent of the quantity used. Retail prices may be much higher than what the districts pay to suppliers such as the Bureau of Reclamation (Congressional Budget Office, 1997).

The water-users association chooses to buy $z^w(0)$ units of water at the source to maximize total net benefits as follows:

$$\underset{z(0)}{Max} \int_0^{z(0)} D^w(\tau)d\tau - C'(z(0))z(0) \tag{23}$$

where $D^w(z(0))$ is the derived demand for aggregate water for the association. The necessary conditions are given by:

$$D^w(z(0)) = C''(z(0))z(0) + C'(z(0)) \equiv MFC(z(0)) \tag{24}$$

where $MFC(z(0))$ is the marginal factor cost of $z(0)$. Define the solution to the above problem as $z^w(0)$. Once the WUA chooses the aggregate level of service $z^w(0)$, it must allocate it efficiently for production. However, given the imperfect input market, the cost of producing aggregate output may be higher than for the social planner.

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[32] This comparison yields insight into the role of a "middleman" (Lerner, 1988) in which the entity is an input monopoly as well as an output monopoly, although we do not develop this case separately.

d. The Canal Operator – a Distribution Monopoly

The canal operator is a distribution monopoly assumed to be a firm that owns the canal and buys water from the generator and sells it as a monopolist to individual firms along the canal.[33] The operator owns and manages the distribution system. The firms produce output which is then sold competitively in the output market. There is a large body of evidence that privatization efforts in water have meant the sale of distribution assets from state-owned utilities to private monopolies that own and manage the canal system. For example, British Waterways, a state-owned water utility has appointed advisors to seek private partners for its 2000-mile national water network. The privatization will only lead to sales of water to industrial users and other water businesses but restore "derelict stretches of the canal system" to move water to areas including Wales and Scotland (Beautiful Britain, 2004). Suez Lyonnaise and Vivendi, two French Fortune 100 companies are private distributors of water in over 120 countries and have recently acquired several U.S. water distribution companies including United Water Resources and U.S. Filter Corporation (Clarke and Barlow, 2004). Before filing for bankruptcy, US energy giant Enron used its ill-gotten wealth to acquire several water companies around the globe in a botched attempt at water privatization.[34]

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[33] This model is somewhat similar to the Independent System Operator (ISO) with market power in the electricity case (see Joskow and Tirole (2000)). Bardhan and Mukherjee (2003) also examine an infrastructure delivery model in which a local government procures the service (e.g., water or electricity) from the utility and allocates it to heterogenous groups (rich and poor) users. However, their focus is on financial decentralization and the effect of bureaucratic capture on service delivery.

[34] A fascinating (with hindsight, rather ironic) personal interest account is given in a year 2000 story in the Wall Street Journal: "Four years ago, Rebecca Mark and Jeffrey Skilling were running neck-and-neck at Enron Corp., both of them rising stars equally likely to lead the Houston energy colossus one day…Today, Mr. Skilling, 47 years old, stands triumphant at Enron as its president and heir apparent to Chairman Kenneth Lay. Ms. Mark, 46, is gone. Their respective fates stand as testimony to the effectiveness of their competing business strategies. Mr. Skilling believed that Enron should own an asset for as long as it took to learn the secrets of a given business and that it must be willing to sell the asset if a better opportunity for the money arose. Ms. Mark pursued a more traditional and capital-intensive approach that involved buying or building "big iron," the generating facilities, pipeline networks and distribution companies that form the backbone of the global energy system. Ms. Mark got a chance to prove the primacy of her point of view when Enron staked $1 billion on creating a global water company called Azurix Corp. and put her in charge. The idea was to establish a beachhead as governments from Argentina to the United Kingdom began privatizing the heavily regulated water business. But almost from the start, Ms. Mark's initiative -- critically dependent on making speedy investments in a politically sensitive sector – stumbled. Ms. Mark believed governments were ready to embrace private capital as a solution to fixing their troubled water systems, just as they had done by privatizing their electricity grids and phone companies. "Water is the commodity of the next century. That's what she'd say." ...Ms. Mark in short order bought water companies or concessions in Britain, Argentina and Mexico and formed a Brazilian joint venture." However, things did not go according to plan. "In Argentina, one of the water concessions had such faulty billing systems that Azurix couldn't collect from most of its customers…in Britain, ..regulators ordered Azurix unit Wessex Water PLC and other water companies to reduce rates on the grounds they were making excessive profits…Taking a page from Mr. Skilling's book, she trumpeted the creation of a U.S. water market in which the liquid could be traded throughout the arid West. At eight pounds a gallon, water is slow to move where it doesn't want to go. The system of pipes and canals needed to move it throughout the West is

Let $\lambda_w^c(x)$ be the marginal cost of water at any location '*x*' and p^c be the equilibrium price in the output market.[35] Since the operator is a water monopoly, define $t_w(x)$ to be the price of water it charges at each location. The operator's maximization problem is given by choosing the aggregate water use $z^c(0)$, distribution investment $k^c(x)$ and water supplied at each location $q^c(x)$ as follows:

$$\underset{z^c(0),k^c(x),q^c(x)}{Maximize}\int_0^{X^c}[t_w(q)q(x)-k(x)]dx-g(z(0))$$

subject to conditions (1) and (3) where $t_w(q)$ is the derived demand for water at each location given by $D^{-1}(Y)f'(q)q$. It is easy to show that the necessary condition that determines $q^c(x)$ is given by

$$p^c f''(q^c)q^c + pf'(qc) = \lambda_w^c(x),$$

which implies that the marginal revenue at each location equals marginal cost.[36] Investment in distribution by the canal operator is given by condition (9), where $\lambda_w^c(x)$ is marginal cost of water at each location. Aggregate water use is determined by the relation $\lambda_w^c(0) = g'(z^c(0))$. The aggregate output Y^c is determined by the supply equals demand condition $D^{-1}(Y) - C^{c\prime}(Y) = 0$ analogous to (22) where $C^{c\prime}(Y)$ is the marginal cost function of output for the operator.

e. Comparison of Alternative Institutions

We first compare the cost functions for each institutional alternative. This can be stated as the following:

PROPOSITION 2: *For any given level of aggregate output Y,*

(a) the producer cartel has the same cost function as the social planner, i.e., $C^p(Y) \equiv C^*(Y)$.

(b) the total and marginal costs of the business-as-usual regime, the canal operator and the water users

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incomplete. There is no federal order, comparable to what exists in the natural-gas and electricity industries, forcing those who own the pipes to make unused capacity available to others. As Azurix's stock price fell and the money it had available for new investments dried up, Enron began to get itchy. Mr. Skilling, who in 1997 became Enron's president and was a member of Azurix's board, felt the water business, where Enron was up against bigger, well-established players such as Vivendi of France, was too capital-intensive and too slow to move to meet his performance benchmarks. Azurix insiders say privately, though, that a less aggressive, more patient owner would have served both companies better" (Smith and Lucchetti, 2000).

[35] The superscript 'c' denotes equilibrium values for the canal operator.

association are higher than optimal. The slope of their marginal cost functions is greater than optimal; i.e., $C^i(Y) \geq C^*(Y)$*;* $C^{i\prime}(Y) \geq C^{*\prime}(Y)$ and $C^{i\prime\prime}(Y) \geq C^{*\prime\prime}(Y)$*, where the superscript i denotes any of the three regimes.*

(c) The marginal cost functions $C^{d\prime}(Y)$*,* $C^{c\prime}(Y)$*,* $C^{w\prime}(Y)$ *and* $C^{*\prime}(Y)$ *are positively sloped.*

Proof: See Appendix.

The marginal cost functions for the optimal and the business-as-usual (BAU) case are shown in Fig.1. The marginal cost function for both the social planner and the producer cartel is given by the cost function $C^{*\prime}(Y)$. The marginal cost of output for the BAU case is everywhere higher than the optimal. The socially optimal price P^* and output Y^* are obtained at the point of intersection of the demand function D and $C^{*\prime}(Y)$. The price for the BAU case P^d and quantity Y^d are determined when demand equals supply $C^{d\prime}(Y)$. The monopolist equates marginal revenue $MR(Y)$ with $C^{*\prime}(Y)$ to give price P^m and quantity Y^m. The figure has been drawn such that the cartel produces a higher output and charges a lower output price than the BAU regime. However, it is easy to see that the converse could happen. The cartel could charge a lower price than the model with sub-optimal distribution if demand were relatively inelastic or if water losses in the latter contributed significantly to raising the marginal cost of output. The latter may happen, for instance, if returns to investments in distribution are low.

The following proposition compares aggregate water use for the cartel and the BAU regime:

PROPOSITION 3: To produce the same level of output, the producer cartel uses less aggregate water and services fewer firms than the BAU regime.

Proof: See Appendix.

Thus the cartel engages in more intensive service at each location than in the model with poor distribution. Next we compare the cartel to the socially optimal regime:

PROPOSITION 4: *The cartel produces less output and charges a higher price than the social planner. It uses less aggregate water and services fewer firms.*

Proof: See Appendix.

Given its market power in the end-use market, the cartel will price its product higher. However, the level

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[36] Sufficiency implies $p^c f'''(q^c)q^c + 2pf'' < 0$.

of aggregate service (water) provided by the cartel is also lower, and service is restricted to a smaller area than under social planning. This is true even though the cartel is not a monopoly either in the market for water generation or in distribution. Next we compare the BAU model with social planning:

PROPOSITION 5: *Business-as-usual* water *distribution leads to lower than optimal output at a higher price. The former also uses less aggregate water and serves a smaller number of firms.*
Proof: See Appendix.

Poor distribution, not only means a lower level of service (less aggregate water used) but a higher price in the end-use market since the cost of producing a given level of service is higher.[37] Moreover, the geographical coverage is also smaller than optimal. The relationship between the water users association and the social planner is shown in Fig.2. The aggregate marginal net benefit as a function of the initial stock of water $z(0)$ is shown as $MNB^*(z(0))$. This is the marginal benefit when water is distributed optimally. The water users association chooses the aggregate stock using the equilibrium condition (24), which equates $MFC(z(0))$ to the marginal net benefit. The corresponding price paid to the supplier is shown as P_w. This price is lower than the optimal price P_w^* and reflects the market power of the association. Aggregate water use by the water association is also smaller than optimal. Arguments similar to the ones made for the cartel suggest that the aggregate output and the size of the grid too will be lower than optimal.

However it is not clear if its output is lower or higher than the cartel or the BAU regime. This depends on the specific characteristics of the input and end-use markets as well as on the cost of distribution of water. For example, if the cost function for water generation is highly elastic (a flat $g(z(0))$ function), then the water users association does not have much market power in the input market. Its behavior will then be closer to that of the social planner. On the other hand if the supply function of water is relatively inelastic, then water use will be significantly below optimal, and the size of the grid will be lower.

An important issue is the distribution of the surplus that may accrue from generation and distribution of water, especially since the set of firms ex-post of privatization may be different than the set ex-ante. For instance, the BAU regime may be replaced upon privatization by a cartel, which may shrink the number of firms serviced by the project. Moreover, the distribution of *ex-post* benefits among the group should

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[37] Empirical observations of the effects of poor distribution tend to focus on the level of service and coverage and not on output prices (Wade, (1988)).

not lead to a distortion in incentives *ex-ante*. One solution may be to distribute ownership shares among the beneficiaries according to some neutral criteria, such as historical use. These shares could be traded, in which case, the price of the share equals the marginal cost of water. If the *ex-post* supply of water is lower than *ex-ante*, then the number of shares in the market will decline, and the utility may buy back and retire the surplus quantity of shares. Firms which were in the market before but do not receive water *ex-post*, may sell their shares and exit the industry.

The question arises as to which institutional arrangement may be a preferred second-best outcome under privatization? If the factor market is relatively elastic, as may happen in a region with a relative abundance of water resources, the buying price of water will be low (even though the aggregate water use is lower) and by (10), the price of water paid by a firm at any location will also be relatively low. This will mean a higher output at each location. If the returns from distribution investments are high, then the marginal benefit from using a larger stock of aggregate water is likely to be high (see Fig.2) leading to a relatively flat marginal benefit curve. In that case monopoly power in the input market will lead to a significant shrinking of the service area. If end-use markets are elastic, as in the case of an export market, the cartel may perform better than the other second-best alternatives since deadweight losses in the retail end are likely to be lower. On the other hand, in regions where distribution losses are relatively low (less porous soils) or the returns from distribution are low (high construction or maintenance costs relative to the cost of water)[38], a BAU regime might be an acceptable substitute for costly government intervention. Even with market failure in distribution, the performance of the system may be closer to optimal. Similarly if both output and input markets are relatively inelastic, then the BAU regime may outperform the other privatization alternatives.

Another important policy issue is the transition from the *status quo* (BAU) to private operation of the distribution system. If the current BAU water system were privatized and replaced by a producer cartel, it is not clear whether aggregate delivery of water use would increase. But in order to produce the same level of output, water allocation would be more intensive, leading to shrinking of the size of the grid. Thus, moving from BAU to a output cartel producing the same aggregate service will mean increased delivery at each location but a shrinking of the grid. On the other hand, when there is imperfect competition in both water generation and the output market, the system may be even smaller in size.

Application to Urban and Industrial Water Use

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[38] In this case, the Nash Equilibrium investment at each location may be close to the optimal.

The model can be easily adapted to examine privatization issues in alternative uses of water such as in the urban and industrial sector. In such settings, transmission losses are likely to be somewhat smaller than in agricultural systems,[39] but pumping costs may be a significant component of distribution costs at each location.[40] The demand for water at each location may be a derived demand, given by $D^{-1}(q)$, with $D^{-1\prime}(q)<0$. At least in the case of urban water, there would be no distinct market for final output. However, for industrial use of water, demand for the end-use (e.g., coal in power generation and mining) may be relevant.

It is easy to see that a distribution monopoly for urban water will lead to a lower aggregate supply relative to the optimal case, and to increased conservation by consumers, in the form of high efficiency equipment.[41] On the other hand, an input monopoly will also lead to a lower aggregate use of water but no such conservation effects. Antiquated distribution systems, such as those that exist in many old metropolitan cities, will exhibit the characteristics of the BAU model, which also uses less aggregate water and provides a smaller coverage.[42] Water prices at each location are likely to be lower than optimal. This may explain the high cost of upgrading urban water infrastructure to current beneficiaries, which is usually accompanied by an expansion of the grid to new consumers.

4. An Illustration

This section presents a simple illustration of the various institutional alternatives using typical cost and demand parameters for the Western United States. The purpose is to show how changes in elasticity and magnitude of demand in the end-use affect allocation under the alternative institutions. Firm demand for water is derived from a quadratic production function for California cotton in terms of water q such that a maximum yield of 1,500 lbs. can be obtained with 3.3 acre-feet of water applied, and a yield of 1,200 lbs.

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[39] Unlike in farming, transmission in urban areas is mostly through metal piping. However, privatized urban water systems in the U.K., which are often held up as a model for other countries to emulate, lose about a third of their treated water in distribution. Water losses in privatized South American systems is close to 50% of the total (Orwin (1999)).

[40] If pumping costs exhibit constant returns to scale with respect to volume and distance traversed, then the shadow price of water will be a linear increasing function of distance from source to consumer.

[41] See Hausman (1979) for an empirical study of consumers choice of energy conservation equipment in response to an increase in price.

[42] In the urban analog of our model, identical consumers are located along a grid. However, if consumers are heterogenous, i.e., have different willingness to pay for urban water, then our results may only hold in the aggregate but not at each location.

is obtained with 2.2 acre-feet (Hanemann (1987)).[43] The production function (in lbs) is given by

$$f(q) = -0.2965 + 1.3134 \bullet q - 0.6463 \bullet q^2 \quad (25)$$

where q is in m/m^2 of water. Differentiating with respect to q gives the marginal product function

$$f'(q) = 1.3134 - 1.2926 \bullet q. \quad (26)$$

Firm fixed costs denoted by F are taken to be $\$433$ per acre or $\$0.107/m^2$ (University of California (1988)). A quadratic function for distribution investment was constructed from average lining and piping costs in 17 states in Western United States (U.S. Department of Interior (1979), Table 15, p. 87).[44] An investment of $\$200$ per meter length of canal in piped systems results in zero distribution losses in the system. Concrete lining with an investment of $\$100/m$ attains a loss factor of $10^{-5}/m$ or a distribution efficiency of 0.8 over a distance of 20 km. When $k=0$, the loss factor is $4 \bullet 10^{-5}$/m yielding an overall distribution efficiency of 0.2. Thus we get

$$a = 4 \bullet 10^{-5} - (4 \bullet 10^{-7} k - 10^{-9} \bullet k^2) \quad (27)$$

so that from condition (3), $a(0) = 4 \bullet 10^{-5}$, and

$$m(k) = 4 \bullet 10^{-7} k - 10^{-9} \bullet k^2, \quad 0 \leq k \leq 200.\ ^{45} \quad (28)$$

A rising long-run marginal cost function for water supply was constructed from average water supply cost data from 18 projects in the Western United States (Wahl (1985)) as

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[43] We assume a field efficiency of 0.9, i.e., only 10 percent of the water allotted to the firm is lost through leakage etc.

[44] These numbers for construction costs, although dated, do not change appreciably over time. Even if they do, it is not the level of costs but the variation between alternative regimes that is important for our comparisons.

[45] The exact loss coefficient, however, would depend on environmental factors such as soil characteristics, ambient temperatures, etc. The results were found to be generally insensitive to variations in the value of $a(0)$.

$$g'(z(0)) = 0.003785 + (3.785 \cdot 10^{-11} z(0)) \tag{29}$$

where marginal cost is in \$ and $z(0)$ is in cu.m. It gives a marginal cost of $0.003785\$/m^3$ (\$4.67 per acre-foot) when $z(0)=0$, and marginal cost values in the range 0.068 to 0.16 \$/m^3 (93.34 to 195.9 \$/acre-foot) for the various models analyzed (see Table 2). A linear functional form was assumed to keep the formulation simple. For computational purposes, the water district is assumed to be of constant width $\alpha = 10^5 m$. The width, of course, does not affect the relative orders of magnitude across models.

An iso-elastic demand function for the commodity (California cotton) is constructed for elasticity values ranging from -1 to -4 (with intervals of 1) such that at a price of \$0.75, the quantity produced is $17.7 \cdot 10^8$ lbs. The demand function is of the form $Y=AP^{-\varepsilon}$ where A is a constant ($=13.725 \cdot 10^8$) and $\varepsilon>0$ is the absolute value of the demand elasticity. The sensitivity of the alternative regimes under increasing demand is examined by an outward shift in the demand function ($A=19.9125 \cdot 10^8$).

To solve for the optimal model, the algorithm starts by assuming an initial value of output price P and $z(0)$, and computes $\lambda_w(0)$ from (13). At $x=0$, (10) gives $m'(k)$. By iterating on k, we compute $k(x)$ that satisfies the derivative of (28), and (27) gives $a(x)$. Knowing $\lambda_w(0)$, (8) and (9) used simultaneously yields $q(x)$ and thus $y(x)$. Next, when $x=1$, using $a(0)$ and $\lambda_w(0)$ in the solution to (10) gives $\lambda_w(1)$, and $z(1)$ is obtained from (1) by subtracting the water already used up previously. Again, $\lambda_w(1)$ and $z(1)$ give $k(1)$ from (9) and the cycle is repeated to give $q(1)$, etc. The process is continued with increasing values of x until exhaustion of $z(0)$ terminates the cycle, and a new value of $z(0)$ is assumed. The algorithm selects the value of $z(0)$ that minimizes total cost (given by (6(a)). For each vector $(P,z(0))$, the corresponding output Y is computed to generate the supply function $Y(P)$. Finally, the equilibrium price and quantity is computed at the intersection of supply and demand. The algorithm was modified suitably for the other institutional regimes. For the BAU case, the Nash Equilibrium investment $k(x)$ is zero. For the output monopoly, supply equals marginal revenue in the output market. For the input monopoly, the price of water equals the marginal cost at a given $z(0)$, but the shadow price of water at source equals the corresponding marginal factor cost. For the canal monopolist, the allocation is determined by equating the marginal revenue for water at each location to the marginal cost of water as shown in Fig.3. The price of water charged by the canal monopoly is P_{cm}. However, it turns out that firms are not able to recover their fixed costs at that price. So, the monopolist charges price t_w, at which each firm exactly covers its total cost and thus makes zero profit.

Simulation Results

The results are shown in Table 2. They can be summarized as follows:[46]

In general, welfare effects are highest under a social planner, closely followed by the producer cartel and the water users association. The distribution monopoly yields the lowest total welfare in all four cases. Looking at the components of social welfare, surplus from water generation is maximized under the water users association, while distribution surplus peaks when there is a distribution monopoly. The generation surplus is also high under social planning, mainly because of the large quantity of aggregate water used, which produces surplus over the intra-marginal units. The distribution monopoly uses less than two thirds of the water under social planning, but covers nearly 20% larger area in the unitary elasticity case. This is because in the former, the supply of water is highly constrained. Because of this reason, the distribution monopoly can support a larger grid. If land availability is an issue, then this regime may not be the appropriate institutional choice. Except for the distribution monopoly, water use at each location is quite homogenous across all the institutional regimes.

As output demand becomes more elastic, the producer cartel increases output and reduces commodity prices, while both price and output in the status quo case decline. When demand elasticity of the end-use product is high, deadweight loss under the cartel is lower than in the status quo. When demand is elastic, the cartel covers a larger area and uses more water in the aggregate. In fact, for an elasticity of -4, the cartel generates higher social welfare than the water users association, and performs almost as good as the social planner. Therefore, for high elasticity in the end-use market (e.g., export commodities) , the producer cartel may be a preferred second best alternative.

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[46] For social planning, aggregate social welfare can be divided into consumer surplus given by

$$\int_0^Y D^{-1}(\theta)d\theta - D^{-1}(Y)Y,$$

and aggregate producer surplus which can be disaggregated into three individual components

$$D^{-1}(Y)Y - C(Y) = [\int_0^X \{(D^{-1}(Y)f(q) - I)\alpha - F - \lambda(x)q(x)\}dx] +$$
$$[\lambda(x)q(x) - k(x) - g'(z(0))z(0)] +$$
$$[g'(z(0))z(0) - \int_0^{z(0))} g'(\phi)d\phi],$$

i.e., the aggregate surplus accruing to producing firms, the distribution agency and the generating utility, as shown by the three bracketed terms. These expressions can be modified appropriately for the other institutional alternatives.

The distribution monopoly and the BAU model are consistently the weak performers, even in the high elasticity case (ε =4). However, the BAU regime always outperforms the latter. This suggests that poor distribution may be preferred to monopoly power in distribution. Water in the latter regime is relatively expensive, since transmission losses are high. Thus the equilibrium price of the end-use commodity is high, leading to a low consumer surplus. As demand becomes more elastic, the underperformance of these two regimes is more pronounced.

It is likely that the higher water prices under a distribution monopoly will lead to increased conservation through use of more efficient technology. This may lead to a better use of water by each firm, and less loss of water. Water prices are also high for the social planner, because of the higher marginal cost associated with the aggregate amount used.

End-use commodity prices are always highest under the status quo regime. Thus almost any institutional reform is likely to reduce commodity prices, simply because of the resulting investment in distribution. This is somewhat counter-intuitive since privatization in general results in an increase in delivery prices. However, that may be because *ex-ante*, prices were lower than marginal cost. In general a cartel performs better than a water users association. If demand elasticity is high, a cartel may even produce a greater output than the latter. The distribution monopoly always underperforms these two, and may be preferred if the goal is to provide service at the extensive margin, or induce firm level conservation.

The alternative regimes are compared under a high demand (50% growth) and a moderate elasticity (ε =2) scenario (Table 4). The high demand case may be thought of as representing growth in demand over time, and the elasticity of -4 as an exercise in evaluating the institutional differences when end-use demand is more elastic, possibly in another region or sector. The order of performance is preserved, namely, the water users association and cartel perform better than the distribution monopoly and the status quo. However the differences are smaller in relative terms.

5. Concluding Remarks

This paper models investment in water distribution and compares alternative institutional mechanisms with market power in water generation, distribution and the end-use commodity. In the past, the production of water has often been viewed as one monolithic entity. However, the public good nature of water distribution means that a water market will not lead to optimal provision. As pointed out by numerous surveys of public sector water projects, the government or the public sector may not be strong enough to undertake this task. Improving water management through privatization may mean a variety of alternative institutional choices. The choice of an institutional regime may depend upon the characteristics of the microstructure of the water market, namely the markets for water generation, distribution and end-use. These lessons are relevant for the delivery of any infrastructure service (water, sanitation, electricity, natural gas, etc.) that entails distribution costs.

The paper yields insights into which privatization alternatives may be appropriate in a given situation. For example, when generation of the service is relatively elastic, than a users association with market power in generation may perform closer to the optimal solution. On the other hand, elastic demand for the final product may indicate that an output cartel or a cooperative with market power in the output market may be preferred to the status quo. Similarly in locations where the scale of the service is important, a distribution monopoly could delivery over a relatively large service area. Monopoly power in distribution may also induce private conservation. In many cases, a poorly functioning distribution system may be preferred to a monopoly in distribution.

The empirical model shows that different institutions may have different impacts upon the geography of the region. For example moving from *status quo* to a distribution monopoly may mean that the area covered may double, yet output may increase only marginally and welfare may actually fall. A general result is that maximizing the number of beneficiaries is not equivalent to maximizing welfare in these second-best regimes. For instance, the distribution monopoly always maximizes the extensive margin yet performs relatively poorly in aggregate welfare and production. A distribution monopoly may be a worse outcome than the status quo and reform may be Pareto improving when market power is present in the input or output markets. This also suggests that policies that support water users associations or continue to provide anti-trust exemption to output cartels may have anciliary benefits in terms of mitigating problems associated with public good provision.

In terms of the management of scarce water resources, moving from the BAU to any of the regimes with distribution investments significantly increases (by as much as 70-80%) the efficiency of water use as measured by output per unit water generated. However, these numbers will be lower if the lost water is re-used elsewhere.[47] In general, consumer surplus also increases significantly from reform, even though the move to a distribution monopoly generates the smallest gain.

Future research could examine private incentives among heterogeneous water users under alternative forms of organization, i.e., what type of institutions will ensure cooperation given locational and possibly income asymmetries along a distribution system? More complex imperfect competition models (e.g, Cournot) with monitoring and enforcement costs could be used to compare different privatization models. Evolutionary game models could be used to examine conditions under which infrastructure projects may deteriorate over time leading to control of the service by a subset of beneficiaries and eventual exclusion of a large segment of the population from the grid.

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[47] see Chakravorty and Umetsu (2003)) for a model where the water lost may be retrieved, albeit at cost.

APPENDIX

PROOF OF PROPOSITION 2:

(a) In order to produce a given output Y, both regimes allocate resources efficiently and therefore have the same cost.

(b) The cost function $C^d(Y)$ is the total cost of producing output Y when investment in distribution $k(x)$ is sub-optimal. $C^*(Y)$ is the minimum cost of producing Y. Therefore, $C^*(Y)$ must be no greater than $C^d(Y)$. Similarly, the canal operator is a monopoly in distribution, and the water users association is a monopsony in generation. Hence $C^*(Y)$ must be no greater than $C^c(Y)$ and $C^w(Y)$.

To establish the second inequality, note that for the same level of aggregate output Y, the BAU model uses more aggregate output, $z^d(0) \geq z^*(0)$ because investments in water distribution are sub-optimal. Since $g''(z(0))>0$, we have $g'(z^d(0)) \geq g^{*\prime}(z^d(0))$, i.e., the BAU marginal cost of water generation is greater than optimal. We can write the identity $C^{d\prime}(Y) \equiv dC^d/dz(0).dz(0)/dY \equiv g'(z^d(0)).dz^d(0)/dY$. Similarly, $C^{*\prime}(Y) \equiv g'(z^*(0)).dz^*(0)/dY$. But $g'(z^d(0)) \geq g^{*\prime}(z^d(0))$ and sub-optimal distribution investment implies more water is required to produce incremental output in the BAU case, i.e., $dz^d(0)/dY \geq dz^*(0)/dY$. This yields $C^{d\prime}(Y) \geq C^{*\prime}(Y)$.

Finally, the slope of the unconstrained marginal cost function must be lower than the slope of the constrained marginal cost function since the former is an envelope of the latter (Silberberg (1990, p. 254). The proof of the other two cases is similar.

(c) The relation $C'(Y) \equiv g'(z(0)).dz(0)/dY$ and the discussion in (b) imply that $C^{*\prime}(Y)$ is positive. The remaining cases are similar. □

PROOF OF PROPOSITION 3:

The first part of the proof is straightforward. To produce the same level of output relative to BAU, the monopolist invests efficiently in water distribution. Aggregate water losses are therefore lower, so that to produce the same output, the monopolist must use a lower aggregate amount of water. Hence $z^p(0) \leq z^d(0)$. To see the second part, (13) and the last inequality yield $\lambda_w{}^p(0) = g'(z^p(0)) \leq g'(z^d(0)) = \lambda_w{}^d(0)$. From (10), $\lambda_w'(x) = \lambda_w(x)a(x)$. Because the cartel invests optimally in distribution and the BAU regime does not, $k^p(x) \geq k^d(x)$ for all $x \in J = [0,X^p] \cap [0,X^d]$. This implies that $a^p(x) \leq a^d(x)$ so that $\lambda_w{}^p(x) \leq \lambda_w{}^d(x)$ for all $x \in J$. Therefore $q^p(x) \geq q^d(x)$ and $f(q^p(x)) \geq f(q^d(x))$. Now suppose $X^p > X^d$. Then

$Y^p = \int_0^{X^p} f(q^p(x))dx = \int_0^{X^d} f(q^d(x))dx = Y^d$. Applying the last two inequalities yields a contradiction.

Hence $X^p \leq X^d$.[48] □

PROOF OF PROPOSITION 4:

The first part is obvious since the cartel is a monopolist in the output market. For the second part, both the cartel and social planner allocate resources efficiently. Since the former produces less aggregate output it uses less aggregate water. Thus $z^p(0) < z^*(0)$. Finally we show that the cartel uses less land area. Suppose $X^p \geq X^*$. Note that the last inequality yields $\lambda_w^p(0) = g'(z^p(0)) < \lambda_w^*(0) = g'(z^*(0))$. Since $\lambda_w(x)$ is continuous on $[0,X)$, $\lambda_w^p(x) < \lambda_w^*(x)$ at locations close to the source $(x=0)$. A higher price of water implies less water use, hence $q^p(x) > q^*(x)$. But this implies that output at every location close to the source is higher in the cartel case. Since its aggregate output is lower than socially optimal, and $X^p \geq X^*$, there must exist an interval $L = [0,X^p] \cap [0,X^*]$ where socially optimal output is higher, i.e., $q^p(x) < q^*(x)$ and $y^p(x) < y^*(x)$ for all $x \in L$. By continuity of $\lambda_w(x)$, $\lambda_w^p(x)$ and $\lambda_w^*(x)$ must cross. Thus socially optimal output is lower than cartel output upstream but higher downstream of the water source. Since $Y^p < Y^*$, we have

$$\int_0^{X^p} y^p(x)dx = \int_0^{X^*} y^p(x)dx + \int_{X^*}^{X^p} y^p(x)dx < \int_0^{X^*} y^*(x)dx$$

so that $\int_{X^*}^{X^p} y^p(x)dx < \int_0^{X^*} (y^*(x) - y^p(x))dx.$

The terms in the last integral are non-negative. That is, cartel production beyond X^*, in the interval $M=[X^*,X^p]$ is lower than the deficit in production in the cartel (relative to optimal) in the interval $N=[0,X^*]$. Thus, the cartel can mimic the optimal allocation of resources by transferring production from area N to area M, and save on distribution losses since interval N is closer to the source. The last inequality implies that this rearrangement is feasible. Thus the cartel is not efficient to begin with, which is a contradiction. So $X^p \leq X^*$. □

PROOF OF PROPOSITION 5:

The first part follows from Proposition 2 and is clear from Fig.1. Since the marginal cost function in the BAU case $C^{d\prime}(Y)$ is everywhere higher than the optimal $C^{*\prime}(Y)$, the equilibrium output price under BAU management is higher and aggregate output is lower than optimal.

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[48] However, when $P_m < P_w$, then $Y_m > Y_w$, i.e., if BAU output were higher than the monopoly output, then the relative sizes of the water stock and area are indeterminate.

For the second part, CHZ show that a model with no conveyance is likely to have lower aggregate marginal benefits which cuts the marginal cost curve below the optimal, leading to a lower value of $z^d(0)$, *i.e.,* $z^d(0) < z^*(0)$. By (13), this implies a lower marginal cost of water at the source, *i.e.,* $\lambda_w{}^d(0) \leq \lambda_w{}^*(0)$. Applying (15) to the respective boundaries of the two regimes we have $[p^* f(q^*) - \lambda^* q^*]_{x=X^*} = [p^d f(q^d) - \lambda^d q^d]_{x=X^d}$. Assume $\lambda_w(X^*) \leq \lambda_w(X_d)$. Since $p^* > p^d$, and $q(\lambda)$ is a monotone decreasing function, $p^* f(q^*) > p^d f(q^d)$. Since the product λq increases with λ, $\lambda^* q^* < \lambda^d q^d$.[49] Substituting these inequalities suggests that the boundary condition will not be satisfied which is a contradiction. Thus $\lambda_w(X^*) > \lambda_w(X_d)$. Now let $X^d > X^*$. Since $\lambda_w{}^d$ is lower than $\lambda_w{}^*$ at the beginning and at the boundary, then $Y^d = \int_0^{X^d} y^d(x)dx > \int_0^{X^*} y^*(x)dx = Y^*$, which is a contradiction. Hence $X^d \leq X^*$.□

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[49] That $q(\lambda)$ *is* monotone decreasing and $\lambda q(\lambda)$ is monotone increasing follows immediately from the proofs of Propositions 1 and 3 in CHZ.

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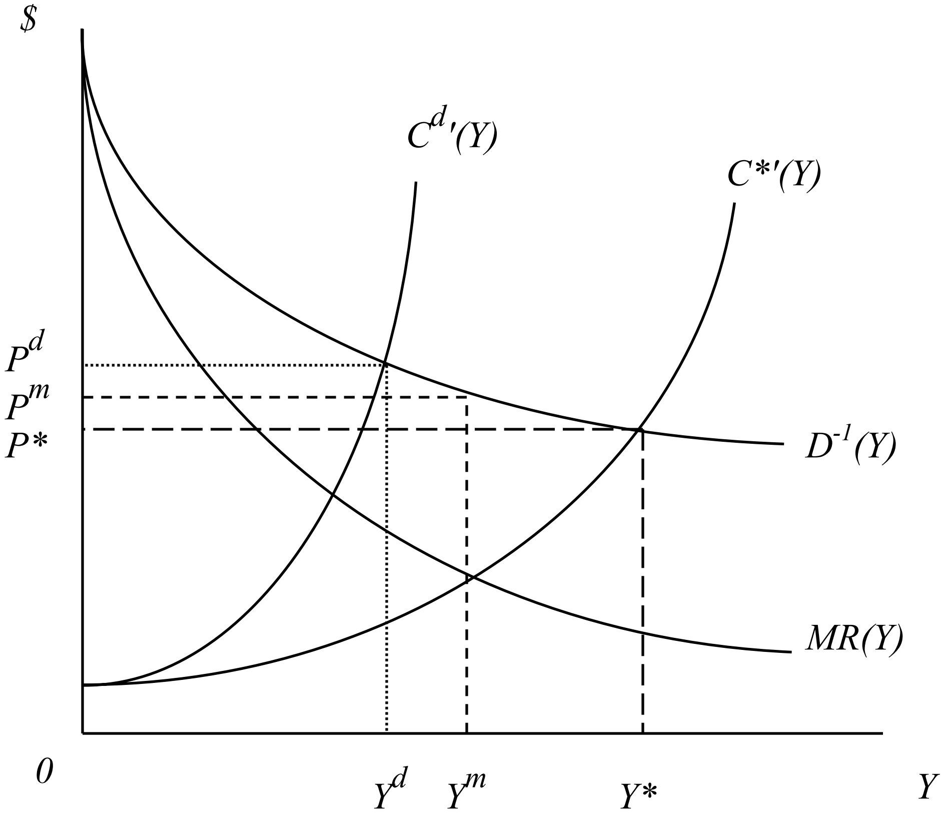

Fig.1. Equilibrium price and quantity under
social planning, business-as-usual and output monopoly

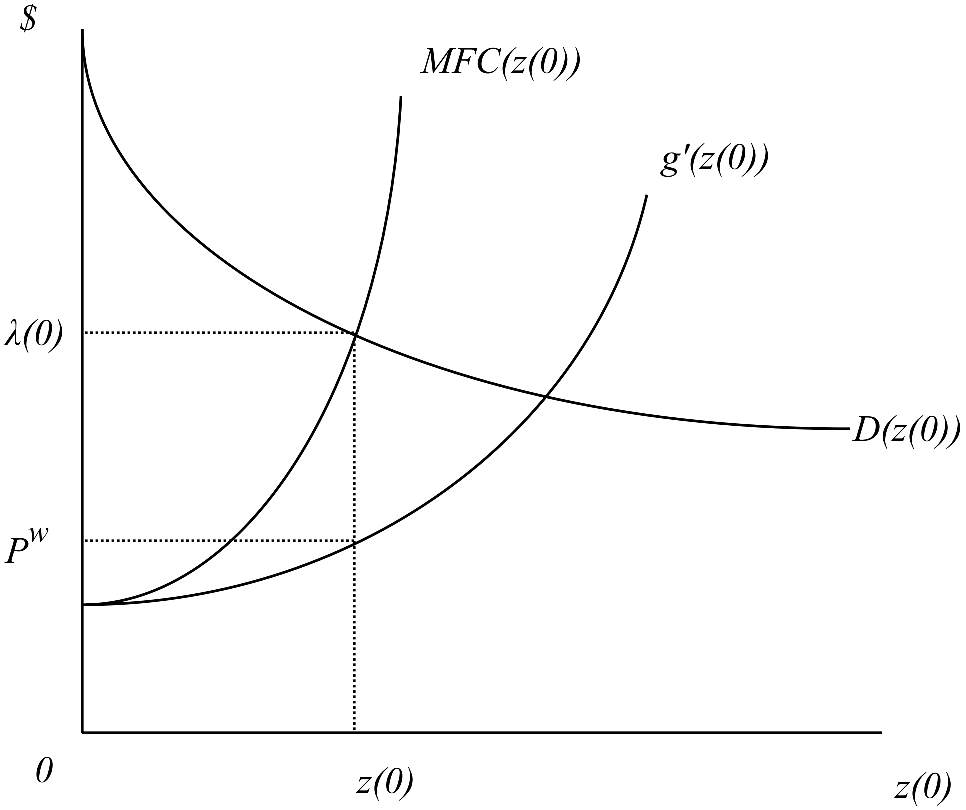

Fig.2. Price and marginal cost of water for the input monopoly

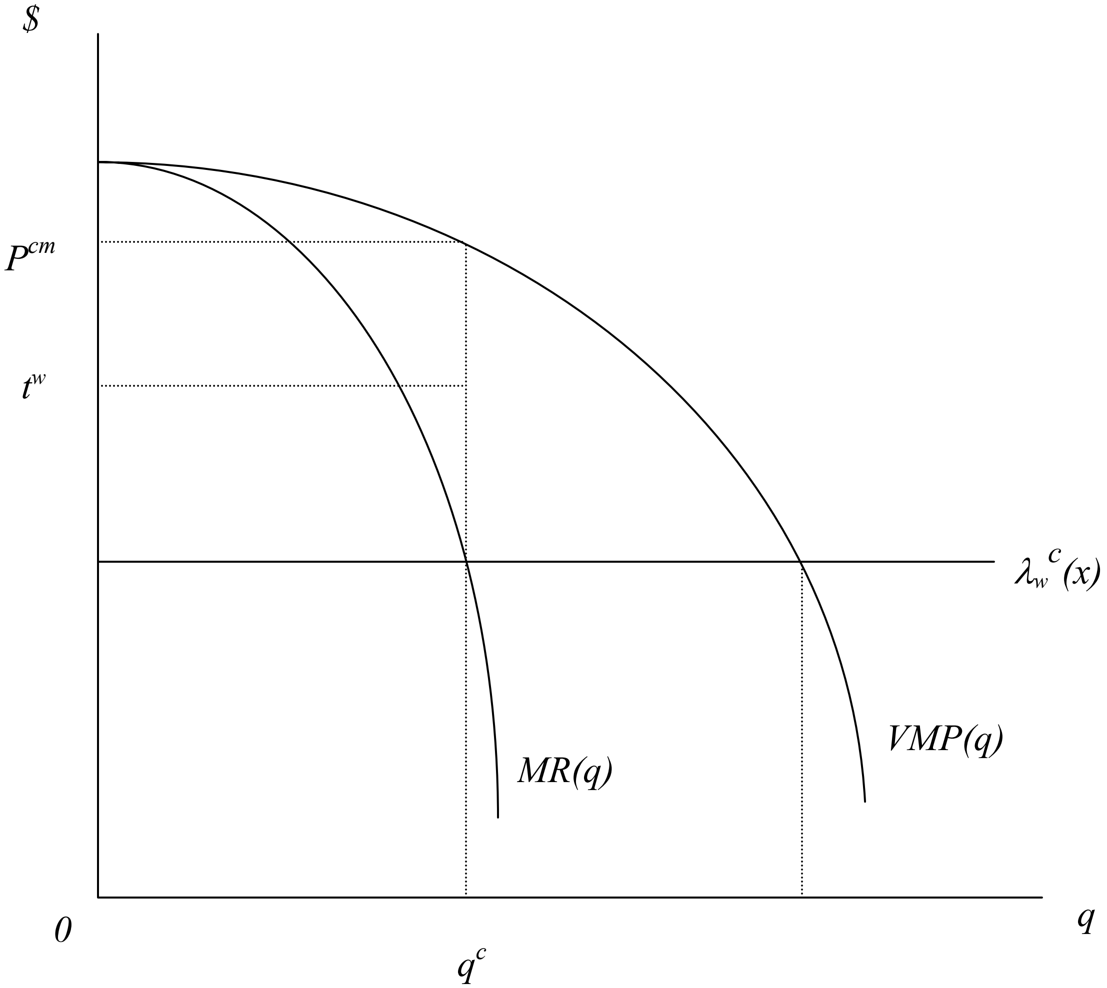

Fig.3. Water price charged by the distribution monopoly at location *x*

Figure 4. Social Planner, Business-as-usual and WUA Equilibrium Price and Quantity

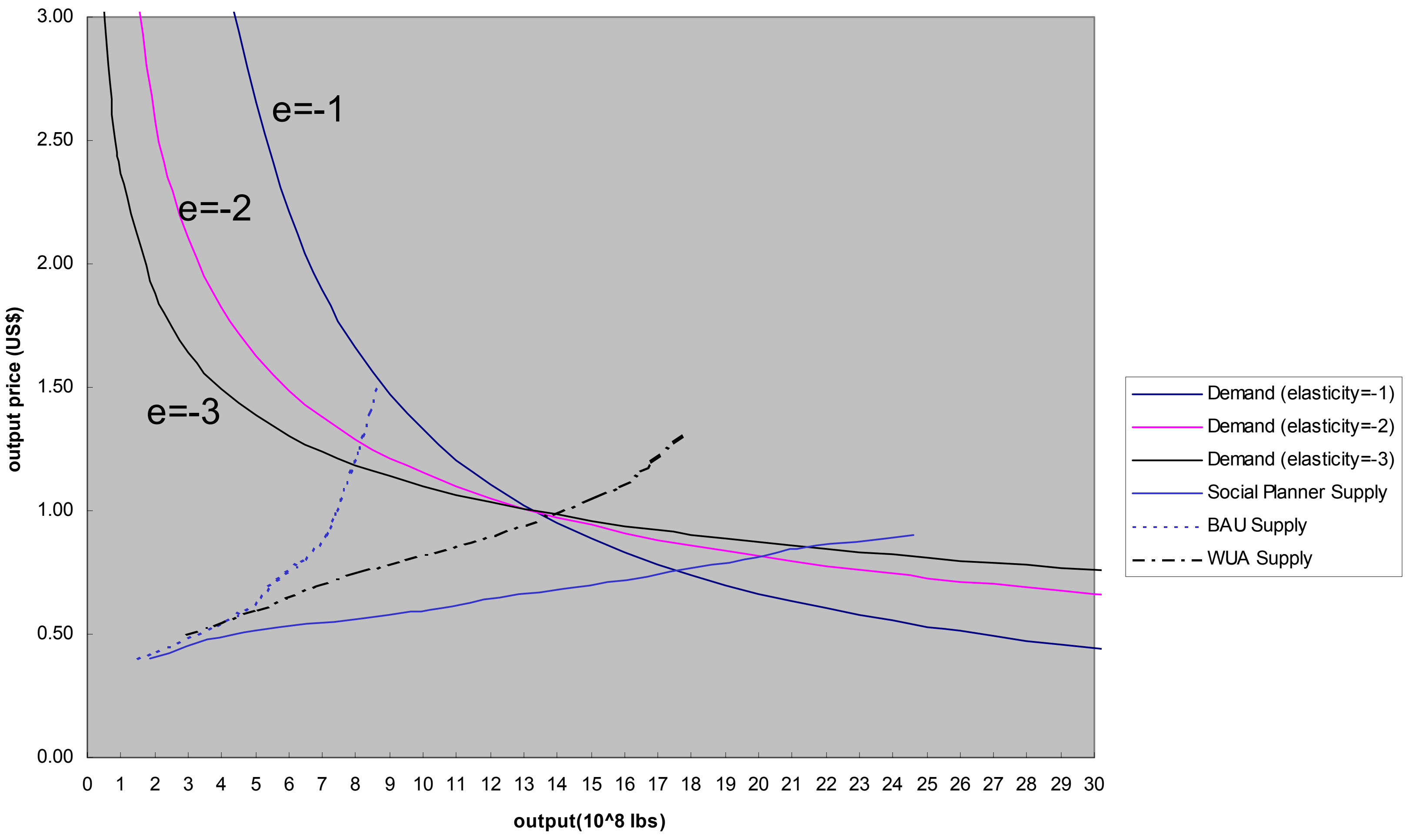

Figure 5. Business-as-usual, Distribution Monopoly and Producer Cartel Equilibrium Price and Quantity

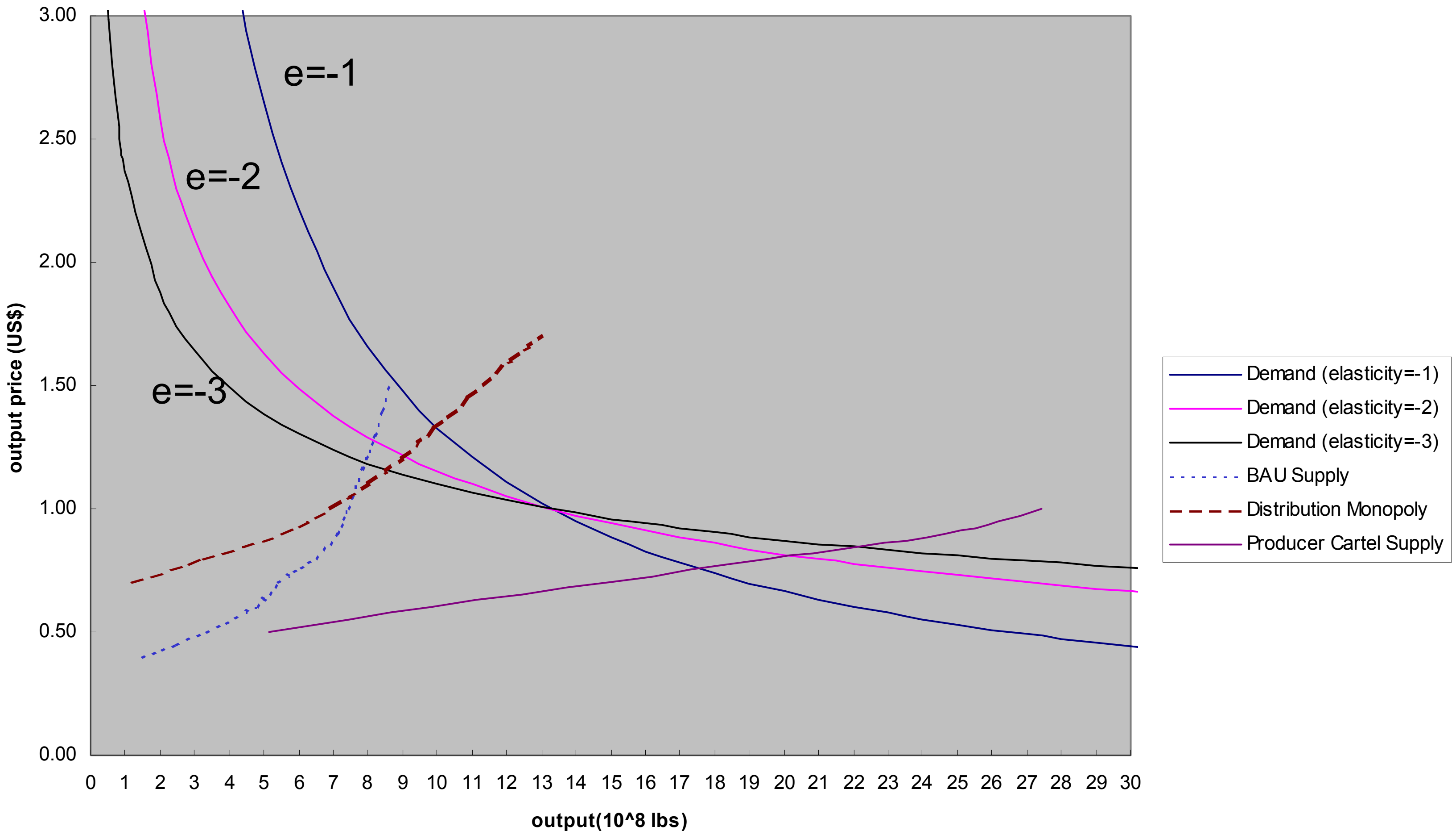

TABLE 1. MARKET POWER IN WATER GENERATION, DISTRIBUTION AND END-USE

	institution	supply	distribution	end-use	water pricing to user
			BAU		
CHZ	BAU utility	competitive	minimal	competitive	average cost
X	BAU water market	competitive	minimal	competitive	marginal cost
			Privatization		
X	canal operator	competitive	monopoly	competitive	Monopoly pricing
	integrated water company	monopoly	monopoly	competitive	Monopoly pricing
	water seller	monopoly	competitive	competitive	marginal cost
X	producer cartel	competitive	competitive	monopoly	marginal cost
X	Social Planner	competitive	competitive	competitive	marginal cost
X	Water Users Assoc (WUA)	monopsony	competitive	competitive	marginal cost
	WUA+Cartel	monopoly	competitive	monopoly	marginal cost

Note: The institutions marked ‘x’ are analyzed in the paper.

TABLE 2. SIMULATION RESULTS

	ε=−1				ε=−2					ε=−3				
	OPT/PC	BAU	WUA	DM	OPT	BAU	WUA	PC	DM	OPT	BAU	WUA	PC	DM
P (\$/lb.)	0.75	1.53	0.97	1.33	0.80	1.30	0.98	1.20	1.21	0.85	1.20	0.99	1.01	1.16
Y (10^8 lbs.)	17.31	8.62	13.59	9.71	19.53	8.18	13.59	9.84	9.02	21.39	7.93	13.59	13.31	8.02
A (10^3 ha)	480	250	400	570	550	230	400	260	520	610	220	400	360	450
z(0) (10^8 cu.m.)	41	34	31	26	46	31	31	24	24	50	30	31	32	21
R_L (10^8 \$)	0.12	5.36	0.45	0	0.22	3.77	0.58	0.13	0	0.53	3.12	0.72	0.12	0
CS (10^8 \$)	-	-	-	-	16.59	10.21	13.55	11.06	10.97	9.19	4.61	6.77	6.51	4.93
PS (10^8 \$)	3.32	7.55	4.14	4.06	4.23	5.63	4.28	7.15	2.91	5.26	4.82	4.41	6.62	2.47
GS (10^8 \$)	3.18	2.19	1.82	1.28	4.00	1.82	5.46	1.09	1.09	4.73	1.70	5.46	1.94	0.83
DS (10^8 \$)	0.02	0	1.87	2.78	0.01	0.04	-1.76	0.03	1.82	0	0	-1.77	0.03	1.64
PR (10^8 \$)	0.12	5.36	0.45	0	0.22	3.77	0.58	6.03	0	0.53	3.12	0.72	4.65	0
Aggr. Welfare	-	-	-	-	20.82	15.84	17.83	18.21	13.88	14.45	9.43	11.18	13.13	7.40
R_h (10^6 \$)	0.246	30.47	1.09	0	0.397	23.30	1.756	0.475	0	0.854	20.24	1.756	0.329	0
R_t (10^6 \$)	0.221	7.042	1.07	0	0.376	5.69	1.739	0.437	0	0.833	4.93	1.739	0.297	0
Y_h (10^8 lbs.)	0.353	0.358	0.331	0.167	0.349	0.360	0.332	0.364	0.170	0.345	0.361	0.331	0.360	0.174
Y_t (10^8 lbs.)	0.353	0.281	0.331	0.167	0.349	0.306	0.331	0.364	0.170	0.345	0.317	0.331	0.360	0.174
q_h (m/sq.m.)	0.852	0.879	0.770	0.455	0.832	0.890	0.770	0.918	0.459	0.817	0.896	0.770	0.887	0.465
q_t (m/sq.m.)	0.852	0.643	0.770	0.455	0.832	0.701	0.770	0.918	0.459	0.817	0.727	0.770	0.887	0.464
K_h (\$/m.)	199.23	0	199.32	198.12	199.39	0	199.32	197.80	197.80	198.79	0	199.32	198.75	197.14
λ_h (\$/cu.m.)	0.1590	0.1328	0.2384	0.1022	0.1779	0.1219	0.2385	0.0946	0.0946	0.1930	0.1162	0.2385	0.1249	0.0833
λ_t (\$/cu.m.)	0.1593	0.3611	0.2387	0.1039	0.1781	0.3058	0.2387	0.0950	0.0961	0.1933	0.2801	0.2387	0.1253	0.0852
tw_h (\$/cu.m.)				0.210					0.172					0.162
tw_t (\$/cu.m.)				0.209					0.171					0.161

Notes: OPT=social planner; BAU=business-as-usual; WUA=water users association; PC=producer cartel; DM=distribution monopoly; GS=generation surplus; DS=distribution surplus; PR=producer rent; h=head; t=tail; t_w=water price charged by DM; Consumer surplus for unitary demand elasticity is not defined.

TABLE 2 (CONTINUED)

	$\varepsilon=-4$				
	OPT	BAU	WUA	PC	DM
P (\$/lb.)	0.87	1.15	0.99	0.97	1.15
Y (10^8 lbs.)	21.39	7.93	13.59	15.00	8.02
A (10^3 ha)	610	220	400	410	450
z(0) (10^8 cu.m.)	50	29.7	31	36	21
R_L (10^8 \$)	0.96	2.72	0.72	0.34	0
CS (10^8 \$)	6.72	2.91	4.56	4.85	2.91
PS (10^8 \$)	5.69	4.42	4.11	6.54	2.39
GS (10^8 \$)	4.73	1.67	5.46	2.45	0.84
DS (10^8 \$)	0.01	0.03	-1.77	0.00	1.55
PR (10^8 \$)	0.96	2.72	0.72	4.09	0
Aggr. Welfare	12.41	7.33	11.18	11.39	5.30
R_h (10^6 \$)	1.543	18.44	1.756	0.806	0
R_t (10^6 \$)	1.523	3.345	1.739	0.783	0
Y_h (10^8 lbs.)	0.345	0.361	0.331	0.357	0.174
Y_t (10^8 lbs.)	0.345	0.317	0.331	0.357	0.174
q_h (m/sq.m.)	0.817	0.896	0.770	0.872	0.465
q_t (m/sq.m.)	0.817	0.727	0.770	0.871	0.464
K_h (\$/m.)	199.48	0	199.32	199.01	197.14
λ_h (\$/cu.m.)	0.1930	0.1162	0.2385	0.1400	0.0833
λ_t (\$/cu.m.)	0.1933	0.2801	0.2387	0.1403	0.0852
tw_h (\$/cu.m.)					0.1583
tw_t (\$/cu.m.)					0.1569

Notes: OPT=social planner; BAU=business-as-usual; WUA=water users association; PC=producer cartel; DM=distribution monopoly; GS=generation surplus; DS=distribution surplus; PR=producer rent; h=head; t=tail; t_w=water price charged by DM

TABLE 3. SENSITIVITY ANALYSIS WITH 50% GROWTH IN DEMAND

	$\varepsilon=-2$				
	OPT	BAU	WUA	PC	DM
P (\$/lb.)	0.90	1.50	1.1	1.31	1.38
Y (10^8 lbs.)	24.63	8.62	15.90	11.59	11.00
A (10^3 ha)	720	250	490	310	670
z(0) (10^8 cu.m.)	57	34.1	36	28	30
R_L (10^8 \$)	0.24	5.1	1.0	0.18	0
CS (10^8 \$)	22.13	13.28	18.10	15.20	14.43
PS (10^8 \$)	6.39	7.29	6.01	9.48	4.59
GS (10^8 \$)	6.15	2.20	7.36	1.48	1.70
DS (10^8 \$)	0.00	-0.01	-2.40	0.04	2.89
PR (10^8 \$)	0.25	5.10	1.05	7.96	0
Aggr. Welfare	28.52	20.57	24.11	24.68	19.02
R_h (10^6 \$)	0.338	29.39	2.093	0.578	0
R_t (10^6 \$)	0.319	6.200	2.076	0.538	0
Y_h (10^8 lbs.)	0.337	0.358	0.318	0.362	0.162
Y_t (10^8 lbs.)	0.337	0.281	0.318	0.362	0.161
q_h (m/sq.m.)	0.790	0.879	0.731	0.903	0.448
q_t (m/sq.m.)	0.789	0.643	0.731	0.902	0.447
K_h (\$/m.)	199.60	0	199.50	198.37	198.58
λ_h (\$/cu.m.)	0.2195	0.1329	0.2763	0.1098	0.1173
λ_t (\$/cu.m.)	0.2198	0.3611	0.2765	0.1102	0.1190
tw_h (\$/cu.m.)					0.215
tw_t(\$/cu.m.)					0.213

Notes: OPT=social planner; BAU=Business-as-usual; WUA=water users association; PC=producer cartel; DM=distribution monopoly; GS=generation surplus; DS=distribution surplus; PR=producer rent; h=head; t=tail; t_w=water price charged by DM.