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DERIVED DEMAND FOR IRRIGATION WATER: THE CALIFORNIA AQUEDUCT*

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Estimation of the demand function for area resources is a major concern of many regional economic analyses. Resource demand is dependent upon several variables, including the nature of demand for the products, supply of other inputs, degree of substitutability of inputs, the time period available for adjustment, and market structure. A major problem is how to explicitly consider these important variables in a reasonable manner with limited research means. This paper reports the application of one approach, a regional linear programming allocation model for California, to the derivation of demand for irrigation water as a productive input to agriculture in one developing subregion -- the West Side of the San Joaquin Valley.

In the past this area, consisting of one million acres, has been only partially irrigated by deep wells which are steadily exhausting the ground water sources. It has been a land of few cotton fields and ranches and many oil fields and tumbleweeds. However, beginning in 1968 the California Aqueduct, a part of the comprehensive California Water Project, began delivering water from the northern part of the valley to this arid zone. Initial development plans for the water project anticipated that more than one-half million acres of this land would be irrigated by 1980.

REGIONAL ALLOCATION MODEL

The linear programming model used here attempts to determine the least-cost spatial pattern of production which would meet specified 1980 production targets for the region. Constraints include rotation requirements and the quantity of land and water available for agricultural use by area. As the price of water in the subregion is varied, the quantity utilized in agriculture changes, tracing out what is in a sense a demand curve for irrigation water.

The state is divided into 95 production areas based on soil and climate characteristics, two of which are in the West Side subregion. The acreage available for agricultural production in each area during the period 1961-65 has been inventoried. Typical yield estimates and costs of producing major vegetables and field crops were obtained for areas with a history of production. These data were adjusted and extended to other areas with similar soil and/or climate. The availability of land and water for vegetables and field crop production in 1980 was projected based upon population projections, rates of urban expansion, planned water projects, and anticipated expansion of orchard crop production in the region. Production costs and yields were projected through a combination of regression analysis and the judgment of a panel of experts.

Demand projections for U. S. agricultural production in 1980 are based upon the work of Daly and Egbert [1, 2], Farrell [5], and the U. S. Department of Agriculture [8]. Adjustments have been made to reflect a revised domestic population projection lower than assumed by two of these sources. The projections were further refined to provide more detail for specific vegetables. Linear programming models have been constructed with alternative assumptions concerning the projected demand for California production. The set of

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production targets on which the water demand analysis is based was projected largely from recent trends in the U. S. share supplied by California.

With regard to several important variables affecting the demand function for a resource, the model treats them as follows:

1. The demand function for the region's products is perfectly inelastic – a fixed level and combination of products will be produced with each commodity's imputed price being equal to the marginal cost of the last unit.
2. The supply of labor and capital is perfectly elastic at specified prices over the entire region. Water supply is also perfectly elastic up to a fixed level within a production area with its supply over the region being a stepped function with respect to price. The availability of agricultural land is perfectly inelastic at any point in time, and its price is derived from the model as imputed rent.
3. Each crop can be produced in many areas; although marginal productivity varies, land in one area can be substituted for land in another. The factor ratios required to produce a commodity within a production area are fixed and one combination of inputs can be substituted for another combination only across areas.
4. The period of adjustment is long run. Therefore, capital investments in plant facilities, as well as short run expenditures on labor and other productive inputs can be changed.
5. The industry is assumed to be perfectly competitive both in the product and factor markets. The regional industry faces a perfectly inelastic product demand function, but the firm faces a perfectly elastic demand. The firm selects that cropping system which maximizes profits without concern for whether its level of production will alter the price of products or factors. So long as the difference between price and marginal cost is not negative, it uses all of its fixed resources in agricultural production.

APPLICATION TO A SUBREGION'S DEMAND FOR WATER

One of the purposes for the development of this model is to estimate optimal adjustments in regional cropping patterns due to projected shifts in demand, rates of urbanization, and public policy. For model details and results of that analysis, see Shumway, et al. [7]. In addition, permutations of the model have been conducted to estimate the derived demand for specific resources. Of major concern is the demand for irrigation water in one developing subregion – the West Side of the San Joaquin Valley.

Although development plans for the California Aqueduct anticipated more than a half million acres of land being irrigated here by 1980, this regional analysis does not support that expectation. With the currently estimated cost of water at $17.00 per acre foot, in 1965 dollars, and the production alternatives considered in this study, less than 300,000 acres in this subregion enter any of the 1980 model solutions.[1] Cotton and melons are the only two crops projected by the model for production there. Unless actual product price levels are higher than the imputed prices generated by the model (which would imply that regional production may be greater than the targets specified), then this conclusion follows: it will be uneconomic in 1980 for farmers to use the total volume of water projected for delivery on the West Side. Since the California Aqueduct is financed by state funds, the government has control over the price charged local districts for water. If it is uneconomic for farmers in several districts to use the water at currently projected irrigation water prices, it may be possible to increase the total annual return to the public's capital investment (and decrease the amount of subsidy) in this project by lowering price.[2]

Parametric programming was applied to the model solution to determine the demand function for irrigation water in this subregion. The optimum quantity of water demanded and the acreage of land to be irrigated in relation to changes in water cost are determined by systematically reducing the cost of irrigation water there by units of $2 per acre foot. Water prices in other areas are assumed to remain constant.

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[1] Some additional production of excluded crop alternatives will occur in this subregion. However, the acreage in these alternatives will not use all the irrigated land expected to be available. The cost of water is too high to support a pasture-hay economy. Therefore, the major alternatives left are orchard crops. Even if a large portion of the projected expansion of these crops were to occur in this subregion, it would require less than 100,000 additional acres by 1980. At least 150,000 fewer acres would be irrigated than has been estimated by the Department of Water Resources.

[2] Alternatively, it may be more profitable to sell the excess water to nonagricultural users. This option is not analyzed, partially because most nonagricultural users are in the Los Angeles area and additional facilities may be required to deliver the extra water over the Tehachapi Mountains. It is assumed in this study that water allocated for agriculture and not demanded there would not be utilized.

Demand for Irrigated Land

It is not until the average price of water declines to $5.00 per acre foot that all of the net model acreage in the subregion enters the model basis. However, at a price of $11.00, two-thirds of the acreage, 504,000 acres in one production area and 163,000 acres in the other, is brought into production. At a price of $13.00, a combined total of 417,000 acres is brought into production. Hence, the cost of water to the farmer would have to be reduced to approximately $12.00 to bring the one-half million acres of land into production for which water is planned to be available in 1980. The crop activity acreage in these two production areas at each water price level is recorded in Table 1. As water price decreases, not only is more land irrigated, but the crop composition moves to the more water-intensive crops.

Demand for Water

A continuous deflated 1980 demand function for irrigation water used by the study crops in these areas is estimated in loglinear form from the eight parametric program observations. The demand function is for all irrigation water in the area, not only that which is delivered via the California Aqueduct. With the quantity of water demanded in the subregion estimated as a function of price, this highly significant least squares regression equation is obtained:

$$\log_{10} Q = 3.77 - .052\ P$$

where Q is quantity of water demanded in the subregion (in 1,000 acre feet) at price P (in deflated dollars). The demand equation is plotted on a semilog scale in Figure 1. The deflated price of water is identified on the vertical axis and the total quantity demanded in the subregion on the horizontal axis.

Table 1. MODEL CROP ACTIVITY ACREAGE IN WEST SIDE PRODUCTION AREAS AT ALTERNATIVE WATER PRICES

Production Area 1

Average subregion water price[a]	Alfalfa hay	Barley-sorghum	Cotton	Dry beans	Safflower	Melons	Potatoes	Total
dollars/acre foot				acres				
17			166,000			40,936		206,936
15			166,000			40,936		206,936
13			166,000	46,694		40,936		253,630
11			166,000	64,872	220,188	40,936	12,003	503,999
9			166,000	64,872	220,188	40,936	12,003	503,999
7	58,725	28,540	166,000		220,188		30,547	504,000
5	293,489	44,511	166,000					504,000
3	338,000		166,000					504,000

Production Area 2

Average subregion water price[a]	Cotton	Dry beans	Safflower	Sugar beets	Melons	Total
dollars/acre foot			acres			
17	65,329					65,329
15	94,742					94,742
13	163,000					163,000
11	163,000					163,000
9	163,000					163,000
7	163,000	64,872			41,319	269,191
5	163,000	61,394	185,628	43,659	41,319	495,000
3	163,000	35,756	196,628	58,297	41,319	495,000

[a] Deflated to 1965 dollars.

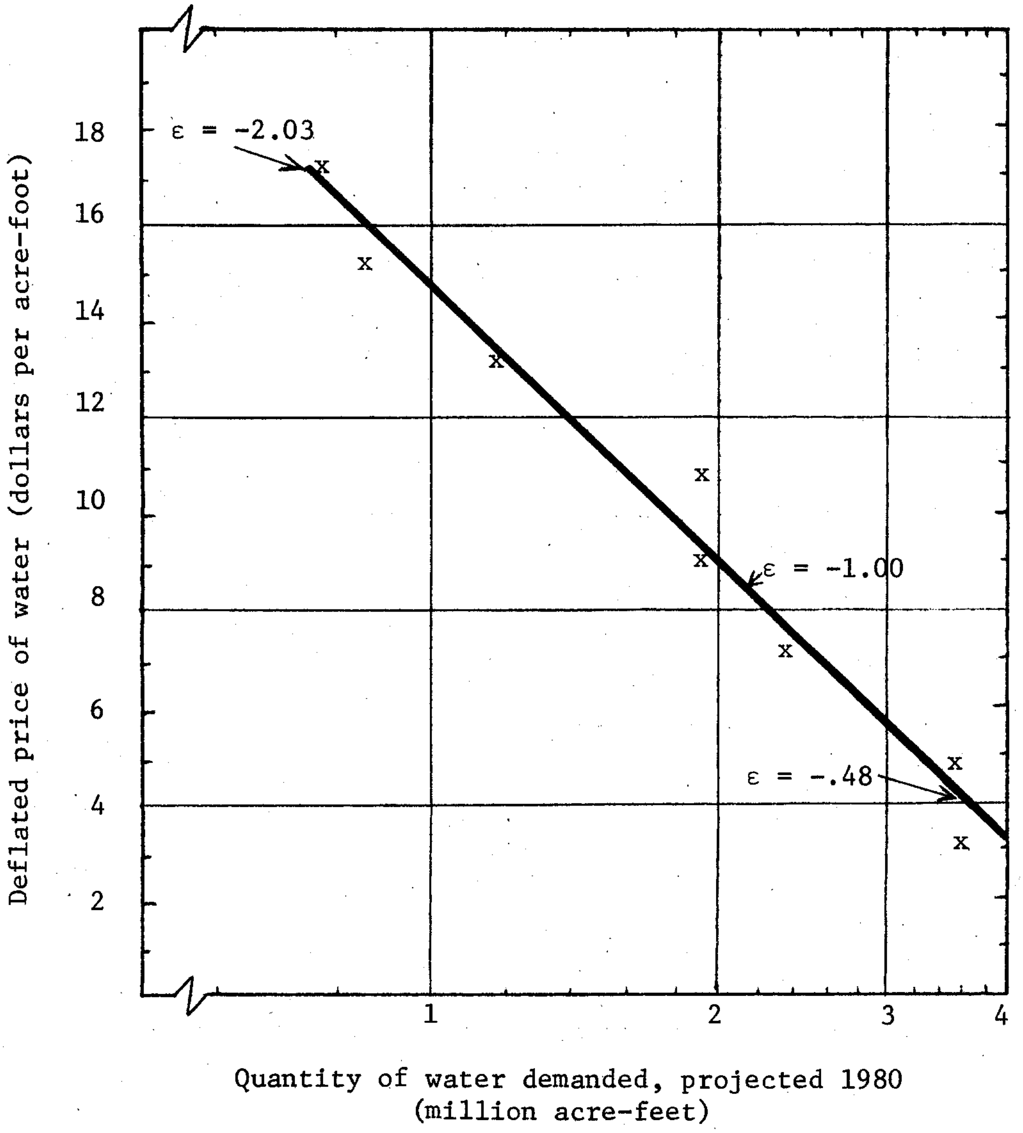

Figure 1. DEMAND FOR WATER, WEST SIDE SUBREGION

The elasticity of demand with respect to the deflated price of water is derived at selected prices and recorded also in the figure. The demand for water is elastic at prices above $8.50 and inelastic below. Hence, total revenue to the water project would be maximized by decreasing the price of water nearly 50 percent.

There are operating, maintenance, and power costs which vary with the amount of water delivered. Therefore, the price at which net returns on the state's investment are maximized would be higher than that at which total returns are maximized. The marginal cost of transporting increments of water up to capacity is estimated to be approximately $5.00 per acre foot for this subregion [3, p. 35]. From the derived demand equation, net returns would be greatest by charging a price of $13.00 per acre foot.

Comparison with Another Study

In contrast to this generally elastic demand function for water on the West Side of the San Joaquin Valley is the inelastic demand for water on East Side farms in one county, Tulare, estimated by Moore and Hedges [6]. At a water price of $9.00 per acre foot, the West Side demand for water is slightly elastic; that is, a one percent decrease in price would result in more than a one percent increase in quantity demanded, so total revenue to water suppliers could be increased by lowering the price in these areas. However, at a price of $9.44 in Tulare County, Moore and Hedges estimated demand to be very inelastic

($e = -0.188$).[3] A one percent decrease in price would result in only a .188 percent increase in quantity demanded; therefore, total revenue to water suppliers would increase by raising the price of water in Tulare County. Even at a price of $23.30 per acre foot, demand was still estimated to be inelastic by Moore and Hedges.

Both sets of demand curves for water were derived using parametric programming. However, certain differences are apparent in the underlying assumptions and technique, as well as the area of analysis. (1) The Moore and Hedges' demand function was for an area already fully developed for agricultural production with existing water distribution systems. Conversely, the demand function on the West Side is for a long run period in an area which is predominantly barren of agricultural production. Consequently, water distribution facilities must be constructed in this subregion and would not be constructed if the price of water appeared too high. (2) Their product demand curves were judged to be perfectly elastic as opposed to a downward sloping demand curve for this larger subregion. However, this difference would cause our results to be biased toward a less elastic water demand function relative to theirs. (3) Perhaps the most significant reason for the difference in elasticity estimated by the two studies is the method of fitting the regression equation to the parametric programming results. The relationship between water price and quantity demanded derived in this study was well represented by a continuous exponential function. From their analysis, Moore and Hedges concluded that the demand curve for water in Tulare County consisted of two discontinuous segments; while the price elasticity of demand is quite low over each segment, the elasticity between them is infinite, and the arc elasticity between the midpoints on both segments is near unity. Therefore, the difference between the estimates of elasticity from these two studies is not as great as it appears at first glance.

If there is an immediate bias in the estimation of demand elasticity for water on the West Side, it is likely to be in the direction of underestimating the true elasticity. Among the five variables affecting the demand for resources, the most heroic assumption in this study is that product demand for the entire region is perfectly inelastic. In the current analysis, the West Side subregion does face a downward sloping demand curve; if it can produce more efficiently, a greater share of the region's output will be purchased from this subregion. However, it is assumed that it competes only with other subregions of the state in supplying a fixed level of output. In reality, it will compete with other regions also: if the price of water is reduced in this subregion, the comparative advantage of the region as a whole will be altered; at any given product price level, the region may then produce more than it would have previously. Therefore, the true elasticity of demand for water in this subregion is probably greater than estimated here since the product demand curves are biased toward being insufficiently elastic.

CONCLUSIONS

With regard to the West Side subregion, this analysis results in the conclusion that the demand for irrigation water is elastic with respect to price in the projected range. Therefore, annual revenues to suppliers of water in this subregion may be increased by lowering the unit price of water.

Decisions concerning the water pricing plan in this developing agricultural subregion also have important implications for other subregions of the state and for other regions. The lower the price of water here, the more will be produced in total, and the lower equilibrium product price levels will be. Therefore, the profitability of agricultural production, and hence the marginal value product of water, in other areas will be affected by the water pricing plan here. Since state and federal agencies supply water to other areas, they may not be willing to see the demand for water dwindle elsewhere and may lower the price of water in those areas.[4] Then the demand curve for water in this subregion would shift downward too.

With regard to the model itself, the impact on the market demand for inputs from the production of multiple commodities with variable product prices, many producers, and alternative factors (with the price of all except rents to land being held constant) is explicitly considered. These features are all essential to an accurate ceteris paribus estimation of the market demand function for an input. This model appears to represent a substantial improvement for

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[3] This elasticity correlates closely with that estimated for a major West Side county by the Department of Water Resources [4, p. 225].

[4] The major losers from increased production on the West Side will likely be producers on the East Side of the San Joaquin Valley. Since state and federal water projects supply large amounts of irrigation water there, the possibility of compensatory water price changes in competing areas in response to changes on the West Side is not entirely remote.

large area analyses over those in which product demand is assumed to be perfectly elastic or in which all competitors are ignored. However, it is limited because it explicitly includes only a portion of the area's major competitors and ignores the real possibility of resource price changes in other areas in response to changes here.

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