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Empirical analysis of water market institutions: The 1991 California water market

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1. Introduction

Water markets are a fashionable topic whenever water resources utilization is discussed. This paper presents some empirical results from the recent 1991 California Drought Water Bank and addresses two questions that are of most concern in the design of future water market structures in California, and the implementation of water banks in other arid regions.

(1): What were the direct benefits and costs of the water bank to the state and regional economies?

(2): What were the levels of externalities generated by the bank, and how would the externalities change with changes in the water bank structure?

In both physical and financial terms, the 1991 California Drought Water Bank was the largest annual set of regional water trades to occur so far in the US and possibly the world. The drought water bank is a prime example of the evolution of a new allocation institution under intense pressure and with very little time available. Under these conditions the usual incremental evolution of institutions was bypassed, and a hundred million dollar emergency water market was literally created in four weeks. Despite the chaos in creating the emergency water market, it is generally acknowledged to have worked very well in reconciling drought year supplies and demands at minimum cost. The concept of water markets is now a permanent part of the water allocation system in California. However, there is considerable political pressure for ways to modify future water markets to minimize the external cost on local economies and the environment.

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The research task is now to use the results of this unique and rapid institutional change to draw conclusions for the design of water markets for the future in California and other regions where the pressures for water reallocation continue to grow.

The paper opens with an overview of the water economy in California and the changes that have led to the emphasis on water reallocation methods over project construction. A brief description of the major results from the 1991 Water Bank is covered in the next section. Two of the major problems for future water market design, namely, third party costs and farmer supply response, are covered in the latter part of the paper that offers some empirical analysis of market constraints and property right structures.

2. Californian and mediterranean water economies

Over the past two decades the increasing costs of new water development and the associated environmental costs have changed the focus of water utilization. Increasingly the problems of water resources utilization devolve to those of providing incentives for the efficient use and reallocation of existing supplies, rather than the physical development of new supply sources. Mediterranean water economies are characterized by the same problems and climate that face California, namely spatial and temporal inequalities of water allocation.

Throughout the mediterranean region urban and environmental water demands continue to grow, while agricultural water users wish to retain the cheaper water that was developed earlier. Nowhere is this problem more acute than in the economy of the State of California, USA, which in terms of its water uses, climate and conflicts has close parallels to Mediterranean countries. The California economy is large by international standards, and irrigated agriculture is a strong component of the economy. However almost all the urban, industrial, and residential water has to be imported to urban regions, some of it as far as 1000 km.

The recent 1987–1991 drought brought the conflict to a crisis in 1991. A short run water market played an essential role in resolving the conflicting drought demands by purchasing 1025 million cubic meters (M^3) of water from low valued agricultural uses, and selling it to higher valued agriculture and municipal and industrial water uses.

Several conclusions on the nature of agricultural sales to water markets and urban demands for purchased water can be drawn from the California water bank experience. These can be summarized by stating that both the demands and supplies for marketed water were more price elastic than had been estimated before establishment of the Bank. Both purchase and sale price was fixed for political reasons, but provided a clear signal for the opportunity cost of water. As well as actually supplying "wet water", the market generated external benefits by modifying demands that would have been higher under a system of cheap water supplied by a political system.

Negative pecuniary and technical externalities occurred in exporting areas, with adverse impacts on the local agricultural economy and some costs on groundwater sources. These external costs need to be resolved to make future water markets politically acceptable in exporting regions.

It is no exaggeration to say that the California economy runs on water. The potential for agricultural production without irrigation water is very limited and, like mediterranean countries, the areas of major rainfall are often far removed from the areas with the greatest potential for high value crops. In California most large urban areas have developed along the coast, particularly in the South where the urban and industrial growth exhausted the local ground and surface water capacity by the late 1920's. In addition to the regionally uneven distribution of water, there is a wide variation of water run off between years. Drought and flood periods are normal for California and most mediterranean river basins.

In the initial stages of water development both the spatial and temporal distribution of water was managed by a very complex system of dams and canals that moved water from North to South and stored water from wet years for use in dry years. The system was originally designed to provide a full supply in the driest recorded years. Due to the cost increase and environmental reasons outlined above, continued expansion of the physical water supply system has been halted since 1975. However, urban and environmental water demands keep growing, and agriculture showed only slight reductions in water use.

3. Operation of the 1991 water bank

The water bank was organized in a very short time, and started negotiating purchases in February at the fixed price of $\$100/1000\ M^3$. Purchases ceased at the end of April 1991.

Purchasers of water from the Bank paid a fixed charge at the Sacramento Delta of $\$140/1000\ M^3$, with most of the difference between purchase and sale price used to pay for carriage water. Thirty percent of the transferred water was needed for carriage water to provide salt protection in the Sacramento Delta. At this price plus the transportation cost from the Delta, the Bank sold 488 million M^3 of water. After the carriage water is included in the sales, 375 million M^3 remained in storage and was carried over to 1992. Three quarters of the water was sold to urban agencies. This is not surprising since in addition to the sale cost, the cost of transporting it to purchasing regions often resulted in a delivered price of over \$185/1000 M3 which, for California agriculture ruled out all but the more profitable fruit, vegetable and nut crops. Table 1 shows the aggregate prices and quantities that occurred in the 1991 California water bank.

Table 1
1991 California Water Bank

	Quantity (1000 M^3)	Price (US$/1000 M^3)
Purchases	1013	100
Sales	488	140
Flow control	150	
Water unsold in 1991	375	

The State Department of Water Resources was able to operate the 1991 bank at an overhead cost of about 8% of the water purchase cost.

Water was purchased in three ways. Half the water purchased was obtained by paying farmers for the water that their irrigated crops would have consumed. The price offered for the water was fixed, but when multiplied by the consumptive water use of the crop, it offered the farmer substantially more profit than could be expected from the lower value crops.

One third of the water purchased also came from farmers in the form of exchanging their surface water rights for groundwater rights and selling the surface water to the bank. The remaining 17 percent of the purchased water came from surface water that was in excess of the requirements for some water districts in the north of the state.

The demand for water from the Bank was obtained from a committee representing the urban and agricultural water purchasers. The number of purchasers was much lower than the number of sellers, but any potential monopoly power that the purchasers may have had was removed by the fixed purchase price condition that the State Governor insisted was part of the Bank. Table 1 shows that 37% of the purchased water in 1991 remained unsold. This water was carried over to 1992 and sold at a lower price. The benefit of the excess water carried over was not included in the net benefit calculations for the 1991 Water Bank.

Both urban and agricultural water users modified their estimates of the demand for water after the bank was in operation and the cost of supplies became known.

The first column in Table 2 is the estimate of the quantities of water that the

Table 2
California drought year demands

	Critical "needs" April 1991 (million M^3)	Actual purchases October 1991 (million M^3)
Urban/industrial	512.50	473.47
Agriculture	256.25	127.50
Total	768.75	601.25

two sectors had to have to supply the "critical needs" stated by their customers. These estimates were made by the large wholesale agencies after the last rains had occurred in the year, and reflected the water requirements that their water agency clients passed on to them. The distinction between requested needs and actual purchases is worth noting. Comparison of the two columns in Table 2 show that the California water buyers have elastic demands, even in the fifth year of a drought. When faced with the high price of purchased water, consumers revised their needs downwards and actual purchases were 11% less than the estimates of "critical needs". Much of this difference was obtained by effective water conservation. In urban areas the average cost of water conservation was estimated at \$240 per 1000 M^3. Most urban areas that purchased water were faced with an additional \$60 transportation cost, making the total cost of purchase and transportation of water from the Water Bank comparable to some conservation methods.

The actual quantity of water sold by the Bank was small in comparison to the total use, however the price of the Bank water set a value for all water which had a potential for being traded. Thus the operation of the Water Bank changed the value of most of the water in the State. This increase in value without an increase in cost to the farmer is a politically acceptable way of sending the signal to water users of the true value of water.

3.1. The direct impacts of the 1991 Water Bank

The Bank generated direct benefits for the State economy by creating a net gain in income and employment by trading water from lower value to higher value uses. Table 3 based on Howitt et al. (1992) shows the net financial effects of the water trades.

Table 3
Statewide net benefits from the 1991 Water Bank (US\$ million)

Exporting regions	
Income lost from crops	76.02
Income gain from water sales	63.27
Export region income loss	−12.75
Importing regions	
Income gain in agriculture	45.40
Urban consumer surplus gain	58.77
Benefits to importing regions	104.17
Net benefits	
Agriculture benefits	32.65
Statewide income benefits	91.42
Value of surplus water	14.40
Total net benefit	105.82

The effect of the Bank on the rural economies in water exporting regions was calculated using the actual changes in the value of output of agricultural production caused by water bank sales and purchases, and applying regional input/output (I/O) multipliers to the changes.

Table 3 shows the net financial effects of the water trades. The financial effect on exporting regions was calculated from the net effect of decreases in revenues associated with crop production, but increases in the net income of the farmers who sold water to the bank. The overall effect on net revenue was slightly negative, since the effect of the increased farmer profits did not fully offset the loss of crop production expenditures on the local economy. The average net income loss to exporting regions is calculated as $12.5 million, which is approximately 5% of the net agricultural income. Due to the diversity of regional production, in many regions the reduction is a much smaller proportion of total regional income.

The regional income lost due to crop fallowing is shown on the first line of Table 3. The positive effect of the additional income from water sale revenues is calculated by using an I/O income multiplier for the appropriate region, and is shown on the second line of Table 3. Clearly farmers would not have sold their water below its value marginal product, but the regional income loss is caused by the difference in multipliers and expenditure patterns between crop expenditures and increases in net farmer income from water sales. In some cases, the additional profits from selling water were largely used to reduce debt, a use which has little beneficial impact on the local economy.

The value of the water to the importing agricultural regions is calculated using the crop specific output multipliers for the crops on which the purchased water was applied. As would be expected from the high water price, purchased water in agricultural regions was used for high valued fruit, nut and vegetable crops. Thus, while the water sold to agricultural crops was only 22% of the total bought, the agricultural income generated by the water was 83% of the total loss. There are three reasons for this asymmetry in value. (1) As mentioned earlier, only half the purchased water was by fallowing contracts which required the reduction or elimination of crop production. Thus half the water was purchased without reducing the regional crop production in water selling regions. (2) The net returns per unit of water was substantially higher for the crops for which water was purchased. (3) The effect of these crops on local income is substantially higher due to the larger amount of local processing and packing involved with the higher valued crops. Due to this large difference in income generation, the net benefits of the water transferred between agricultural regions is substantial.

The urban benefits are harder to correctly estimate. Some analysts cite very high values of marginal urban water use of $800–$1000/M^3 of water that are often imputed from intensive manufacturing uses. However, these high average values do not reflect the marginal value of urban water in California in 1991. Urban benefits were calculated using an estimated demand function for water in

Table 4
Statewide employment impacts of the 1991 Water Bank

Exporting agricultural regions	
Jobs lost from crops	3133
Jobs gained from revenues	1485
Net loss	– 1648
Importing agricultural regions	1153
Net loss to agriculture	– 495
Importing urban regions	4236
Net statewide gain	3741

the urban areas. The elasticity of demand was taken from Vaux and Howitt (1984), and the market clearing price was assumed to be the net cost of water purchased from the bank and delivered to the urban areas.

The net benefit to all importing regions is estimated in Table 3 at 104 million dollars. This can be thought of as a lower bound on the benefits. Adding a very conservative estimate of the value of the excess water bought and carried over to 1992, the total net direct benefit to the State economy increases to at least 106 million dollars.

The sale of water between regions had a positive net effect on employment. Jobs were lost in the water exporting regions, but the gain in jobs in the importing regions far outweighed the losses. Table 4 shows the estimated impacts on employment by sector. In estimating the effect on urban employment we face the same problem as with the urban income multipliers. The job multipliers used for the urban sector are low compared to the average industrial use multiplier, but reflect a change in water availability to the urban "green" industry of landscaping and horticulture. The average multiplier used was 17.6 jobs generated per 1000 M^3 of water, where a job is defined as employment of unskilled labor for a period of six months. This value is considerably below many of the urban employment multipliers used, but probably more accurate for the actual use of the additional water in 1991.

Table 4 shows that, unlike the income effect, the agricultural industry had a net reduction in jobs due to its sales and purchases with the Bank. However, only 22% of the purchased water was resold to agriculture and the State of California as a whole had the benefits of an additional 3,741 jobs from the movement of water by the Bank. In addition, we can conclude that for that water that was traded within agriculture, there were net gains in agricultural jobs from trade.

These broad measures show that in terms of both income and jobs, the water bank generated substantial net gains to the state and most regions. When considering any resource reallocation, the benefits and losses should be jointly reviewed. In terms of income, the net loss of $12.75 million has a favorable ration of 8.2 : 1 to the net income gain to the state. The equivalent ratio for job gains to losses is lower at 2.3 : 1, but still shows substantial net gain.

4. Third party impacts: a two county case study

The introduction of water markets is a conscious shift in the nature of water property rights for existing users. Allowing water users to sell water to a market acknowledges the implicit property right that water users have established and capitalized into their land values. However, private property rights are not the only issue; other rights in areas of origin must also be considered. The use of irrigation water in a region generates significant pecuniary and technical external effects. Many of these third party effects are non-point in nature and difficult to assign to a particular water seller. In addition, many irrigation developments in California and elsewhere in the US were partially funded at public expense. In allowing the farmer to capitalize some of the past or present public subsidies, it seems reasonable that the public restrict the third party costs caused by water transfers. Thus private property rights cannot be considered exclusive and other rights in areas of origin must be considered.

A distinction should be drawn between the short- and long-run effects of a water bank. With periodic reductions in economic activity, capital and labor remain in the district but are at times underemployed. Under permanent shifts, capital and labor must make other arrangements for the future. In some cases the costs of permanent adjustment may be lower than the costs of periodic shifts in economic production.

Indirect third-party economic impacts are usually ignored in the analysis of overall economic impacts, since there are also offsetting indirect impacts in the regions that import and use the purchased water, usually to a more productive use than the exporting region. However, since water is a resource whose ultimate ownership is vested with the State, the dominant political and legal view in California is that the exercise of individual private property rights in water should be constrained by consideration of the greater good in the region. Under this viewpoint, the onus is on those advocating the efficiencies of water trades to show that there are no substantial third-party impacts, before the transfer rights are partially or totally allocated to individuals.

A compromise position between the extremes of fully public or completely private property rights is achieved by assigning rights to private trades within certain constraints such as those mentioned above.

In 1992 a case study on the third party impacts from water trades in 1991 was conducted in a two county region (Coppock and Krieth, 1993). Due to the intensive modelling and survey methods needed to measure the third party effects, the region had to be restricted. However, the two counties selected provided one quarter of the water purchased by the State bank and some local trades. In addition, water was purchased by all three methods and from a wide range of crops, making the conclusions applicable to other areas with similar conditions in California and elsewhere.

In measuring the third-party costs of the 1991 Drought Water Bank we reflect the current political viewpoint in California that areas of origin of water have some property rights to the water, and thus the secondary economic costs to the local agricultural economy should be added to the direct externality impacts. It is interesting to note that the pecuniary externalities on local businesses are also an important constraint to the establishment of a trading system in air pollution rights for the Los Angeles basin.

The effects of water sales on regional income and employment were estimated using a more detailed model than the Statewide measures in the previous section. To allow for the shift in crops within the region and the substitution of inputs and technology for traded water, the net change in crop acreage and water use was modelled using a calibrated constant elasticity of substitution (CES) model of regional agricultural production. The model was calibrated against the 1990 crop production patterns obtained from aerial photographs and regional aggregation using a GIS procedure. Fourteen production regions were identified in the two counties which were based on soil type, microclimate, cropping pattern and differences in water delivery systems. Regional input use and crop yields were obtained from regional farm management records. The effect of the 1991 drought water bank on the level and composition of regional agricultural production was simulated by changing the production model to 1991 costs and expected prices and reducing the available irrigated acreage by the amount that was fallowed in the various subregions due to water sales to the State Bank and local transfers. The regional model incorporates those adjustments in production pattern or input use that past data implies. For example, the increase in the value of water due to the 1991 drought stimulated an increase in the investment level in irrigation technology.

The economic third party effects of the change in agricultural production were calculated by applying income and employment input/output multipliers to the changes in agricultural production generated by the regional model. The regional production model enables the direct and indirect effects of different water sale scenarios to be simulated.

Estimates of the effects of water sales on the changes in the levels of agricultural business sales, profits and agricultural employment in the two county region were also obtained from a primary survey. A stratified sample of 188 farmers and 108 agricultural businesses was obtained from the two county area. The survey response was representative of the region, covering a large proportion of those who did and did not find impacts on their operations attributable to the water bank. The questionnaire explicitly asked the respondent to separate out the effects of the water bank from other annual changes such as the drought and economic recession. Table 5 compares the two methods of estimating the agricultural sector income changes due to the 1991 water bank. There is a close correspondence between the estimates generated by the production and I/O models, and those reported from the survey of agricultural businesses.

The survey of agricultural businesses showed a range of opinion among

Table 5
Aggregate county income changes from water sales: Yolo and Solano Counties, California 1991

	Reduction due to water sales	
Simulation model		
Agricultural income	Yolo 5%	Solano 3.2
Primary survey (two county average)		
Agricultural business sales	4.0%	
Agricultural business profits	6.5%	

respondents. When asked about changes in sales to their farmer customers, 62% reported that they had experienced no effects from the sale of water by farmers. Thirty one percent of the respondents reported a decrease in sales, while 6 percent reported an increase. The reduction in sales averaged 4 percent over the whole sample. Twenty five percent of the respondents reported a loss of profits attributed to water sales, the profit loss averaged 6.5 percent.

Given the close agreement between the survey and simulation results for the actual 1991 water transfers, we felt confident in using the production and I/O models to simulate the impacts from alternative water purchase scenarios.

As mentioned earlier in the paper, the 1991 California water market was implemented extremely rapidly with the minimum of institutional design and offered to purchase water from farmers for a brief three month period. In addition to the time restriction on purchases there was considerable doubt concerning the ownership risks involved if farmers sold certain water rights. For example, the Federal Bureau of Reclamation only sanctioned water sales from those contractors who had clearly established rights before the particular project was built. In other regions, the ability to transfer sold water to the purchaser was in doubt. For these reasons, factors other than the simple value marginal product of water determined the short run initial response of farmers to the water bank purchase offer.

Fig. 1 plots the location of different types of water sales contract in the two county region in 1991. The geographic clustering of water sales is very evident in Fig. 1. This clustering intensified the localized effect of externalities, but also reduced the potential sales impact on a county basis. The effect of reducing the clustering was examined using the simulation models for two very different scenarios.

The first scenario defined a greatly expanded market in which water sales were determined solely by their value marginal product, but were subject to regional restrictions on the total water sold from any of the fourteen subregions specified in the model.

This scenario is termed the "Restricted" run. The second scenario, loosely termed "Free sales", had water sales driven by the same value marginal product criteria, but not subject to any restrictions on location or quantity sold. The effects on county income and employment of these two scenarios and the 1991 results

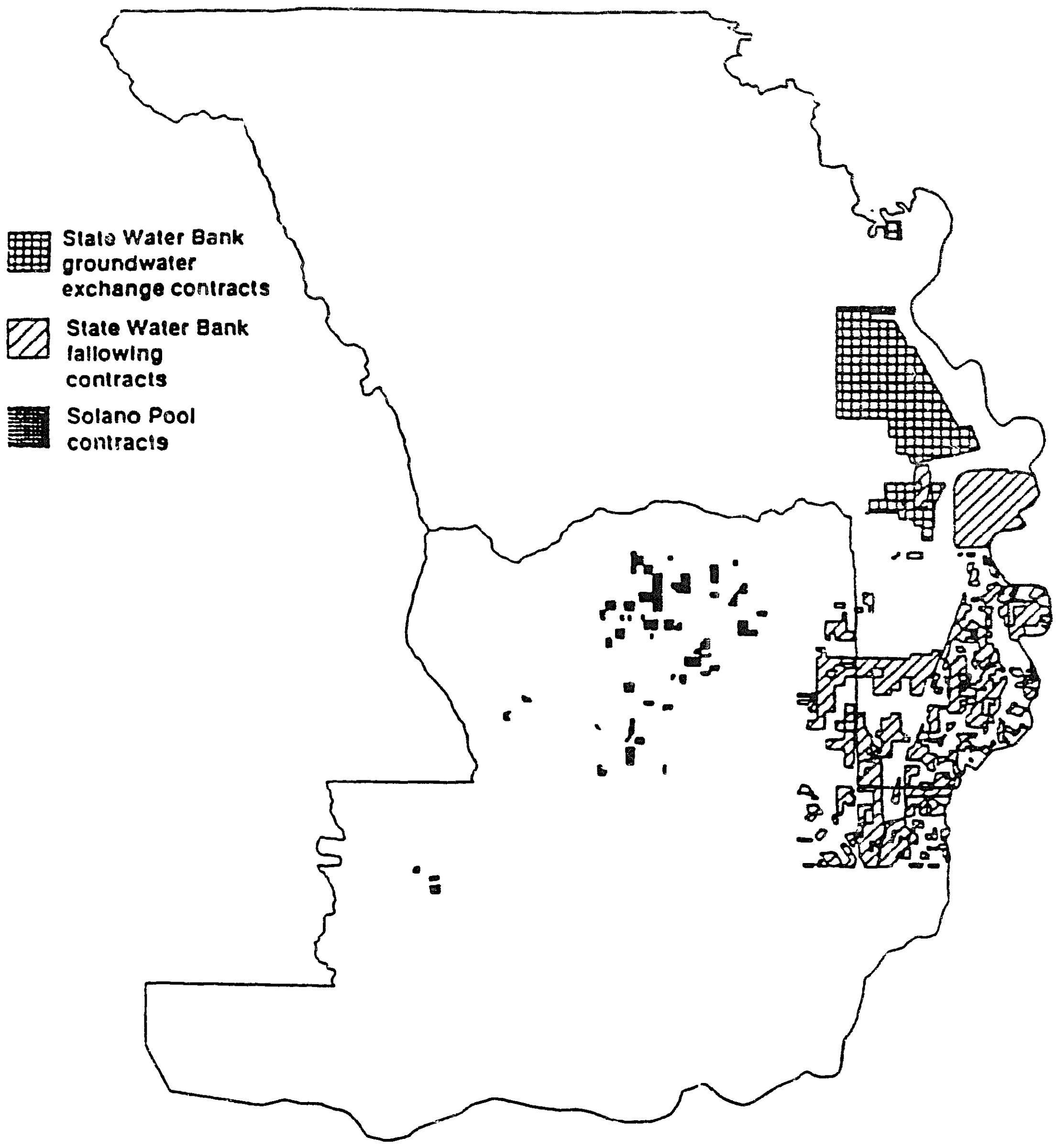

Fig. 1. Water transfer areas.

were then plotted against the amount of water transferred. The results are used to suggest a policy that could reduce third-party impacts to levels acceptable to the exporting region.

4.1. *Simulating the effects of regional water sale restrictions*

Predictably, suggestions on potential modifications to future water banks range over the spectrum of opinion from those advocating more freedom in the water market structure, to those who would give veto powers over water trades to local pressure groups. The following section calculates how the income and employ-

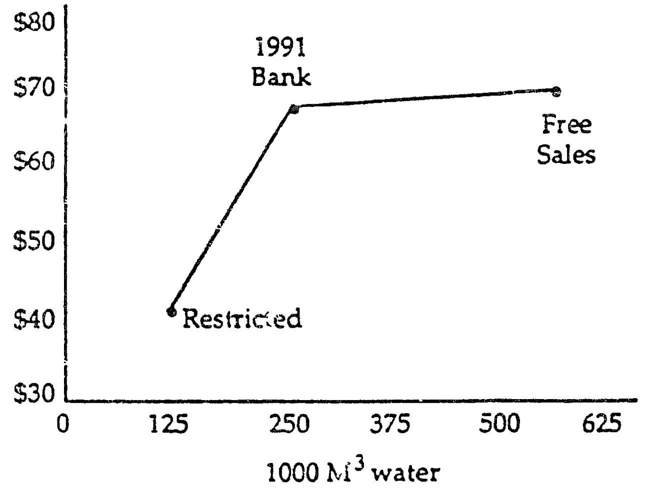

Fig. 2. Change in county income per unit of water transferred.

ment impacts change on a county basis with the changed intensity of water trades. The income and employment changes are calculated for two additional scenarios and are compared with the 1991 county model.

Unlike the complications of the 1991 water market mentioned earlier, sales decisions in both scenarios are driven by simple profit maximizing criteria. Scenario one analyzes the effects of widening the distribution of water sales by local district restrictions on the total quantity sold. Scenario two allows the opposite extreme, a completely free market in water sales which assumes away the institutional complications of differing property rights and transport facilities.

In scenario one, the water available for sale is restricted to 15 percent of the 1991 surface supply for each of fourteen sub-county production regions. Scenario two allows free access to the market at the fixed 1991 price of $100 per 1000 M^3 consumptive water. The institutional assumptions underlying these scenarios are: (a) that all water rights in the counties are well defined, (b) that water rights are completely secure from challenges that may be stimulated from participation in water trades, and (c) that there are no regions in the counties in which water trades would involve significant transport costs or water losses.

These two simulated scenarios were compared with the actual 1991 data, using three summary measures: (a) the amount of water transferred, (b) the reduction in county agricultural income, and (c) the change in county agricultural jobs. Figs. 2 and 3 depict the results.

The 1991 pattern of county water sales shown in Fig. 1 changes dramatically between the two computer-generated simulations. On average over the counties, restrictions reduce the total water sold from the two counties to half that sold in 1991. The free sales scenario, unfettered by timing and institutional constraints, more than doubles the total water sold. The change in water sales is most dramatic in Solano County which experiences a reduction in irrigated acreage of over 40 percent under the unconstrained scenario.

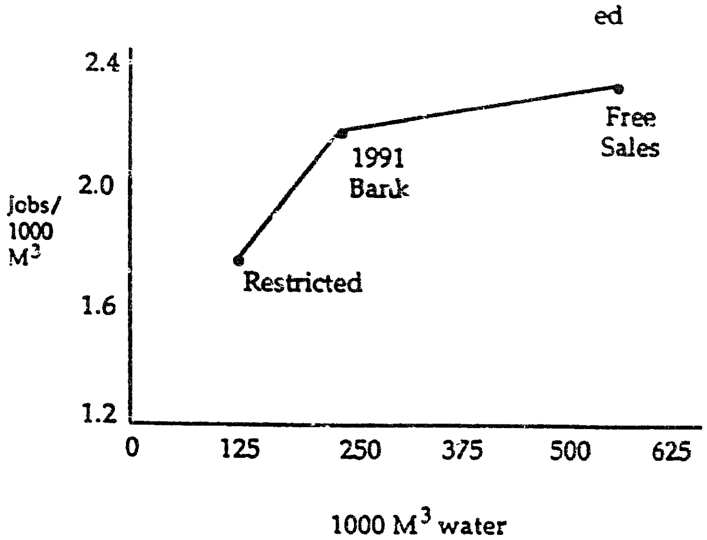

Fig. 3. Change in county jobs per unit of water transferred.

The simulated sales are driven by equating the value marginal product of irrigation water to the offered purchase price in each of the fourteen subregions defined in the model. Optimality of the private return to farmers is therefore axiomatic in the model. Given the range of yields, soil types and crop profitability in the farms modelled, the marginal value of water will clearly increase as water sales are expanded. The pertinent question for considering or designing regulations on water trades is how do the externality costs of lost county income and employment change with the regulation of water sales. These effects are shown in Figs. 2 and 3.

Figs. 2 and 3 show how the marginal loss in county income and jobs per acre foot sold changes as the total water sales from the region change. The results for the "Free sales" and "Restricted" scenarios are generated by the computer simulation model. The equivalent measures for the actual 1991 banks are also plotted on the figures. The main conclusion to draw from these plots is that the marginal cost of third-party impacts has the usual private cost property of increasing with the quantity of water sold. The externality costs are shown to increase at a decreasing rate, whereas the private marginal cost of water sales increases at an increasing rate due to the pattern of high value crops in the region. However, the results suggest that the marginal total social cost of water sales in a region increases notably with the intensity of water trades.

Fig. 2 shows that the income loss per unit water sold almost doubles between the restricted and 1991 scenarios, but has little further increase per unit at higher levels. Fig. 3 shows that the number of jobs lost per 1000 cubic meters increases by 30 percent when the amount doubles at low levels, and moves a further 18 percent with a five-fold increase in the water traded.

Considering that the labor and secondary income-generating capacity of crops grown in the area is strongly correlated with their net return per unit of water applied, these results corroborate the observations that the crops that a profit-conscious farmer will fallow first are those that have the lowest third-party impacts.

It follows that spreading the water sales over a wider area and reducing the concentration of water trades in certain areas (Fig. 1), could reduce third party impacts without reducing the total water sold, by reducing the marginal externality cost per unit of water traded. Under the "Restricted" scenario, the county wide externality cost is reduced by both the reduction of the total water traded and the lower marginal externality cost per unit of water.

The increasing marginal externality cost functions suggest that an efficient balance between statewide benefits and local third party costs could be calculated. Such a calculation would require that satisfactory social "weights" could be established to enable the local externality costs to be directly compared with the broader social benefits of water trades such as those shown in Tables 3 and 4. Given the difficulty of agreement on such weights, the force of local property rights on water can be used to restrict the level of local externality costs by regional trading regulations such as those analyzed.

5. Summary

These results from the 1991 California water bank add empirical support to the theory that inter sectoral and inter regional water markets are a practical policy for reallocating water. Both the supply from farmers and the urban and agricultural demands showed evidence of being more elastic than had been supposed.

The level of pecuniary and technical externalities on water exporting regions proved to be a politically sensitive result of water markets. Measurement of the levels of third party costs in the form of changes in income to local agriculturally related businesses or a reduction in the agricultural employment do not show large percentage changes that are caused by the 1991 water sales. The results of the simulation model of the local agricultural economy were checked against a primary survey of agricultural businesses and found to be very consistent in the estimation of income reduction. The reason for the political concern over third party impacts on exporting counties is found when the intra county concentration of water sales in 1991 is plotted using a GIS system. Under the pattern of sales that emerges, local concentrations of water sales would have caused significant reductions in the sales and profits of small specialized businesses.

However, the simulation model results indicate that moderate trade limits to ensure the spatial distribution of water sales can reduce the externality level within politically acceptable bounds. This result is encouraging for the design of future water markets, since it can be expected from this preliminary evidence that farmers will continue to respond to financial and institutional incentives.

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