Measuring the Costs of Reallocating Water from Agriculture: A Multi-Model Approach

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Abstract

Increasing demand for water by the environment and urban consumers, coupled with the difficulty of developing new water supplies, is forcing farmers in the western United States to cope with reduced surface water deliveries. The cost of improving water quality is shown to depend critically on how the supply reductions are allocated among users and on the extent of water trading. A central contribution of this paper is a methodology for measuring the impacts of water supply policy reforms on irrigated agriculture. The paper nests three empirical models in a general conceptual framework. The models differ in terms of their degree of detail and assumptions about input substitution. By comparing model results, it is possible to place bounds on the consequences of policy changes, and to identify critical factors determining economic impacts. The models are applied to the problem of improving water quality in the San Francisco Bay/Delta estuary.

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I. Introduction

Agriculture in the western United States, particularly California, is highly dependent on the diversion of water resources for irrigation. At the same time, population growth, increased industrialization and, most importantly, heightened public awareness of environmental benefits from enhancing instream flows are all exerting tremendous pressure on federal and state agencies to reduce these diversions. This paper presents a framework for assessing the costs of reducing agricultural water supplies and applies this method to California agriculture.

The design of this framework recognizes some of the unique features of water resources use and management, in particular:

(1) Barriers to trade in water resulting from the water rights regime. The analysis will consider alternative implementation procedures for the water supply cuts, varying the extent to which water trading is allowed and the regions affected by their water supply cuts.

(2) Heterogeneity in terms of cropping patterns and water availability and productivity among regions.

(3) Multiplicity of responses to water supply reductions including: (a) changes in land allocation among crops, (b) adoption of water conserving practices, (c) use of ground water, and (d) fallowing of lands.

The modeling framework was developed to provide inputs to policymakers in assessing alternative versions of the Central Valley Project Improvement Act (CVPIA) and provides various measures of economic impacts, including impacts of supply cuts on producers' surplus, producers' revenue, state product, employment, and irrigated acreage. Furthermore, recognizing the large uncertainty regarding producers behavior and water productivity in crop production, differences between responses in the short run and the long run, and data and computational constraints, the empirical analysis does not rely on one comprehensive model that incorporates all aspects of the problem at hand. Instead, this paper presents an overall conceptual framework but obtains policy impacts from three empirical models, each emphasizing different aspects of agricultural water use in the Central Valley.

The paper is structured as follows. Section II below provides background on the economics of agricultural water use in general and the particulars of the California policy problem. Section III provides a conceptual model and analysis of the impacts of water supply reduction policies. The particulars of the California policy problem and the three empirical models used to analyze it are presented in section IV. Section V presents the empirical findings, and conclusions and direction for further research are presented in Section VI.

II. A Conceptual Model of the Economic Impacts of Water Supply Reduction

The modeling framework applied here consists of a microeconomic model of resource allocation by the irrigated agricultural sector. Optimization is conducted subject to water supply reductions and economic relationships that provide additional assessment measures, including estimated impacts of supply response on employment and gross regional product.

The model recognizes the heterogeneity of producers, by assuming that production is carried out by J micro production units of various sizes. Such units may be interpreted as farms, water districts, or counties depending on the application and the data available. The micro unit indicator is j, $j = 1, J$; and the land base of each unit is denoted by Lj. It is assumed that there are no constraints on water movement within the micro units, but there may be barriers to trade and transfer of water between micro units. Indeed, water rights regimes, such as the prior appropriation system and riparian rights systems, restrict trading; and major features of a policy reform are the extent of water trading and that transfer is allowed.

The analysis is conducted for $N + 1$ water policy scenarios, with n a scenario indicator $n = 0, 1, 2, ..., N$. The scenario $n = 0$ corresponds to the preregulatory or base water allocation.

Under each scenario, microunits are aggregated into regions. Water trading is feasible within regions but not between regions. Let K^n be the number of regions under scenario n and k^n be the region indicator, so that $k^n = 1, ..., K^n$. The set of microunits in region k^n is denoted by R_k^n. For example, if we have eight microunits divided into two regions under scenario n, $R_1^n = \{1,2,3,4\}$ $R_2^n = \{5,6,7,8\}$.

Each microunit has an initial "endowment" of surface or ground water representing annual surface water rights and ground water pumping capacity. Let $\overline{S}_j$ be annual surface water available to district j in the base scenario and $\overline{G}_j$ be annual ground water available to district j. Alternative policy scenarios affect these water availability constraints.

In the base scenario, total water available to region k^n is $\sum_{j \in R_k^0} \left(\overline{S}_j + \overline{G}_j\right)$.

However, surface water availability differs among alternative scenarios. Let ΔS_k^n be the reduction of water supply available to region k^n. The overall surface water supply reduction in scenario n is

$$\Delta S_n = \sum_{k^n=1}^{K_n} \Delta S_k^n.$$

This change reflects the total amount of water reallocated from agriculture. Actual use levels of ground and surface water at region j are denoted by G_j and S_j, respectively, with $S_j < \overline{S}_j$ and $G_j \leq \overline{G}_j$.

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Theory and empirical evidence suggest that California growers have responded to reductions in water supply by (i) changing land allocation among crops, (ii) increasing the among of ground water pumping, and (iii) modernizing their water application methods (Green and Sunding; Green et al., 1996; Zilberman et al., 1995). The modeling of production relationships makes these choices feasible here. There are I crops and i is the crop indicator, $i = 1, I$. Let the amount of water applied to crop i in microunit j be denoted by A_{ij} and let L_{ij} be the amount of land allocated to the production of crop i at microunit j. Let Y_{ij} be the output of crop i at microunit j. For modeling convenience total output is represented as the product of yield per acre, $y_{ij,}$ and acreage of crop i in microunit j is

$$Y_{ij} = y_{ij} L_{ij}.$$

Output is produced by land, labor, irrigation equipment, and other inputs (e.g., chemicals), and is affected by local environmental conditions. The general specification of the per acre production function is

$$y_{ij} = f(L_{ij}, a_{ij}, z_{ij}, \theta_{ij})$$

where

$a_{ij} = A_{ij} / L_{ij}$ (applied water per acre)

$z_{ij} = Z_{ij} / L_{ij}$ (annual irrigation equipment cost per acre)

$Z_{ij} =$ total irrigation equipment cost on crop i in microunit j

and

θ_{ij} = regional environmental quality parameters.

This specification is consistent with the observations of Dinar and Zilberman. Specifically, they argue that increased annual irrigation equipment costs increase output by increasing irrigation efficiency and that both land quality (in particular, water-holding capacity) and water quality (especially salinity) affect the productivity of water. Specific applications may have special functional forms, but all specifications maintain concavity.

Yield per acre may decline as land use increases (i.e., $\frac{\partial y_{ij}}{\partial L_{ij}} \leq 0$) because of decreasing marginal productivity of land.

Let the cost of surface water at microunit j be W_j^s and cost of ground water be W_j^g[1]. Generally, $W_j^g > W_j^s$, so that surface water is cheaper than ground water. The cost of inputs other than water and irrigation technology are assumed to be a convex function of crop i acreage in microunit j and is denoted by the function $C_{ij}(L_{ij})$ with

$$\frac{\partial^2 C_{ij}}{\partial L_{ij}^2} \geq 0.$$

This cost function reflects the important empirical observation that land fertility is heterogeneous in California and that increases in acreage lead to increased expenditures on inputs, such as fertilizers, that augment land productivity.[2]

The most general specification of output markets would assume that producers face downward-sloping demand curves and that output prices are determined endogenously. In this case, the optimization problem will maximize the sum of producer and consumer surplus subject to resource constraints. In our model, we assume price-taking behavior and denote the price of output i by P_i. This assumption simplifies the presentation, and California producers face a high price elasticity in the commodities affected by the water policy changes considered.

Assuming profit-maximizing behavior by growers, the aggregate regional optimization problems under scenario n are

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[1]These costs are delivery costs or water costs paid by users. Since we are interested in developing a regional optimization model that will provide competitive outcomes, we do not consider differences between private and public costs of obtaining water.

[2] We distinguish between dimensions of land quality such as water-holding capacity that affect productvity indirectly (for example through their effect on the productivity of applied water) and other dimensions such as fertility that affect productivity directly.

(1) $$\Pi^n = \max \sum_{j=1}^{J} \sum_{i=1}^{I} P_i Y_{ij} - W_j^s S_j - W_j^G G_j - Z_{ij} - C(L_{ij}) \cdot$$

(2) $$\text{s. t.} \quad \sum_{I=1}^{I} A_{ij} = S_j + G_j \quad \forall j$$

(3) $$\sum_{j \in R_k^n} \left(S_j + G_j\right) \leq \sum_{j \in R_k^n} \bar{S}_j + \bar{G}_j - \Delta S_k^n \quad \forall k$$

(4) $$\sum_{i=1}^{I} L_{ij} \leq L_j \quad \forall j .$$

Constraint (2) states that total water used in crops is comprised of either surface water or ground water. Condition (3) is the most important constraint as it sets a limit on the water available to each region under a given policy scenario. Availability is the sum of water available to districts under initial allocation minus the amount diverted under the specific scenario.

The solution of the regional optimization problem using Kuhn-Tucker conditions requires assigning shadow prices for each of the constraints. The shadow price of equation (2) is W_j^d. This is the shadow cost of water delivery and is equal to W_j^s if only surface water is used and W_j^g if ground water is used in district *j*. The shadow price of the regional water constraint (3) is V_k^n. Thus, the marginal cost of a unit of water in district *j* that belongs to region *k* under scenario *n* is $W_j^d + V_k^n$.

If the production function is differentiable, optimal water use per acre with crop *i* at district *j* is at the level where the value of marginal product of water is equal to the shadow price of water.

(5) $$P_i \frac{\partial f_{ij}}{\partial a_{ij}} = W_j^d + V_k^n \quad \forall_{i,j} .$$

Optimal irrigation cost per acre is determined similarly at the level where the value of marginal product of the expenditure is equal to its price.

(6) $$P_i \frac{\partial f_{ij}}{\partial z_{ij}} = 1$$

The shadow price of the land availability constraint in district j is r_j, and under standard assumptions, land is allocated to crop i in district j so that the value of marginal product of land is equal to r_j, i.e.,

(7) $$r_j = P_i f_{ij}(\ldots) - \left(W_j^d + V_k^h\right)a_{ij} - z_{ij} - \frac{\partial C_{ij}}{\partial L_{ij}} + P_i L_{ij} \cdot \frac{\partial f_{ij}}{\partial L_{ij}} \ \forall i, j \ L_{ij} > 0.$$

Condition (7) states that the optimal acreage of crop i at district j is such that net marginal benefit of land is equal to its shadow price. Marginal net benefits of land are the difference between revenue added by marginal land and extra cost of water, irrigation technology, and other inputs as well as the extra cost associated with the decline of land productivity. The conditions are more elaborate if there are land availability constraints for individual crops.

In principle, conceptual and empirical analysis requires solving the model under scenario 0, the initial condition, and then under each alternative scenario. The net income effect of a policy under the scenario denoted by $\Delta\Pi^n$ is the change in producer surplus between scenario 0 and scenario n, i.e.,

$$\Delta\Pi^n = \Pi^0 - \Pi^n.$$

It is expected that, for most scenarios, $\Delta\Pi^n > 0$, namely, reduction in water supply reduces overall income. But different scenarios assume different partitions of the regions. Under the initial scenario ($n = 0$), the state is divided into K_0 regions, where water trading is feasible within regions and where water trading is allowed between regions. Two types of scenarios are likely to be associated with a given reduction in overall surface water supply. Under water trade scenarios, trading is allowed throughout the state; under proportional cuts scenarios, the supply reductions to regions are proportional to initial allocations so that the reduction in surface water for regions under such scenarios, ΔS_k^n, is

$$\Delta S_k^n = \Delta \overline{S} \frac{S_k^0}{\sum_{k=1}^{K_o} S_k^0}.$$

By the La Chatelier Principle, given total supply reduction, aggregate profit is higher under the free trade scenario as there are fewer constraints. In some cases, a water reform that reduces surface water supply and allows trading may increase profit $\left(\Delta\Pi^n > 0\right)$ if gains from trading are greater than losses from surface water supply reductions.

Standard welfare analysis considers impacts on consumer and producer surplus, but policymakers may be interested in changes in other variables.[3] Other such variables are gross farm income, regional income, and employment.

The gross income effect of scenario *n*, ΔR^n, is derived by subtracting gross revenues of scenario *n* from gross revenues of the initial scenario.

$$\Delta R^n = \sum_{i=1}^{n} \sum_{j=1}^{J} P_i \left(Y_{ij}^o - Y_{ij}^n\right).$$

As with net income, it seems that gross revenues will decline as aggregate water levels decline. However, under some scenarios, the reduced water supply may lead producers to adopt modern irrigation technologies, which tend to increase per acre yields (Caswell and Zilberman) but also entail higher production cost. Under these scenarios, the higher yield will result in increased revenues in spite of the overall water supply reductions.

The impact of water policy changes on the nonagricultural economy is another useful policy indicator. Let ψ_i be a regional impact coefficient, denoting an increase in regional product (both direct and indirect effects) associated with a \$1.00 increase in revenues of crop *i*. The reduction in regional impact associated with policy scenario *n*, ΔRNP^n is

[3]These impact measures were requested from us by the USEPA for their use in designing water quality standards.

$$\Delta RP^n = \sum_{i=1}^{N}\sum_{j=1}^{J} P_i\left(Y_{ij}^0 - Y_{ij}^n\right)\psi_i$$

In most cases one expects regional product to decline as a result of reduction in water supply. However, if supply reduction is associated with increased water trading possibilities and higher water prices, regional income may increase because of adoption of conservation technologies that increase yield or increase water used for production of high value crops. These crops generate more revenue per acre feet of water than low value crops and have stronger linkages to the non-agricultural regional economy due to their higher labor requirements.

Similarly, let ΔEM^n be the employment loss associated with scenario *n*. Formally,

$$\Delta EM^n = \sum_{i=1}^{I}\sum_{j=1}^{J} P_i\left(Y_{ij}^0 - Y_{ij}^n\right)\theta_i .$$

In many cases ΔEM^n is likely to be positive, but in some situations less water but more trading and conservation may lead to increased employment of $\Delta EM < 0$.

III. On California Agriculture and Bay-Delta Problem

California's water delivery system relies on a sophisticated network of water reservoirs and aqueducts. Much of the water that is used for irrigation in the Central Valley is snow melt from the Sierra mountains that lie to the east of the Valley and is conveyed by rivers and canals. Prior to World War II growers in the Sacramento Valley (the portion of the Central Valley north of the Bay/Delta) and the east side of the San Joaquin Valley (the southern component of the Central Valley) established a network of private aqueducts to provide surface water for irrigation. After the war, two major public water projects (the federal Central Valley Project (CVP) and the State Water Project (SWP)) were completed. These projects provide water that allow irrigation in western and southern parts of the Valley and also deliver water to the cities in the south. The Colorado River provides water to the Imperial Valley and urban areas of Southern California. In most parts of California, water is allocated according to the prior appropriation system which queue users and restrict training (Gardner). The contractors of the state and federal water projects have junior rights relative to the growers in the east side who establish water rights earlier.

The California water project modified the water flow in the state where almost 75 percent of natural runoff occurs north of the San Francisco Bay Delta where nearly 80 percent of the water is south of the Bay Delta (State of California, 1993). The Bay/Delta is the largest and most productive estuary on the Pacific Coast. Its watershed drains 40 percent of California's land area, supports over 120 fish species, and includes the largest brackish marsh in the western United States. In the last two decades, however, the fish and wildlife resources in the Bay/Delta watershed have declined to record low levels. Biologists believe that most of the decline has been caused by increased diversions from the Delta to cities and farms (Moyle and Yoshiyama, 1992). As evidence of reduced biological productivity, two Bay/Delta species are currently listed as threatened species under the Endangered Species Act (winter run Chinook salmon and Delta smelt) and two other species (Sacramento splittail and longfin smelt) are candidates for protection.

Three pieces of legislation bear directly on remedying the decline of the Bay/Delta: the Clean Water Act (CWA), the Endangered Species Act (ESA), and the Central Valley Project Improvement Act (CVPIA). Section 303 of the CWA requires each state to adopt water quality standards specifying designated uses and instream water criteria to protect those uses for all "waters of the United States" located within their state. The U. S. EPA has the authority to review and approve or disapprove any new or revised standards adopted by a state. In response to the State of California's unwillingness to develop and implement water quality standards sufficient to protect designated uses of the Bay/Delta, four federal agencies (U.S. EPA, U.S. Fish and Wildlife Service, Bureau of Reclamation, and National Marine Fisheries Service) issued a comprehensive management plan for the Bay/Delta that satisfies CWA and ESA requirements. In addition, the recently enacted CVPIA is an effort to restore the biological health of the Bay/Delta by reducing diversions and modifying the operation of the CVP.

All of these statutes will result in an increased flow through the Bay/Delta estuary, and it is likely that ultimately *all* of the accompanying water supply reductions will fall on agriculture. Some of these cutbacks will come directly from the Bureau of Reclamation or the State of California in the form of reduced deliveries to growers. Further, because the CVPIA also permits transfers of federal water from growers to cities outside the CVP service area, it is highly likely that utilities such as Southern California's Metropolitan Water District will trade with growers to replace any cuts that urban areas receive. The Drought Water Bank existing during the 1987-1992 drought provides a precedent for such rural-urban trading (Dixon et al., 1993).

Growers in California's Central Valley, who produce nearly half of all fresh fruits and vegetables consumed in the United States, operate under a variety of conditions in terms of weather, soil quality, pest control problems, labor supplies, marketing channels, and water rights. These differences result in an immense variety of productivity of applied water in California. A study by Sunding et al., for example, shows that the bottom 20 percent of water in terms of value (primarily used for irrigated pasture and rice) produces less than 5 percent of agricultural value while the top 20 percent of water produces about 60 percent of total value. This large disparity in water productivity suggests that water reform that transfers the less productive water to the environment is much more efficient than reform that removes water used to produce high value crops.

Thus, the impacts of water supply reductions depend at least in part on how the cuts are allocated within the Valley. Proposed policies to reduce diversions for irrigation do not specify how the supply cuts will be allocated, so one objective of this paper is to assess the impacts of alternative implementation strategies for given aggregate supply reductions. The importance of the interregional distribution of supply reductions precludes the use of econometrically estimated aggregate relationships for impact analysis. Instead, impact analysis must be conducted with disaggregated models of the regional agricultural economy.

IV. Alternative Impact Models

Policy impacts are likely to vary with the planning horizon and are subject to much uncertainty. The immediate impacts of supply reduction may differ from longer run impacts since in the short run growers' flexibility is much more limited. Production function parameters, water availability, and costs are subjects to much variability and randomness. Ideally, an impact assessment model should be versatile and comprehensive to generate various types of impact estimates. Unfortunately, a model that accounts for heterogeneity among growing regions and all dimensions of grower response to water supply changes does not exist and would be quite costly to construct. Instead, this paper obtains policy impact estimates from three models, each emphasizing a different aspect of Central Valley agriculture. The results of these various models provide a range of impacts within which the actual outcomes are likely to lie.

The three impact models are numerical applications of the model presented above. They differ in their assumptions regarding production technologies and the set of responses that growers have in adjusting to changes. They also differ in the degree of detail in the data they use, in particular, the type and number of basic units of analysis they assume. A model that includes a response set with a wide variety of options requires a complex nonlinear programming algorithm and a large amount of data for each decision maker. As the response set becomes smaller, less data are required for each decision unit. These lower data requirements per unit may allow larger numbers of decision-making units. Thus, the models that allow more responses to policy changes have smaller and larger basic units.

The models considered the impact of several multidimensional policy scenarios. First, two levels of aggregate water supply to agriculture are considered. The policies involve some aggregate reduction in surface water available to agriculture. The lower level of 0.8 MAF corresponds to requirement of annual enhancement of instream flows. The higher level of annual reduction is 1.3 MAF, and it was derived by U. S. EPA and the USFWS, in the context of their work on endangered species protection.

The second dimension of the water allocation policies considered in this paper is the allocation of the aggregate cutback among growers. To a large extent, the final allocation of the supply reduction is an open question, depending on what state or federal agency takes responsibility for the decision. If the State of California makes the decision, then all water users in the State which consumption affects Bay/Delta flows are potential targets for cutbacks. However, if the federal government implements the reduced diversions, then only CVP users are liable for the reductions. Thus, the allocation of the cuts is treated as a choice variable, and a variety of initial allocation schemes are considered.

Third, the extent of water trading is currently a policy choice, particularly for the State of California. Trading is highly active within small units such as water districts, and a large volume of water is traded between neighboring districts within the CVP system. There is, however, controversy about how much water can and should be traded among growers, between growers and urban areas, and between basins. Further, there are physical constraints on conveyance that are, at present, hard to define precisely due to hydrological uncertainties and constantly changing regulatory restrictions on pumping. Thus, the scope of the water market is treated here as a policy variable, and the impact models are used to examine a wide array of trading scenarios.

The following sections describe each of the three impact models in more detail and discuss how each model calculates the economic consequences of agricultural water supply reductions.

1. CARM Model

CARM is a nonlinear programming model developed at the University of California which has been applied to analyze the impact of numerous policies and events. Most recently, it has been used to study the impact of the drought (Howitt, 1991). The data base for this model is updated constantly. Before conducting any policy analysis, the model is calibrated; and in our case, it was able to predict land-use and water allocation choices more than 99 percent of liability.

The basic units of analysis in the model are clusters of water districts with similar growing conditions and water rights; there are 27 basic units and 34 crops in the model. Within each of the basic units, growers maximize profits by choosing land allocation among crops and the amount of fallowed land. Costs of production are quadratic in land area, reflecting the fact that land quality varies within each of the clusters and the lowest-quality land will come out of production first. Farm profits are maximized subject to linear resource constraints on arable land and surface water supplies; ground water pumping is held constant in the model to reflect constraints on pumping capacity. The impacts of water supply policies are modeled precisely by changing the various regional constraints on available surface water. The CARM model measures the impacts of water supply reductions on net income and revenue in each of the basic units and also estimates changes in State product and employment, both of which are estimated using revenue multipliers.

The CARM model considers four policy scenarios: two "Proportional Allocation" scenarios in which the total supply reduction is allocated proportionally among some set of basic units with no trading, and two "Local Market Allocation" scenarios in which there is trading among the basic units suffering the supply reduction. Within each type of scenario, there is a further breakdown based on the region facing the initial cutback. In the "Delta-Mendota" scenarios, all cuts come from the basic units in the Delta-Mendota region (which is entirely within the San Joaquin Valley), while in the "San Joaquin" scenarios, all initial cuts come from the basic units in the entire San Joaquin Valley. Thus, the "Local Market Allocation - San Joaquin" scenario models a policy in which all growers in the San Joaquin Valley have their surface water allocation reduced proportionally to their base allotment and there is trading among all basic units in the San Joaquin Valley. This configuration of scenarios permits examination of the effects of both the initial allocation of the water supply cuts and the scope of the water market.

2. The Agroeconomic Model

This model has the least detail in terms of number of crops (11) and regions (4) but has the most advanced specifications of water productivity. This specification allows investigation of the impacts of water supply reductions on irrigation technology choices under alternative scenarios, and also enables adjustment of predicted water use and technology choices to variations in weather and land quality. The model was constructed initially to analyze water and drainage policies and is described in detail in Dinar, Hatchett, and Loehman (1991).

The modeling approach of Letey and Dinar (1986) provides the foundation for deriving production functions for each of the crops at the various regions. The Letey and Dinar model provides a set of generic production functions for each crop, relating yield to the amount of applied water, water quality (salinity), and water application uniformity. It provides formulas to adjust the functions to location-specific conditions in each regions (precipitation, evaporation, temperature, maximum crop yields). These adjustment procedures were applied using data on average temperature and precipitation provided by CSAC (1990) and data on pan evaporation provided by CIMIS (1992). Maximum crop yields were derived from observed yields at the four regions using procedures suggested by Knapp et al. (1986). Irrigation technology choices in the agroeconomic model are captured in terms of the uniformity of applied irrigation water, with more advanced technologies having a higher CUC value. Higher CUC values are also associated with greater irrigation hardware and/or management costs, and the agroeconomic model assumes that the marginal cost of irrigation is increasing in uniformity and that there are no scale effects with regard to the size of the irrigated field.

The analysis considers four agricultural production regions in the Central Valley—Sacramento, San Joaquin, Fresno, and Kern. Surface and ground water use (as of 1985) were provided by DWR for each hydrological region and was adjusted to provide constraints for water use in production regions.

Data on agricultural production in each of the regions are based on data from Agricultural Commission Reports for representative (and largest) countries in each region in 1990. Data concerning crop prices and cost of production for each of the eight crops are based on University of California Cooperative Extension budgets in the various regions in 1990 prices. Cost of irrigation was taken from the Bureau of Reclamation data. Both ground and water prices in the area south of the Delta regions (Fresno and Kern) were higher than in the Sacramento and San Joaquin regions. These sources of information are all combined to generate the objective function and constraints of the optimization problem in (1). A Positive Mathematical Programming calibration procedure (Howitt and House, 1986) is used to calibrate observed land allocation among crops and produce the base run results for each region. The model is then altered to simulate the impact of changes in surface water supply policies by changing regional surface water constraints.

The agroeconomic model examines three policy scenarios. The "Proportional" scenario assumes that the cuts in surface water deliveries are allocated proportionally among growers in both the Sacramento and San Joaquin Valleys and that there are only markets for water within each of the four regions. The "San Joaquin" scenario assumes that all cuts come from the San Joaquin Valley, and that there is trading among the basic units in this area only. Finally, the "Efficient" scenario assumes that there is a market for surface water encompassing all four regions so that water is allocated according to its marginal value in the entire Central Valley.

3. Rationing Model

The rationing model measures immediate impacts from changes in water supply policy and relies on the most detail micro level data. The basic unit of the rationing model is the individual water district. The water districts are grouped into five regions according to their proximity to various CVP facilities and have similar water rights and growing conditions. The model also captures the largest number of crops among the three impact models and is the only model to include both annuals and perennials.

Growers in the rationing model respond to reductions in surface water availability by ceasing production of the crops with the lowest marginal value of applied water. This approach is motivated by the fact that growers have a large degree of flexibility when they make long-term decisions regarding irrigation technology and cropping patterns but have only limited flexibility in the short run. In this respect, the model is based on the "putty-clay" approach developed by Houthakker (1955) and Johansen (1972) and refined by Hochman and Zilberman (1978).

Another fact motivating the rationing analysis is the large degree of heterogeneity in California agriculture. The Central Valley consists of many production regions that vary both in terms of weather and land quality. Existing crop allocation patterns have evolved over time to maximize the overall benefits from agricultural production. At each location, farmers have invested substantial resources in production infrastructure, including equipment for harvesting, packing, and irrigation. As a result, crop mix choices are largely predetermined in the short run and appropriate for individual locations.

Agronomic evidence suggests that, within a given production technology, a crop should either be irrigated with a certain amount of water, the "water requirement," or not irrigated at all (Letey et al., 1985, and Letey and Dinar, 1986). As a result of these considerations, water supply reductions that change the preconditions for a successful crop mix are likely to be met in the short run with the only response available to growers: reducing the amount of land cultivated while retaining the existing production technology on the land remaining in production.

The rationing model calculates the impacts of water policy changes on farm revenue, fallowing, state product, and employment. The latter measures are computed with revenue multipliers. Two policy scenarios are simulated by the rationing model: the "Proportional" scenario in which the supply reduction is allocated pro rata among all CVP contractors in the Central Valley with no trading among regions, and the "Efficient" scenario in which there is an interregional market for surface water incorporating both the Sacramento and San Joaquin Valleys. In this latter scenario, as discussed earlier, the total impacts of the supply reduction are independent of the initial allocation of the cutbacks.

V. Results of the Impact Analyses

Table 1 summarizes the impacts measured by the three models. The estimated impacts are quite consistent between models. This consistency is apparent by comparing the results of the agroeconomic model, which computes profit, with the results of the rationing model, which has impacts on revenue, and comparing them to the CARM model, which has impacts on both profit and revenue.

All of the models suggest that the incremental costs of removing water from the Central Valley increase sharply as the quantity reallocated increases. Increasing the amount of water devoted to environmental protection from 0.8 MAF to 1.3 MAF more than doubles the cost of the regulation to growers. Experimental runs with higher levels of water supply reductions show that this tendency continues and incremental costs of water supply reduction increase as water scarcity increases. This result is attributable to the fact that profit-maximizing farmers will first reduce or cease production of low-value crops in response to reductions in water supply, and will only cease producing high-value crops if the reductions are drastic.

The results of Table 1 further suggest that the overall level of the water supply cut is not the most important factor affecting the social cost of protecting Bay/Delta water quality. Rather, the impacts depend more importantly on the extent of a water market and, when trading is limited, on how supply cuts are distributed among regions. If a market mechanism is used to allocate an annual reduction of 0.8 MAF among a large body of growers in the Central Valley, both the CARM model and the agroeconomic model estimate the annual reduction as around $10 million, and the CARM model suggests that the revenue reduction is approximately $19 million. Using a proportional allocation for the same region, the agroeconomic and CARM models both suggest that the annual reduction of profits is nearly $45 million, and the CARM model suggests that annual revenue reductions are around $85 million. The rationing model suggests that if the 0.8 MAF reduction applies to CVP contractors alone, under the market solution revenue reductions are close to $40 million, and under the proportional solution reductions total about $100 million. If the cuts are restricted to the Delta-Mendota Canal area, the most water-efficient region in the San Joaquin Valley, the CARM model suggests that with a market allocation, the revenue losses are around $110 million, and with proportional allocation, losses are close to $165 million.

When the overall water supply reduction is 1.3 MAF, then according to both the agronomic and CARM models, profit loss is close to $30 million if the cut applies to a large group of farmers in the San Joaquin Valley, and the revenue effect is about $52 million annually. If the allocation is proportional for a large region, both the CARM and agronomic models predict annual profit reductions of around $77 million and revenue reductions of around $145 million. When the cuts are targeted to the CVP contractors, revenue losses with a water market are around $100 million, and with a proportional allocation, about $224 million. When the cuts are aimed at growers in the Delta-Mendota Canal area, revenue losses can reach $276 million annually.

VI. Concluding Comments

There is increasing pressure in the western United States to protect natural resources by enhancing instream flows. Such policies inevitably mean reducing diversions to irrigated agriculture. This paper presents a method for measuring the impacts on agriculture of such reductions. The fundamental tension to be addressed in constructing an agricultural impact model is between the detail necessary to permit examination of the distributional consequences impacts, and the fact that growers have a multidimensional response to policy changes. Rather than constructing a highly complex model incorporating all growing regions and all responses, this paper argues that the results of existing, smaller models can be compared to accurately measure policy impacts in a cost-effective way.

With regard to the Bay/Delta problem, the three impact analyses considered here suggest that the overall cost of improved water quality in the estuary can be reduced dramatically by allowing broad-scale water trading among growers. In particular, the costs are much lower if the most of the reduction is born by growers in the Sacramento Valley instead of the west side of the San Joaquin Valley, including the Delta-Mendota Canal region. Reducing the scale of agricultural production in the Sacramento Valley effectively diminishes the acreage planted to irrigated pasture and field crops including alfalfa, wheat, beans, rice and feed corn.

This least-cost solution may face political and physical feasibility constraints because local concerns may well resist large scale, out-of-area trades. Policies that entail either limiting water supply reductions to one region or proportional cuts represent higher cost alternatives than the least cost alternative. These are likely to be the solutions for the short run without extensive transfers. These will cost about $100 million for the 0.8

MAF cut and about $225 million for the 1.3 MAF cut. Direct costs per acre foot in lost farm returns range from $50 to $80/AF depending on location and quantity of water removed.

One of the implications of the analysis is that if the lack of conveyance infrastructure is a physical barrier to trade, then enhanced conveyance facilities such as the Peripheral Canal can lower the costs of water quality regulations by reducing the transaction costs associated with water trading. The buildup of water storage reservoirs can further reduce the impact of supply reductions. Increased storage facilities south of the Delta may enhance the ability of growers to trade water between the Sacramento and San Joaquin Valleys and with urban areas. Future economic analysis should measure the costs and benefits of these facilities.

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Table 1
Summary of Impacts on California Agriculture

Cuts in CVP Deliveries (acre feet)	Model	Decrease in Revenue ($million)	Decrease in Profit ($million)	Decrease in Gross State Product ($million)	Decrease in Labor (000 person years)	Acres Fallowed (000 acres)
800,000						
	CARM					
	Proportional Allocation					
	San Joaquin	85.96	45.50	90.26	2.15	
	Local Market Allocation					
	San Joaquin	18.88	9.82	19.82	.47	
	Agroeconomic					
	Proportional		53.05			127
	South of Delta		36.87			14
	Rationing					
	Proportional	97.38		102.86	4.49	243
	Efficient	40.21		46.25	2.02	132
1,300,000						
	CARM					
	Proportional Allocation					
	San Joaquin	145.83	76.95	153.12	3.65	
	Local Market Allocation					
	San Joaquin	52.43	26.69	55.05	1.31	
	Agroeconomic					
	Proportional		118.44			239
	South of.Delta		59.14			39
	Rationing					
	Proportional	224.88		226.63	10.80	373
	Efficient	96.62		111.90	4.87	321

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