UCD Department of Agricultural Economics

WORKING PAPER SERIES

#20655

University of California, Davis
Department of Agricultural Economics

EMPIRICAL TESTS OF WATER AND LAND AS QUANTITY-RATIONED INPUTS IN CALIFORNIA AGRICULTURE

by
Michael R. Moore and Ariel Dinar

Working Paper No. 92-04

Empirical Tests of Water and Land as Quantity-Rationed Inputs in California Agriculture

Michael R. Moore[1] and Ariel Dinar[2]

Draft date: January 31, 1992

Correspondence:

Economic Research Service; Room 534
1301 New York Ave., NW
Washington, D.C. 20005-4788
(202) 219-0411

[1] Resources and Technology Division, Economic Research Service, USDA.
[2] Department of Agricultural Economics, University of California, Davis and Economic Research Service, USDA.

Empirical Tests of Water and Land as Quantity-Rationed Inputs in California Agriculture

Abstract

This paper evaluates competing models of input use for two inputs, surface water and land, in central California agriculture. Applying a multioutput production approach in a long-run setting, a variable input model is compared to a fixed input model using non-nested hypothesis tests. Test results support the fixed input model for surface water and the variable input model for land. That surface water is a quantity-rationed input addresses an important water policy issue, recontracting for Central Valley Project water supply. Since observed water prices do not affect behavior, marginal or small CVP price increases would not induce irrigation water conservation. Results from the final model specifications show the impact of a water-quantity-based conservation policy on crop-specific land and water use. Elasticities indicate that quantity restrictions would have the greatest effect on land and water allocated to cotton production.

Empirical Tests of Water and Land as Quantity-Rationed Inputs in California Agriculture

Proper analysis of multioutput production systems requires knowledge of whether an input is fixed or flexible in the pertinent production period. In addition to determining the correct approach to analyzing use of the input itself, this information affects specification of the multioutput profit function, crop-specific profit functions, and the output supply or input demand functions derived from the profit functions. Further, an allocatable fixed input creates an "apparent" jointness in production when maximizing multioutput profit, while a variable input does not (Chambers and Just; Leathers; Shumway, et al.). Whether the firm is in long-run equilibrium in an input thus determines the appropriate test for input nonjointness in the multioutput technology (Chambers and Just).

This paper develops several empirical tests of two competing models of input use: a variable input model and a fixed input model. The tests are applied independently to two inputs, surface water and land. In the model development, the multioutput production technology restricts only water or land, or both, to be fixed at the farm level. Crop-level allocations of water and land are not restricted, and all other inputs are modelled as variable. The analysis is long run in this regard.

The approach of testing whether water or land are variable or fixed inputs in a long-run setting compares with recent research on input use in a multicrop framework. Both Chambers and Just and Just, et al. (1983) modelled land as a fixed, allocatable input as a maintained assumption. Moore and Negri recently modelled land and surface water as fixed, allocatable inputs as maintained assumptions. These three papers did not test the veracity of these assumptions.[1] The present paper, in contrast, tests whether these inputs are variable or fixed in the context of central California agriculture. Just, et al. (1990) tested two alternative models of short-run water allocation while holding crop-specific land allocations fixed. The two models were a variable input model and a satisficing ("behavioral") model.[2] This paper differs by comparing a variable input model and a fixed input model of water use in a longer-run production setting. Since institutions may dictate that water is a quantity-rationed resource, the longer-run setting is more relevant to public policy on water allocation.

The multioutput production framework creates two opportunities to shape the research. First, crop-choice decisions by producers can be analyzed because every farm does not grow every crop. The crop-choice decision is studied with discrete-choice econometric methods, with both variable input models and fixed input models defined. Second, decisions on crop-level input use of water and land present similar opportunities to compare competing models. Rigorous models of crop-level variable input demand functions and optimal fixed-input allocation functions establish a basis for this comparison. For both the crop-choice models and the input-use models, non-nested hypothesis tests determine which of the competing models represent true models.

Econometric estimation of crop-level models (with four crops possible) creates a set of results for each input. In this context, a final determination of whether surface water and/or land are variable or fixed inputs does not reduce to a single hypothesis test. Instead, several tests contribute to a general conclusion about the nature of these inputs. The conclusions are reasonably clear, in the end, despite the complexity. The variable input model is rejected as an explanation of surface water use; surface water should be modelled as a fixed, allocatable input. The evidence supports the variable input model of land use over the fixed input model. Although land frequently is modelled as a fixed input, producers in central California are in long-run equilibrium in land use.

The finding that surface water is a quantity-rationed input addresses an important water policy issue. Most producers in this region of California receive surface water supply via long-term contracts with the federal Bureau of Reclamation's Central Valley Project (CVP). Recontracting for CVP water is currently underway, although final federal policy on CVP recontracting remains to be set. As a means of inducing irrigation water conservation, price increases are being considered as a key component of recontracting policy. Given that water is quantity rationed rather than price allocated, however, marginal or small price increases would not affect producer behavior and, in particular, would not induce water conservation. More significant price increases, reductions in contractual deliveries, or deregulation of water markets would be required to do so. This research questions the general ability of a price policy to achieve a goal of CVP water conservation.

The paper continues with three substantive parts and a concluding section. The first part develops the competing models of input use and the test procedures for deciding between the models. The second part reports the empirical results, including the hypothesis-test results and the final specifications of the model elements given the test results. The third part draws implications for CVP recontracting from the results.

Alternative Models of Input Use: Variable Input versus Fixed Input

Heuristically, variable input models differ from fixed input models in a simple way: when an input is variable, its price will be among the exogenous variables explaining production decisions involving own-input use, other input use, and output; when an input is fixed, its quantity will help explain similar decisions. This part of the paper defines with some formality the economic models applied in the research and describes the hypothesis tests to compare the models.

Three general cases are developed to structure the statistical tests: (1) a case comparing a model in which water is a variable input versus a model in which water is a fixed input, while maintaining land as a variable input; (2) a case that repeats (1) except for maintaining land as a fixed input; and (3) a case comparing a model in which land is a variable input versus a model in which land is a fixed input, while maintaining water as a fixed input (based on results from cases (1) and (2)). The analysis requires both cases (1) and (2) because whether land is variable or fixed is not known *a priori*. Each case involves three subcases: (a) comparison of crop-choice models; (b) comparison of crop-level input use models; and (c) comparison of farm-level input use models.

Several items characterize development of the models. The assumption of perfect competition is adopted with producers taking prices as exogenous. The dual approach to production economics is applied. Input nonjointness is assumed so that crop-specific profit functions can be defined. The notation used is: $\mathbf{p}$ is a vector of crop prices; p_i is price of crop i $(i=1,\ldots,m)$; r_N is land price; r_W is water price; $\mathbf{r}$ is a vector of variable input prices other than land and water; n_i is land allocated to crop i; w_i is water allocated to crop i; N is farm-level quantity of land; W is farm-level quantity of water; d_i is a discrete-choice variable equal to 1 if crop i is grown and 0 if crop i is not grown; $\mathbf{x}$ is a vector of other exogenous variables in the empirical analysis (e.g., average rainfall, average temperature, and other variables defined later), $\pi_i(\bullet)$ is the restricted profit function of crop i; $\Pi(\bullet)$ is the multioutput profit function of the firm. The profit functions are assumed to be well-behaved in terms of the conventional assumptions on linear homogeneity, monotonicity, and convexity.

Case 1: Water as Variable or Fixed, with Land Assumed Variable

For each subcase, this case presents two distinct economic models--one describing water as a variable input and one describing water as a quantity-rationed input--and a third artificial nesting model, which combines the two independent models into a single equation. Non-nested hypothesis tests are applied with the artificial nesting model.

CASE 1(a): Crop-choice models. A simple model of crop choice is developed here. A farmer chooses to grow a crop based on all crop prices; variable input prices and/or fixed input quantities of land or water; other variable input prices; and exogenous farm characteristics. For example, a large surface-water endowment may increase the likelihood that a farmer grows alfalfa and other forage crops, all which have large water requirements. In the model, define d_i equal to 1 when crop i is grown (i.e., when $n_i > 0$) and d_i equal to 0 when crop i is not grown (i.e., when $n_i = 0$).[3] A model of water as a variable input is

$$d_i = f_i(p, r, r_N, r_W; x), \qquad i = 1, \ldots, m. \tag{1}$$

In contrast, a model of water as a fixed input is

$$d_i = g_i(p, r, r_N, W; x), \qquad i = 1, \ldots, m. \tag{2}$$

The non-nested hypothesis test follows a non-nested *F* test procedure, in which a general model that includes both hypothesis is formed as an artificial nesting model (Fomby, et al., p. 415-416; Pesaran). The general model is

$$d_i = h_i(p, r, r_N, r_W, W; x), \qquad i = 1, \ldots, m. \tag{3}$$

Equation (3) will be estimated as a probit model with the equation specified as linear function of the variables. The multicrop system entails four crops. Thus estimates are obtained, and tests are applied, for each of the four crops.

In this case, estimates of restricted versions of equation (3) are not necessary to implement the tests because each involves only a single variable. Consequently, the null hypothesis that equation (1) represents the true model is tested with a two-tailed *t*-test on the coefficient for r_w in estimates of (3). A significant coefficient indicates that the variable input model is the true model. The null hypothesis that equation (2) represents the true model is tested with a two-tailed *t*-test on the coefficient for W. (The test is two-tailed since theory does not generate a hypothesis that the coefficient is positive or negative.) A significant coefficient on W similarly indicates that the fixed input model is the true model of water use. As with all non-nested hypothesis tests, rejecting or accepting both null hypotheses is possible.

CASE 1(b): Crop-level water use models. Development of these two models takes a more formal approach. Following the dual approach to production economics, application of Hotelling's lemma generates the crop-level demand function for water as a variable input:

$$-\frac{\partial \pi_i(p_i, r, r_N, r_W; x)}{\partial r_W} = w_i(p_i, r, r_N, r_W; x), \qquad i = 1, \ldots m. \tag{4}$$

To derive crop-level allocation functions for water as a fixed, allocatable input, the following constrained optimization problem must be solved:

$$\Pi(p, r, r_N, W; x) = \max_{w_1 \ldots w_m} \left\{ \sum_{i=1}^{m} \pi_i(p_i, r, r_N, w_i; x) : \sum_{i=1}^{m} w_i = W \right\}. \tag{5}$$

Solving this explicitly for an interior solution yields the optimal allocation equations, $w_i^*(p, r, r_N, W; x)$ (Shumway, et al.). This produces two competing models of crop-level water use, $w_i(p_i, r, r_N, r_W; x)$ and $w_i^*(p, r, r_N, W; x)$. The general artificial nesting model encompassing these models is

$$w_i = w_i(p, r, r_N, r_W, W; x), \qquad i = 1, \ldots, m. \tag{6}$$

The null hypothesis of water as a variable input will be tested with a one-tailed *t*-test of the coefficient on r_W in equation (6). The test is one-tailed because production theory generates the hypothesis that input demand functions slope downward in own-input price. The null hypothesis of water as a fixed input will be tested by estimating the general model in unrestricted form, and then re-estimating it with the restrictions that $p_{\sim i} = W = 0$, where ~i indicates crops other than crop i. The test is implemented as a likelihood ratio test, rather than an *F*-test, because the crop-level water data are used to fit a tobit model. The tobit model is applied since the water data form censored dependent variables, i.e., all producers do not grow all four crops.

To derive empirically-estimable forms for $w_i(p_i, r, r_N, r_W; x)$ and $w_i^*(p, r, r_N, W; x)$, a specific functional form must be adopted for the crop-specific restricted profit functions. We use the normalized quadratic functional form, which is a member of the class of flexible functional forms (Lau; Shumway). Applying equation (4) generates a form for $w_i(p, r, r_N, r_W; x)$ that is linear in the exogenous variables.[4] Solving equation (5) for the $w_i^*(p, r, r_N, W; x)$ requires additional effort involving four algebraic steps: setting up a Lagrangian function to represent the constrained maximization problem; deriving the necessary conditions for an interior solution;

recursively setting the necessary conditions equal to a single, arbitrary necessary condition to remove the (unobserved) shadow price on the fixed input; and solving the system of equations composed of the (m-1) subsequent equations and the input constraint. This yields a form for the $w_i^*(p,r,r_N,W;\mathbf{x})$ that is linear in the exogenous variables.[5] As the union of the two models, the general model in equation (6) also has a linear-in-parameters form. The empirical application utilizes this form.

CASE 1(c): <u>Farm-level water demand model</u>. A farm-level model of water as a variable input offers final evidence on the issue. Applying Hotelling's lemma to the multioutput profit function yields

$$-\frac{\partial \Pi(p,r,r_N,r_W;x)}{\partial r_W} = W(p,r,r_N,r_W;x)\ . \tag{7}$$

The subcase simply involves conducting a one-tailed t-test on the empirical estimate of the coefficient on r_W. The subcase creates no information on the model of water as a fixed input, i.e., it does not test competing models of water use.

Adopting a normalized quadratic form to the multioutput profit function, $\Pi(\bullet)$, again creates a linear form for estimation of $W(\mathbf{p},\mathbf{r},r_N,r_W;\mathbf{x})$.

Case 2: Water as Variable or Fixed, with Land Assumed Fixed

Modifying the models of Case 1 to the condition of land as a fixed input generally involves replacing land price (r_N) with land quantity (N) in the specifications. The crop-level water quantity models are a slight exception.

CASE 2(a): <u>Crop-choice models</u>. Only the artificial nesting model is stated since the two base models are apparent. It is

$$d_i = h_i(p,r,N,r_W,W;x)\ , \qquad i = 1,\ldots,m. \tag{8}$$

As in Case 1, equation (8) will be estimated with a probit model with the equation specified as a linear function of the variables. The procedures to test the respective null hypotheses of water as a variable input or a fixed input follow the procedures defined previously.

CASE 2(b): <u>Crop-level water use models</u>. The derivation of the variable input model follows the procedure used to derive equation (4) with one additional nuance. The crop-specific restricted profit function for this case is $\pi_i(p_i, \mathbf{r}, n_i, r_W; \mathbf{x})$. Applying Hotelling's lemma to the profit function yields the restricted water demand function, $w_i(p_i, \mathbf{r}, n_i, r_W; \mathbf{x})$. Substituting optimal land allocation equations, $n_i^*(\mathbf{p}, \mathbf{r}, N, r_W; \mathbf{x})$,[6] for n_i in the function creates the final version of the demand function, $w_i^*(\mathbf{p}, \mathbf{r}, N, r_W; \mathbf{x})$. This substitution simplifies the non-nested hypothesis test to a *t*-test rather than an *F*-test.

To derive crop-level water allocation functions, a constrained optimization problem analogous to equation (5) is solved:

$$\Pi(p, r, N, W; x) = \max_{\substack{n_1 \ldots n_m \\ w_1 \ldots w_m}} \left\{ \sum_{i=1}^{m} \pi_i(p_i, r, n_i, w_i; x) : \quad \sum_{i=1}^{m} n_i = N \text{ and } \sum_{i=1}^{m} w_i = W \right\}. \tag{9}$$

Solving (9) for an interior solution yields optimal allocation equations for water, $w_i^*(\mathbf{p}, \mathbf{r}, N, W; \mathbf{x})$, and land, $n_i^*(\mathbf{p}, \mathbf{r}, N, W; \mathbf{x})$; only the water allocation equations are used here. The artificial nesting model encompassing the competing models of water use is

$$w_i = w_i(p, r, N, r_W, W; x), \qquad i = 1, \ldots, m. \tag{10}$$

The hypotheses tests will be conducted as in Case 1. The variable input model will be tested with a *t*-test of the coefficient on r_W in an estimate of (10). The fixed input model with a likelihood-ratio test comparing the unrestricted form to a restricted form that holds $p_{\sim i} = W = 0$.

For the problem in equation (9) with two fixed, allocatable inputs, using normalized quadratic forms for the crop-specific profit functions yields optimal water and land allocation functions that are linear-in-parameters (Moore and Negri). Thus, as before, a linear specification of equation (10) is estimated.

CASE 2(c): Farm-level water demand model. A farm-level model again provides additional evidence on the whether water is a variable input (but no evidence on the fixed input model). The water demand function is

$$-\frac{\partial \Pi(p, r, N, r_W; x)}{\partial r_W} = W(p, r, N, r_W; x) . \tag{11}$$

The procedures and functional form of Case 1 are repeated here.

Case 3: Land as Variable or Fixed, with Water Assumed Fixed

Case 3 reverses the roles of water and land. The tests now pertain to competing models of land use, with water modelled as a maintained assumption. In this case, water is modelled as a fixed input: the empirical results will show this to be correct given implementation of Cases 1 and 2. The analytical structure of Case 3 is identical to Case 2, and Case 2 also built on Case 1. Thus, the hypothesis tests concerning variable input models and fixed input models of land use and the specification of the profit functions and functions to be estimated follow earlier procedures. The details will not be repeated here. As before, the essence of the tests involve comparisons of the performance of land price (r_N) and land quantity (N) as determinants of producer behavior.

CASE 3(a): Crop-choice models. The artificial nesting model for the crop-choice models is

$$d_i = h_i(p, r, r_N, N, W; x) , \qquad i = 1, \ldots, m. \tag{12}$$

CASE 3(b): Crop-level land use models. The artificial nesting model for the competing crop-level land use models is

$$n_i = n_i(p, r, r_N, N, W; x), \qquad i = 1, \ldots, m. \tag{13}$$

Equations (12) and (13) will be estimated for four crops to evaluate the competing land models.

CASE 3(c): Farm-level land demand model. As with previous cases, this test provides information only on land price as a determinant of the total quantity of land demanded; it does not cover the competing model of land as a fixed input. The variable input demand function for land is

$$-\frac{\partial \Pi(p, r, r_N, W; x)}{\partial r_N} = N(p, r, r_N, W; x) . \tag{14}$$

The nested test applied here is a *t* test on r_N.

Empirical Results

Data and Variables

The primary data are from a cross-sectional, whole-farm survey of farm operators on the west side of the San Joaquin Valley in central California for the 1988 crop production year. The dataset includes crop-level water and land use for four crop groups: cotton, other field crops (primarily wheat), forages (primarily alfalfa), and vegetables. The data set has 109 observations, with each observation representing a farm that grows crops from two or more of the crop groups. Individual farms in the region rely on one or more irrigation water sources, including water delivered from irrigation districts, groundwater pumped from on-farm wells, and direct diversions of surface water from rivers or streams. Most of the water provided by irrigation districts is purchased via long-term contracts with the federal Central Valley Project or the California State Water Project. In the dataset, surface water is the marginal water supply because surface water price exceeds marginal groundwater pumping cost. Climate data from the weather station closest to the farm are also included as secondary data (CIMIS, NOAA). For additional information on the survey, data, and variables used in the analysis, see Dinar and Campbell.

Exogenous variables from the survey include output prices, input prices, and several other exogenous variables representing physical and economic characteristics of the farm. The output price data are farm-level producer prices lagged one year. For each observation, an output price index was computed for each crop group to form the output price variables.[7] Input price variables include wage rate, marginal surface water price, and assessed land value. Wage rate is the numeraire price in the analysis (a procedure used to satisfy linear homogeneity of the profit functions as a maintained assumption). Irrigation technology cost indices are computed for each farm observation by combining survey data with information from a secondary source (CH2M Hill, 1989).[8] The other physical and economic variables include:

OWNSHR: Ratio of acreage owned by the farm operator to acreage farmed.
GWAVAIL: Dummy variable equalling 1 when the farm uses groundwater in addition to surface water; 0 otherwise.
ENVRN: Proxy variable for on-farm environmental conditions, created by principal component analysis of data on depth to groundwater, soil salinity, soil alkalinity, and soil selenium.
RAIN: 1982-1989 average annual rainfall (inches).
TEMP: 1982-1989 average daily temperature (degrees Fahrenheit).
FTIRRG: Dummy variable equalling 1 when the farm employs a full-time irrigator; 0 otherwise.
ORGCHAR: Farm organizational characteristics (see Campbell and Dinar).

The two climate variables are used because relatively long-run decisions are being analyzed; weather variables would be appropriate for analyzing decisions made subsequent to crop-level land allocations. These eight supplemental variables are included in the estimation of every equation.

Hypothesis Tests of Alternative Models

The crop-choice models (equations (3), (8), and (12)) are estimated with the probit econometric model. The crop-level models (equations (6), (10), and (13)) are estimated with the tobit econometric model (Maddala, chapter 6). The tobit model, unlike OLS, produces unbiased coefficient estimates when the dependent variable is censored. The farm-level demand functions (equations (7), (11), and (14)) are estimated with OLS.

The hypothesis tests involve non-nested hypothesis tests for the crop-choice equations and crop-level input use equations and a nested hypothesis test for the farm-level input demand equations. The non-nested tests of the competing models apply a technique that is commonly termed a non-nested *F*-test: an artificial nesting model is created that includes all of the exogenous variables of the two models, i.e., a model of the union of the two sets of exogenous variables (Fomby, et al., p. 415-416). Conventionally, the model is estimated unrestricted, then re-estimated with joint restrictions placed on variables unique to one model. An *F*-test accepts or rejects that model as the true model. A test of the second model follows by placing restrictions on variables unique to the second model and conducting an *F*-test. All outcomes are possible: both models can be rejected, both can be accepted, or only one model can be accepted.

Most of the non-nested hypothesis tests applied here are *t*-tests rather than *F*-tests: tests of the variable input model (fixed input model) simplify to a test of the significance of the relevant input price (input quantity). Restricted regression estimates are not required. The exception is with the fixed input model of Case 1(b), which requires a joint test. That model is tested with a likelihood ratio test because the equations are estimated with the tobit model and a maximum likelihood technique. The likelihood ratio test applies the χ^2 distribution with the number of restrictions equal to four for this case.

Cases 1 and 2, in combination, assess the competing models of water use. Both cases are developed because a desirable goal is to establish one model as better independently of how land is modelled. Results from the crop-choice equations (equations (3) and (8) and cases 1(a) and 2(a)) do not support either model in general (Table 1). When land is modelled as a variable input, both water models are rejected for every crop-choice decision. Neither the water price variable nor the water quantity variable is significantly different from zero in any of the crop-specific artificial nesting models. When land is modelled as fixed, the variable input model performs as the true model for field crops, while the fixed input model performs as the true model with vegetables. Evidence from these hypothesis tests, collectively, is inconclusive. The water variables simply do not affect discrete choices on which crops to grow.

The crop-level water use equations (equations (6) and (10) and cases 1(b) and 2(b)) provide evidence in support of the fixed input model. The eight hypothesis tests of the variable input model reject the model for 3 of 4 crops regardless of the land specification. Field crops are the single exception, with a negative, significant coefficient on the water price variable in the nested models for field crops. In contrast, the fixed input model is accepted as the true model in 6 of 8 tests. The test statistic values in the 6 cases strongly support the model. Further, one occasion when the fixed input model is rejected--with forages in case 1(b)--would be accepted at a slightly relaxed significance level.

The farm-level water demand functions (equations (7) and (11) and cases 1(c) and 2(c)) provide final evidence. These do not support the variable input model because the coefficient on water price is insignificant in the two demand functions.

On balance, we conclude that the fixed input model is the true model of water use.[9] Although the model did not explain crop-choice decisions, the tobit model of crop-level water use decisions represents more general decision-making than the probit model. The tobit utilizes information from both crop-choice decisions, through observations at the limit, and non-limit water quantity decisions. The variable input model was generally rejected as a model of crop-level water use through application of tobit regressions. The fixed input model was accepted, almost universally, as the correct model via the tobit procedures.

In the competing models of land use, the variable input model outperforms the fixed input model in the hypothesis tests (Case 3 in Table 1). The land models' tests are specified with water as a fixed input based on results from Cases 1 and 2. Based on the *t*-test results for the artificial nesting models, the variable input model is accepted as the true model in 4 of 4 crop-choice equations and 3 of 4 crop-level land use equations. The fourth land use equation (field crops), in fact, is accepted when evaluated at the .10 level.[10] In contrast, the fixed input model of land use is accepted as the true model in only 2 of 8 crop-specific equations. It is not accepted in any crop-choice equation, but is accepted with cotton and field crops land demand functions. Curiously, land price performs poorly in the farm-level land demand model (case 3(c)) despite performing well at the crop level. On balance, though, the evidence supports the model of land as a variable input. The farms are in long-run equilibrium in land use.

Reporting of Final Specifications

Based on results from the hypothesis tests, final specification of the behavioral equations involves modelling land as a variable input and water as a fixed input. The equations reported are crop-choice decisions, $d_i(p,r,r_N,W;\mathbf{x})$, in Table 2; land demand functions, $n_i(p,r,r_N,W;\mathbf{x})$, in Table 3; and water allocation equations, $w_i^*(p,r,r_N,W;\mathbf{x})$, in Table 4. The results are described in two parts: general reporting on the performance of variables other than land price and water quantity, followed by specific comments on the role of land price and water quantity as determinants of producer behavior.

Several comments apply generally to the results. First, output prices generally do not perform well in the three sets of equations. Two factors may explain this. The variables use cross-sectional data from a relatively small geographic region, thus creating concern about inadequate variation to produce meaningful results in econometric analysis. Further, certain rigidities may make prices relatively ineffective determinants of behavior anyway. The rigidities include the federal cotton program, which influences cotton acreage decisions directly and other decisions indirectly, and multi-year contracts with vegetable processors, which are common in California.

Second, irrigation technology prices, operating as variable input prices, perform unevenly. In this region, production of certain crops correlates heavily with certain irrigation technologies: cotton with furrow and border technologies; field and forage crops with border and furrow technologies; and vegetables with furrow and sprinkler technologies (Dinar and Campbell). The assessment of technology prices involves whether reasonable signs occur with the crops given the correlations; theory does not provide definite expectations for these signs. A consistent pattern develops across the three sets of equations in that, when a price works for a crop in the crop-choice equation, it also tends to work in the other equations. For cotton, the negative influence of border technology price is reasonable; the positive influence of furrow price is unreasonable; and the absence of an influence of sprinkler price is plausible, although a positive influence would be more reasonable. A similar mix of results also occurs with the sets of equations for forage crops and for vegetables, while the technology prices are insignificant in the three field crop equations.

Third, the remaining exogenous variables, which capture physical and organizational factors related to the farm, produce some interesting results. Several of these variables are uniformly statistically insignificant. This is surprising with OWNSHR, ENVRN, and ORGCHAR. Yet it is also interesting that these features exert no discernible effect on land use and water allocation decisions. Other variables affect decisions related to certain crops. GWAVAIL, for example, has a positive influence on forage crop choice, land demand, and water allocation; a negative influence on cotton land demand and water allocation; and a negative influence on vegetable crop choice. GWAVAIL effectively serves as a proxy for bad water quality because, in this region, groundwater sources are much more saline that surface water supplies. This explains the variable's performance: alfalfa, the dominant forage crop, is very salt tolerant once past the germination stage; cotton, while reasonably salt tolerant, is less so than alfalfa; and many vegetables, e.g., tomatoes, are very sensitive to saline conditions. The climate variables, RAIN and TEMP, affect cotton-related decisions in all three equations. The coefficient on RAIN is negative in the cotton equations. Two factors explaining this are, first, cotton yield is sensitive to the timing and volume of irrigations and, two, water from rainfall can affect the quality of cotton bolls. In other words, rainfall generally is a negative event in cotton production. The coefficient on TEMP is positive in the cotton equations because cotton requires a long growing season and tolerates high temperatures. With the other crops, RAIN and TEMP likely had inadequate variation to explain production decisions. Finally, vegetable production decisions correlate with FTIRRG, a dummy variable indicating the presence of an on-farm irrigator. This is reasonable since vegetable product quality depends on irrigation timing. However, the relationship likely is correlation rather than causality.

Land price and water quantity are the most interesting variables to study closely in the context of crop-specific land use and water allocation decisions. In many economic models, land is modelled as fixed and water as variable. Results here thus are novel *per se*. These variables also have enough cross-sectional variation to perform well econometrically.

Focus initially on the role of land price. Unlike water quantity, land price performs well statistically in every crop-choice equation (Table 2). The results basically reflect the finding that land is a variable input: for every crop, the probability of growing the crop declines in land price. If land were fixed, in contrast, land reallocations would occur in response to changes in price. A mixture of positive and negative coefficients likely would be present.

Land prices perform similarly well in the land demand functions (Table 3). Field crops are the one case in which land price performs stronger in the crop-choice decision than in the land use decision. The coefficient on land price nevertheless is significant at the .10 level (in a one-tailed test) in field crops' land demand. In terms of the price elasticity of demand, vegetable acreage is the most responsive to price changes (and is quite elastic at -1.61), followed by cotton acreage (-0.79), forage crop acreage

(-0.40), and field crop acreage (-0.26).

The water quantity variable performs differently than land price in the crop-choice and input use equations. As a farm-level fixed input, producers appear to ignore water quantity when making decisions on crop choice. Once these decisions are made, however, water quantity performs very well statistically in both the land demand and water allocation equations. A one acre-foot increase in the water constraint increases acreage by: 0.225 acres of cotton; 0.090 acres of field crops; 0.056 acres of vegetables; and 0.029 acres of forage crops (Table 3). Similarly, a one-acre foot increase in the constraint is apportioned among crops as: 0.659 acre-feet to cotton; 0.217 acre-feet to vegetables; 0.162 acre-feet to field crops; and 0.124 acre-feet to forage crops (Table 4).

Policy Implication: Central Valley Project Recontracting

The econometric results address an important federal water policy issue in California: the price and quantity terms of water service contracts for the federal Central Valley Project (CVP). The CVP annually serves over 2 million cropland acres with roughly 4 million acre-feet of water diverted and transported from the major central California rivers. The Bureau of Reclamation, an agency in the U.S. Department of the Interior, constructed and administers the CVP. Roughly 120 irrigation and water districts contract with the federal government for CVP irrigation water supply. Most farms in the study region receive irrigation water from the CVP.

The terms of CVP water service contract renewals are a controversial issue (Candee and Bern; Moore, p. 148-150). CVP contracts typically cover a 40-year period and charge irrigation water prices greatly below the long-run marginal cost of water supply.[11] Beginning in 1989 and continuing into the early 21st century, CVP contracts with individual water districts are expiring. Recipients of irrigation water naturally favor renewing contracts at existing water prices, water entitlements, and contract lengths. Wildlife and environmental interests, concerned over the absence of water to protect riparian ecosystems and fish species, favor contract terms that could induce irrigation water conservation, i.e., higher water prices or reduced water entitlements, or both. The controversy extends to federal agencies, with the Department of the Interior endorsing renewal at existing terms and the U.S. Environmental Protection Agency, the Council on Environmental Quality, and the U.S. General Accounting Office supporting analysis of various incentives for irrigation water conservation (Council on Environmental Quality; Moore; U.S General Accounting Office). Final policy on CVP recontracting awaits the completion of an Environmental Impact Statement under the guidelines of the National Environmental Policy Act (Candee and Bern).

This paper's results address the issue in two ways. First, the tests determining that water is a fixed input raise the issue of the general effectiveness of higher water prices as a conservation policy instrument. Because the administratively-set water prices do not affect producer behavior at the margin, small water-price increases would not affect land use and water allocation decisions and, in particular, would not induce water conservation. More significant price increases,[12] reduction in contractual entitlements, or deregulation of water markets would be required to achieve a goal of CVP water conservation.

Second, the econometric results with water specified as a fixed input establish a quantitative basis for evaluating the effects of a quantity-based conservation policy. The U.S. Congress is currently considering such a policy as a legislative-branch approach to CVP recontracting. The Senate held hearings in 1991 on a bill governing CVP policy, the Central Valley Project Improvement Act (U.S. Congress). The proposed law would reduce irrigation water deliveries to each CVP water district by 10 percent as a means of creating additional instream water flow for fish and wildlife purposes. The land demand and water allocation equations offer a strong set of results to study in this context. For example, the land demand elasticities with respect to the water constraint illustrate how cropping pattern would change in response to a change in CVP water entitlement (Table 5). With a water-supply *reduction*, cotton acreage would respond elastically: a 10 percent reduction in water supply would reduce cotton acreage by more than 20 percent. Acreage in field crops, vegetables, and forage crops would respond inelastically, with acreage decreasing slightly more than 7 percent, almost 5 percent, and more than 3 percent, respectively. The water allocation elasticities can be interpreted similarly (Table 5). A water-supply reduction would produce an elastic reduction in cotton water allocations, and all other water allocations would decline inelastically.

A comprehensive analysis of the effects of a water-supply reduction throughout the CVP service area cannot be conducted because the paper's study region covers only a portion of the service area. However, the results are reasonably representative of cotton production, which occurs in the southern portion of the Central Valley in an area that contains the present study region. In 1987, CVP cotton acreage was 532,673 acres, or 5.4 percent of the national total of 9,826,081 cotton acres (U.S. Department of the Interior, Bureau of Reclamation; U.S. Department of Commerce). Using cotton's land demand elasticity, 2.01, a uniform 10 percent water-supply reduction translates into roughly a 106,000 decrease in CVP cotton acres. This equals 1.1 percent of the national total. The conclusion, then, is that a 10 percent water-supply reduction would likely produce a non-marginal decrease in national cotton production, with a related increase in cotton's market price. The welfare effects and distributional impacts could be significant.[13] This points out the need for a complete analysis of the effects of alternative CVP water allocation policies on agricultural producers and consumers.

Conclusions

The research demonstrates the importance of testing alternative models of long-run input use. Land is frequently modelled as a fixed input as a maintained assumption, and water is frequently modelled as a variable input. The results here reverse the conventional wisdom: producers are in long-run equilibrium in land, yet surface water is a quantity-rationed input. This finding dictates the correct specification of crop-specific land and water use equations. The implications extend to determining the correct specification of profit functions and input nonjointness tests.

The approach developed in the paper utilizes opportunities created by the availability of crop-specific input use data on multioutput production. The alternative models are evaluated by applying non-nested hypothesis tests to crop-choice equations and crop-specific land and water use equations.

For studying water supply policy, the long-run model of water use dominates a short-run model (i.e., a model that fixes crop-specific land use). The long-run model accurately portrays the incentives given to the multicrop producer by water price or farm-level water supply. The application of the econometric results to CVP water allocation policy illustrates this use of the model. Most important, the finding that surface water is a quantity-rationed input implies that marginal or small water price increases would not alter producer behavior and, specifically, would not induce water conservation.

Two implications for future research come out of the paper. One, in terms of basic research, a model of water as a fixed input also makes sense in the context of short-run analysis of input allocation in multicrop systems. In previous research, a satisficing (or behavioral) model and a variable input model were tested as competing models. A model similar to this paper's model of water as a fixed, allocatable input can be tested against the other two competing models of short-run water allocation. Two, in terms of policy analysis, the results indicate that, if adopted as a CVP water policy, quantity restrictions could produce a significant decline in cotton output from central California. The national market price of cotton easily could increase as a consequence. The present analysis, though, cannot be extended to other major CVP crops. A more comprehensive analysis is needed of CVP water policy alternatives and their effects on agricultural production and commodity markets.

Footnotes

1. An unpublished paper by Kanazawa tested competing models of water use. The paper concluded that, in the Westlands Water District in California, surface water is a fixed input, with shadow prices for irrigation water exceeding prices paid by producers. The present paper develops a different economic model and applies different econometric methods than the Kanazawa research.

2. In an unpublished working paper, Wichelns and Howitt applied an approach similar to the Just, et al. (1990) approach to two inputs, water and land. While the present paper is comparable to the Wichelns and Howitt paper in that two competing models of input use are applied to water and land, the modelling approach, econometric analysis, and data set differ completely.

3. A more formal model can be developed of the crop-choice decision (following Maddala, p. 22). Consider the case of land modelled as a variable input and water modelled as a fixed input. The crop-specific profit of producing crop i is $\pi_i(p, r, r_N, W; \mathbf{x})$. Adding an error term, this can be written as

$$\pi_{ij} = \pi_{ij}(p, r, r_N, W; x) + u_{ij} \qquad i=1,\ldots,m;\ j=1,\ldots,n$$

where j indicates individual observations. The π_{ij} are not observed. We do observe a dummy variable, d_{ij}, that indicates whether or not crop i is grown. It is defined by

$$\begin{array}{ll} d_i=1 & if\ \pi_{ij}>0 \\ d_i=0 & otherwise. \end{array}$$

By assuming that the u_{ij} are distributed $IN(0,\sigma^2)$, the probit model can be applied to estimate the probability of growing crop i dependent on the exogenous variables.

4. The normalized quadratic profit function expresses output and input prices relative to a numeraire price to maintain linear homogeneity of the function in prices. For notational ease, the functions in the text will not be altered to reflect this. In the empirical application, though, price variables are expressed as relative prices.

5. The advantage of adopting a normalized quadratic profit function for the $\pi_i(p_i, r, r_N, w_i; \mathbf{x})$ is that each necessary condition is a linear equation with the implicit form of $g_i(p_i, r, r_N, w_i; \mathbf{x}, \lambda) = 0$, for $i=1,\ldots,m$, where λ is water's shadow price. The linearity enables derivation of an explicit closed-form solution to the equation system of m equations and m unknowns. Assuming an interior solution, a four-step algebraic procedure yields estimable optimal water allocation equations, $w_i^*(p, r, r_N, W; \mathbf{x})$, that are linear-in-parameters. See Moore and Negri for an expanded discussion of this approach for the case of two fixed, allocatable inputs.

6. Optimal land allocation functions are derived by solving the constrained optimization problem in equation (5) with land as a fixed, allocatable input rather than water.

7. The output price index for each crop group is computed as

$$[\sum_{i=1}^{s}(p_i y_i)]/\sum_{i=1}^{s} y_i$$

where s represents the number of crops in the particular crop group and y_i is output of crop i.

8. The irrigation technology cost indices are the annualized cost per acre of operating the various technologies. Each index is technology specific, i.e., sprinkler, furrow, and flood each have a unique cost index. They are computed as

$$[\sum_{i=1}^{t}(w_i x_i)]/\sum_{i=1}^{t} x_i$$

where t represents different management levels of a specific technology, w_i represents the cost of operating a specific technology at the different management levels, and x_i is acreage in a specific technology.

9. To supplement the results, non-nested hypothesis tests are conducted on the competing models of water use in explaining crop-specific land use decisions. Land is modelled as a variable input (which, as Case 3 will conclude, is the correct model). The artificial nesting model is $n_i(\mathbf{p}, \mathbf{r}, r_N, r_W, W; \mathbf{x})$. The *t*-test results are similar to the results with the water use equations. The fixed input model of water use performs strongly as the true model in all four crops' land demand equations: *t*-statistic values on the coefficient on water quantity (W) are greater than 2.0 for every crop. The variable input model performs as the true model only with field crops. These results strengthen the conlusion that surface water should be modelled as a fixed input.

10. In the four crop-choice equations, a two-tailed *t*-test on the coefficient on land price serves as the non-nested hypothesis test while, in the four land use equations, a one-tailed *t*-test on the same coefficient completes the test; the second set of tests are one-tailed because the alternative hypothesis is that the coefficient on land price is negative (as a testable hypothesis of the theory of the competitive firm).

11. The irrigation construction cost subsidy for the San Luis Unit, a major component of the CVP, is an estimated 84.7 percent of total constuction cost, or $1,422 per acre (Wahl, p. 35). The San Luis Unit has 571,888 irrigable acres. While many studies have analyzed the capital subsidy for reclamation water supply, many CVP water-service prices do not even cover short-run operating and maintenance costs (Wahl, p. 58-59).

12. Full-cost pricing of water (where "full-cost" is defined by the Reclamation Reform Act of 1982) characterizes a standard of "more significant" price increases. For three water districts in the study area, full-cost pricing would increase water prices by $22.67 per acre-foot for Panoche Water District, $24.58 per acre-foot for Broadview Water District, and $28.00 per acre-foot for Westlands Water District (U.S. Department of the Interior, Office of the Secretary).

13. A simple calculation illustrates the potential first-round effects on cotton producer returns. Assume, for the sake of the illustration, that: (1) a 1.1 percent national acreage decrease translates into a 1.0 percent cotton production decrease and (2) the price elasticity of demand for cotton is -0.5. Additional information is that the value of 1987 U.S. upland cotton production was $4.405 billion (U.S. Department of Agriculture). These figures imply that a 10 percent CVP water-supply reduction would increase the national value of 1987 upland cotton production by almost $22 million.

References

CH2M Hill, Inc. "Irrigation System Costs and Performance in the San Joaquin Valley." Sacramento, September 1989.

California Irrigation Management Information System (CIMIS). Water Conservation Office, California Department of Water Resources. Sacramento, CA, 1982-1990.

Campbell, M. B., and A. Dinar. "A Model of Farm Organization Structure: Levels of Complexity and Input Use." Working Paper, San Joaquin Valley Drainage Program, Sacramento, CA, 1990.

Candee, H., and M. D. Bern. "Western Irrigation Contracts and NEPA." Environment, 32(July/August 1990): 2-3, 42-44.

Chambers, R. G., and R. E. Just. "Estimating Multioutput Technologies." American Journal of Agricultural Economics, 71(1989): 980-95.

Council on Environmental Quality, Executive Office of the President. "Recommendations of the Council on Environmental Quality Regarding the Proposal by the Department of the Interior's Bureau of Reclamation to Renew Long-Term Water Contracts for the Orange Cove and other Friant Unit Irrigation Districts of the Central Valley Project in California." Federal Register, 54(128), July 6, 1989: 28477-28491.

Dinar, A. and M. B. Campbell. "Adoption of Improved Irrigation and Drainage Reduction Technologies in the Westside of the San Joaquin Valley; Part 1: Literature Review, Survey Methods, and Descriptive Results." Research Report, San Joaquin Valley Drainage Program, Sacramento, CA, 1990.

Fomby, T. B., R. C. Hill, and S. R. Johnson. Advanced Econometric Methods. New York: Springer-Verlag, 1984.

Just R. E., D. Zilberman, and E. Hochman. "Estimation of Multicrop Production Functions." American Journal of Agricultural Economics, 65(1983): 770-80.

Just, R. E., D. Zilberman, E. Hochman, and Z. Bar-Shira. "Input Allocation in Multicrop Systems." American Journal of Agricultural Economics, 72(1990): 200-9.

Kanazawa, M. T. "The Economic Efficiency of the Water Supply Policies of the Bureau of Reclamation: A Reconsideration." Discussion paper, Department of Economics, Carleton College, Northfield, MN, 1988.

Lau, L. J. "Applications of Profit Functions." In Production Economics: A Dual Approach to Theory and Applications, M. Fuss and D. McFadden, eds., vol. 1, chap. I.3. Amsterdam: North-Holland Publishing Co., 1978.

Maddala, G.S. Limited-Dependent and Qualitative Variables in Econometrics. Cambridge: Cambridge University Press, 1983.

Moore, M.R. "The Bureau of Reclamation's New Mandate for Irrigation Water Conservation: Purposes and Policy Alternatives." Water Resources

Research, 27(1991): 145-155.

Moore, M. R., and D. H. Negri. "A Multicrop Model of Irrigated Agriculture, Applied to Water Allocation Policy of the Bureau of Reclamation." Western Journal of Agricultural Economics, forthcoming.

NOAA weather data from EARTHINFO [need exact citation for this]

Pesaran, M. H. "Comparison of Local Power of Alternative Tests of Non-Nested Regression Models." Econometrica, 50(1982): 1287-1305.

Shumway, C. R., R. Pope, and E. Nash. "Allocatable Fixed Inputs and Jointness in Agricultural Production: Implications for Economic Modeling." American Journal of Agricultural Economics, 66(1984):72-78.

U.S. Congress, Senate. Central Valley Project Improvement Act. S. 484. 102d Congress, 1st Session, February 26, 1991.

U.S. Department of Agriculture, National Agricultural Statistics Service. Agricultural Statistics 1988. Washington, D.C.: U.S. Government Printing Office, 1988.

U.S. Department of Commerce, Bureau of the Census. 1987 Census of Agriculture: Volume 1, Part 51. Washington, D.C.: U.S. Government Printing Office, 1988.

U.S. Department of the Interior, Bureau of Reclamation. 1987 Summary Statistics: Water, Land, and Related Data. Denver, Colorado, 1988.

U.S. Department of the Interior, Office of the Secretary. H.R. 1443, Irrigation Subsidy Legislation: Questions from the Subcommittee on Interior and Insular Affairs, memorandum, Washington, D.C., February 24, 1988.

U.S. General Accounting Office. Reclamation Law: Changes Needed Before Water Service Contracts are Renewed. Report No. RCED-91-175, August 1991.

Wahl, R. W. Markets for Federal Water. Washington, D.C.: Resources for the Future, 1989.

Wichelns, D., and R. E. Howitt. "Price-Responsive 'Fixed' Inputs and Fixed-Proportion 'Variable' Inputs in Multicrop Systems." Discussion paper, University of Rhode Island, Kingston, RI, 1991.

TABLE 1. HYPOTHESIS TESTS OF COMPETING MODELS OF WATER AND LAND USE

Case 1: Water Models with Land a Variable Input

1(a): Crop-choice equations.

Crop	Model	Null Hypothesis	t-test Statistic	Finding[1]
Cotton	Variable	$r_W = 0$	1.573	Reject model (do not reject H_o)
	Fixed	$W = 0$	0.506	Reject model (do not reject H_o)
Field Crops	Variable	(repeat	-1.917	Reject model (do not reject H_o)
	Fixed	pattern)	-0.101	Reject model (do not reject H_o)
Forage Crops	Variable		0.447	Reject model (do not reject H_o)
	Fixed		0.311	Reject model (do not reject H_o)
Vegetables	Variable		0.113	Reject model (do not reject H_o)
	Fixed		1.538	Reject model (do not reject H_o)

1(b): Crop-level water use equations.

Crop	Model	Null Hypothesis	Test Statistic[2]	Finding
Cotton	Variable	$r_W = 0$	0.458 (t)	Reject model (do not reject H_o)
	Fixed	$p_{\sim i} = W = 0$	91.444 (LR)	Accept model (reject H_o)
Field Crops	Variable	(repeat	-2.777 (t)	Accept model (reject H_o)
	Fixed	pattern)	27.066 (LR)	Accept model (reject H_o)
Forage Crops	Variable		0.267 (t)	Reject model (do not reject H_o)
	Fixed		6.036 (LR)	Reject model (do not reject H_o)
Vegetables	Variable		1.605 (t)	Reject model (do not reject H_o)
	Fixed		17.268 (LR)	Accept model (reject H_o)

1(c): Farm-level water demand equation.

Model: Variable input
Null hypothesis: $r_W = 0$
t-test Statistic: 0.555
Finding: Do not reject H_o; water price statistically insignificant

---

[1] All tests in Table 1 are conducted at the .05 significance level. The t-tests are two-tailed in the crop-choice equations, but one-tailed in the quantity equations because H_a is r_W (or r_N) < 0 for those cases.

[2] This case involves both t-tests (denoted t) and likelihood ratio tests (denoted LR).

TABLE 1. HYPOTHESIS TESTS OF COMPETING MODELS OF WATER AND LAND USE *(continued)*

Case 2: Water Models with Land a Fixed Input

2(a): Crop-choice equations.

Crop	Model	Null Hypothesis	*t*-test Statistic	Finding
Cotton	Variable	$r_W = 0$	1.401	Reject model (do not reject H_o)
	Fixed	$W = 0$	-0.796	Reject model (do not reject H_o)
Field Crops	Variable	(repeat	-2.270	Accept model (reject H_o)
	Fixed	pattern)	-1.727	Reject model (do not reject H_o)
Forage Crops	Variable		0.414	Reject model (do not reject H_o)
	Fixed		1.533	Reject model (do not reject H_o)
Vegetables	Variable		0.842	Reject model (do not reject H_o)
	Fixed		1.980	Accept model (reject H_o)

2(b): Crop-level water use equations.

Crop	Model	Null Hypothesis	*t*-test Statistic	Finding
Cotton	Variable	$r_W = 0$	0.305	Reject model (do not reject H_o)
	Fixed	$W = 0$	2.068	Accept model (reject H_o)
Field Crops	Variable	(repeat	-3.107	Accept model (reject H_o)
	Fixed	pattern)	-0.558	Reject model (do not reject H_o)
Forage Crops	Variable		0.057	Reject model (do not reject H_o)
	Fixed		4.978	Accept model (reject H_o)
Vegetables	Variable		2.121	Reject model (reject H_a of $r_W < 0$)
	Fixed		3.568	Accept model (reject H_o)

2(c): Farm-level water demand equation.

Model: Variable input
t-test Statistic: -0.358

Null hypothesis: $r_W = 0$
Finding: Do not reject H_o; water price statistically insignificant

TABLE 1. HYPOTHESIS TESTS OF COMPETING MODELS OF WATER AND LAND USE (*continued*)

Case 3: Land Models with Water a Fixed Input[3]

3(a): Crop-choice equations.

Crop	Model	Null Hypothesis	*t*-test Statistic	Finding
Cotton	Variable	$r_N = 0$	-2.847	Accept model (reject H_o)
	Fixed	$N = 0$	1.079	Reject model (do not reject H_o)
Field Crops	Variable	(repeat	-2.047	Accept model (reject H_o)
	Fixed	pattern)	1.680	Reject model (do not reject H_o)
Forage Crops	Variable		-1.990	Accept model (reject H_o)
	Fixed		-1.589	Reject model (do not reject H_o)
Vegetables	Variable		-2.558	Accept model (reject H_o)
	Fixed		-1.786	Reject model (do not reject H_o)

3(b): Crop-level land use equations.

Crop	Model	Null Hypothesis	*t*-test Statistic	Finding
Cotton	Variable	$r_N = 0$	-1.980	Accept model (reject H_o)
	Fixed	$N = 0$	5.573	Accept model (reject H_o)
Field Crops	Variable	(repeat	-1.394	Reject model (do not reject H_o)
	Fixed	pattern)	5.420	Accept model (reject H_o)
Forage Crops	Variable		-2.576	Accept model (reject H_o)
	Fixed		-1.628	Reject model (do not reject H_o)
Vegetables	Variable		-2.085	Accept model (reject H_o)
	Fixed		-0.583	Reject model (do not reject H_o)

3(c): Farm-level land demand equation.

Model: Variable input

Null hypothesis: $r_N = 0$

***t*-test Statistic:** -0.363

Finding: Do not reject H_o; land price statistically insignificant

---

[3] Water is modelled as fixed in the competing land models because of the results of Cases 1 and 2.

Table 2. Probit Estimates of Crop-Choice Models; Final Specification[1]

Variable	Crop			
	Cotton	Field Crops	Forage Crops	Vegetables
Prices:[2]				
Cotton	-0.333E-02	-0.123E-02	-0.172E-02	0.812E-02
	(-1.831)	(-1.073)	(-1.369)	(3.492)
Field Crops	-0.276E-02	-0.257E-02	-0.201E-02	0.605E-02
	(-0.569)	(-0.925)	(-0.587)	(1.378)
Forage Crops	0.110E-02	-0.271E-02	0.677E-03	-0.824E-02
	(0.382)	(-1.170)	(0.438)	(-1.760)
Vegetables	-0.221E-02	0.683E-03	0.528E-04	0.166E-02
	(-0.986)	(0.947)	(0.050)	(1.236)
Border IT[3]	-0.388E-01	0.138E-01	0.250E-01	0.830E-01
	(-1.738)	(1.169)	(1.732)	(3.071)
Furrow IT	0.1017	0.628E-02	-0.234E-01	-0.790E-01
	(3.765)	(0.425)	(-1.334)	(-3.041)
Sprinkler IT	-0.324E-02	0.724E-03	0.105E-01	-0.518E-01
	(-0.329)	(0.149)	(1.945)	(-3.701)
Land	-0.584E-03	-0.154E-03	-0.129E-03	-0.707E-03
	(-3.002)	(-2.068)	(-1.905)	(-2.439)
Water Quantity	0.598E-04	-0.337E-05	0.119E-04	0.547E-04
	(0.805)	(-0.095)	(0.326)	(1.537)
OWNSHR	0.537E-01	-0.2689	-0.1938	-0.6443
	(0.113)	(-0.928)	(-0.730)	(-1.307)
GWAVAIL	-0.2726	-0.3952	0.7453	-0.8403
	(-0.524)	(-1.219)	(2.080)	(-1.903)
ENVRN	0.1287	-0.2285	0.1392	-0.3816
	(0.235)	(-0.619)	(0.324)	(-0.767)
RAIN	-0.1660	0.186E-01	0.170E-01	-0.502E-01
	(-2.352)	(0.865)	(0.771)	(-1.301)
TEMP	0.2854	0.384E-01	-0.2449	0.2245
	(1.839)	(0.368)	(-2.137)	(1.556)
FTIRRG	-0.8158	-0.1771	-0.6751	0.8750
	(-1.447)	(-0.503)	(-1.787)	(1.859)
ORGCHAR	0.218E-01	0.357E-01	-0.265E-01	-0.497E-01
	(0.297)	(0.731)	(-0.489)	(-0.821)
Constant	-15.259	-1.9305	15.755	-12.795
	(-1.594)	(-0.296)	(2.199)	(-1.418)
Value of Log Likelihood Function	-27.97	-66.29	-55.92	-37.24

---

[1] Final specification involves land modelled as a variable input and water modelled as a fixed input. Numbers in parenthesis are values of *t*-statistics.

[2] Output and input price variables are divided by wage rate.

[3] "IT" stands for irrigation technology.

Table 3. Tobit Estimates of Crop-level Land Demand Functions; Final Specification[1]

Variable	Crop			
	Cotton	Field Crops	Forage Crops	Vegetables
<u>Prices</u>:[2]				
Cotton	-1.5945	-0.4875	-0.5086	3.2949
	(-3.185)	(-0.855)	(-1.068)	(3.197)
Field Crops	-0.6872	-1.4226	-0.3474	2.1900
	(-0.546)	(-1.069)	(-0.266)	(1.212)
Forage Crops	0.2907	-1.5172	0.3082	-5.9459
	(0.568)	(-0.987)	(0.629)	(-1.909)
Vegetables	-0.8625	0.3441	0.736E-01	0.5348
	(-1.316)	(0.944)	(0.189)	(0.862)
Border IT[3]	-20.817	7.4973	10.883	16.248
	(-2.569)	(1.291)	(2.051)	(1.886)
Furrow IT	38.890	0.5899	-15.675	-25.552
	(4.582)	(0.083)	(-2.304)	(-2.123)
Sprinkler IT	1.6410	0.8360	4.8582	-15.885
	(0.536)	(0.338)	(2.332)	(-3.498)
Land	-0.1395	0.524E-01	-0.609E-01	-0.2894
	(-2.020)	(-1.457)	(-2.498)	(-2.084)
Water Quantity	0.2249	0.902E-01	0.294E-01	0.556E-01
	(9.192)	(4.902)	(2.126)	(2.855)
OWNSHR	22.545	-150.33	-33.897	-233.38
	(0.210)	(-0.984)	(-0.333)	(-0.921)
GWAVAIL	-301.65	-259.36	262.09	-257.25
	(-2.184)	(-1.592)	(1.946)	(-1.171)
ENVRN	232.03	-99.290	3.3111	-191.73
	(1.399)	(-0.559)	(0.021)	(-0.834)
RAIN	-78.588	2.7863	6.3212	7.2970
	(-3.963)	(0.254)	(0.730)	(0.418)
TEMP	76.541	6.9063	-81.980	59.535
	(1.819)	(0.139)	(-1.913)	(0.838)
FTIRRG	-408.51	-105.76	-202.74	653.21
	(-2.578)	(-0.632)	(-1.417)	(2.703)
ORGCHAR	20.432	-2.1897	-30.722	17.279
	(0.982)	(-0.096)	(-1.432)	(0.607)
Constant	-4238.8	-419.68	5319.8	-4116.4
	(-1.614)	(-0.136)	(1.992)	(-0.929)
Value of log-likelihood function	-507.14	-401.46	-350.34	-358.16

[1] Final specification involves land modelled as a variable input and water modelled as a fixed input. Numbers in parenthesis are values of *t*-statistics.

[2] Output and input price variables are divided by wage rate.

[3] "IT" stands for irrigation technology.

Table 4. Tobit Estimates of Crop-level Water Allocation Functions; Final Specification[1]

Variable	Crop			
	Cotton	Field Crops	Forage Crops	Vegetables
Prices:[2]				
Cotton	-3.4105	-0.2307	-0.5375	9.599
	(-2.421)	(-0.228)	(-0.305)	(2.995)
Field Crops	-2.7111	-2.6799	-1.1717	4.4248
	(-0.738)	(-1.074)	(-0.239)	(0.778)
Forage Crops	1.4947	-1.0428	2.2858	-17.740
	(1.040)	(-0.660)	(1.288)	(-1.854)
Vegetables	-1.9131	0.4995	-0.1113	2.544
	(-1.026)	(0.774)	(-0.077)	(1.264)
Border IT[3]	-62.173	11.181	29.921	57.295
	(-2.584)	(1.021)	(1.498)	(2.094)
Furrow IT	93.407	-7.4697	-69.950	-72.363
	(3.868)	(-0.573)	(-2.744)	(-1.890)
Sprinkler IT	4.7946	1.1661	16.562	-51.700
	(0.542)	(0.255)	(2.101)	(-3.573)
Land	-0.3881	-0.749E-01	-0.1533	-0.9654
	(-1.862)	(-1.104)	(-1.685)	(-2.141)
Water Quantity	0.6587	0.1625	0.1244	0.2167
	(9.327)	(4.720)	(2.420)	(3.477)
OWNSHR	50.682	-283.30	41.836	-1072.2
	(0.165)	(-0.986)	(0.110)	(-1.321)
GWAVAIL	-625.64	-274.32	1382.7	-575.41
	(-1.605)	(-0.912)	(2.743)	(-0.833)
ENVRN	445.50	-232.55	403.09	-788.49
	(0.939)	(-0.690)	(0.694)	(-1.081)
RAIN	-229.61	14.398	27.917	43.059
	(-4.028)	(0.703)	(0.859)	(0.771)
TEMP	271.95	84.829	-184.39	191.42
	(2.254)	(0.886)	(-1.143)	(0.858)
FTIRRG	-875.54	-103.00	-511.01	1752.0
	(-1.980)	(-0.332)	(-0.965)	(2.319)
ORGCHAR	74.741	42.447	-69.477	-4.9740
	(1.256)	(0.999)	(-0.882)	(-0.055)
Constant	-15453	-5627.3	11527	-12889
	(-2.055)	(-0.942)	(1.147)	(-0.926)
Value of log-likelihood function	-583.65	-425.60	-407.40	-407.39

---

[1] Final specification involves land modelled as a variable input and water modelled as a fixed, allocatable input. Numbers in parenthesis are values of *t*-statistics.

[2] Output and input price variables are divided by wage rate.

[3] "IT" stands for irrigation technology.

Table 5. Input Use Elasticities with Respect to the Water Constraint[1]

	Crop			
	Cotton	Field Crops	Forage Crops	Vegetables
Land Demand Elasticity	2.01	0.71	0.31	0.49
Water Allocation Elasticity	2.01	0.66	0.35	0.61

[1] The standard elasticity formulas apply: $(\partial n_i/\partial W)(W/n_i)$ for land demand and $(\partial w_i/\partial W)(W/w_i)$ for water allocation.