THE CHOICE OF TECHNIQUES

AND

TECHNOLOGICAL CHANGE

IN U. S. AGRICULTURE

1948 - 1983

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The Producer's Problem of Technique Choice

Traditional estimations of production functions and other functions which characterize technological parameters, assume, at least implicitly, that only one technique is universally available. This approach fits one surface or production frontier to the data. A branch of this approach tries to detect and interpret deviations from the frontier. Interpretations of deviations become logically problematic however, since they are inconsistent with the maintained hypothesis under which the surface was estimated.

An alternative approach, the choice of technique approach, allows for the existence of multiple techniques which are available in the production of an output.[1] Producers maximize profit by allocating inputs to (implementing) techniques, constrained by available fixed inputs. Profitability of any technique, if implemented, will be a function of input and output prices.

More formally, let J techniques be available to a producer in production of an output. Then the behavior of a representative producer is described by the solution to:

$$(1) \qquad \max_{v_j, b_j} \quad \Pi = \sum_{j=1}^{J} p\, F_j(v_j, b_j) - \sum_{j=1}^{J} w_j\, v_j$$

$$\text{subject to:} \quad b - \sum_j b_j = 0$$

where p is the output price, v_j are variable inputs with input prices w_j and b_j are allocatable fixed inputs, which must sum to the available total of fixed inputs. The F_j may be either different techniques used to produce a single output, or different outputs. In the later case, different outputs are

1. The discussion in this section summarizes material in Mundlak [1988].

likely to have different prices and a j subscript must be added to p. The Kuhn-Tucker necessary conditions for maximization of (1) include:

$$(2) \qquad p\,F_{vj} - w_j \le 0, \qquad j = 1, \ldots, J$$

$$(3) \qquad p\,F_{bj} - \lambda \le 0, \qquad j = 1, \ldots, J$$

where λ is the multiplier on the constraint and F_{ij} denotes differentiation of F_j with respect to i. Additionally imposing that v_j and $b_j \ge 0$ implies that whenever (2) or (3) are negative, that v_j^* and b_j^* (the v_j and b_j which maximize (1)) are 0, and technique j is not implemented.

Figure 1 illustrates the case where two techniques are available in the production of one output with two inputs (capital and labor). Technique M (modern) is cheaper at higher capital / labor ratios while technique T (traditional) is cheaper at lower capital labor ratios. Define $\tilde{\omega}$ as the wage / rental ratio which is tangent to both isoquants. For $\omega < \tilde{\omega}$ only the traditional technique is implemented while for $\omega > \tilde{\omega}$ only the modern technique is implemented. At $\omega = \tilde{\omega}$, both techniques are implemented, and the degree of relative implementation is determined by the capital / labor ratio.

Important to notice in Figure 1 is that the production frontier is not the lower envelope of the available techniques, for at $\omega = \tilde{\omega}$, producers can do better than the lower envelope by taking a convex combination of the techniques. If the choice of technique decision accurately describes the environment in which production decisions are made, then at issue is how to measure aggregate production functions in this environment.

Measurement of Choice of Technique Production Functions

One approach to solving the problem of multiple techniques is to specify and estimate a separate production function for each technique. This may be the preferred approach when experimental data is available on each technique.

There are two drawbacks to this strategy: when data are available on inputs used in each technique, this approach uses up degrees of freedom and when data are available only at an aggregate level (when we observe not v_j but $\Sigma\, v_j$) the approach cannot be used. The later is the case in aggregate U. S. agricultural production statistics where only $\Sigma\, v_j$ is observed. This approach allows measurement of technique choice without forcing specification of techniques that are implemented.

The proposed alternative to specifying functions for each technique is to find a function $F(\Sigma\, v_j,\ \Sigma\, b_j)$ which well approximates $\Sigma\, F_j(v_j,\ b_j)$. Mundlak suggests [Mundlak 1988a] that the production function F(x,z) (where x are inputs; z are state variables), may be approximated by[2]:

$$(4) \qquad F(x,z) = \Gamma(x^*,x,z) + \sum_{i=1}^{I} \beta_i(x^*,x,z)\, x_i$$

where x* are the profit maximizing input quantities and x are the observed input quantities. Equation (4) is a Cobb - Douglas production function, functions of the state of the economy and of inputs. The functional forms used to approximate the parameters Γ and β are:

$$(5) \qquad \Gamma(x^*,x,z) = \pi_{00} + \sum_{s=1}^{S} \pi_{0s}\, z_s + \sum_{i=1}^{I} \Big(\delta_{0i}\, x_i^2 + \sum_{\ell \neq i} \theta_{i\ell}\, x_i\, x_\ell \Big) + \sum_{i=1}^{I} \psi_{ii}\, z_i\, x_i$$

$$(6) \qquad \beta_k(x^*,x,z) = \pi_{k0} + \sum_{s=1}^{S} \pi_{ks}\, z_s + \sum_{i=1}^{I} \gamma_{ki}\, x_i \qquad k = 1,\ldots,I$$

2. See [Mundlak 1988] for a derivation of (13) as a second order Taylor series expansion of F(x,s) about x* where x are the utility maximizing (observed) inputs and x* are the profit maximizing inputs.

Examples of estimation of the system (4), (5), and (6) are Cavallo and Mundlak [1982] for the Argentine economy (updated and extended in Mundlak, Cavallo and Domenech [1987]) and Coeymans and Mundlak [1987] for the Chilean economy.

Since implemented techniques are functions of input and prices, input and output prices should be included as state variables in equations (5) and (6). Additional state variables should be fixed factors available to producers, prices of outputs if multiple outputs are produced, and measures of risk.

To more easily interpret (5) and (6), conduct two exercises: in the first set all the π's and ψ's = 0; in the second set the δ's, θ's, ψ's and γ's = 0.

The first exercise results in the estimation of the primal (production) function. The functional form is a special case of the Generalized Power Production suggested by De Janvry [1972]. With $\gamma_{ki} = 0$ for all k and i, the system approximates a translog production function with constant returns to scale. This parameterization is used by De Janvry [1972] to measure the effects of fertilizer price policies on the productivity of Argentine agriculture. When $\gamma_{ki} \neq 0$ the production function has variable returns to scale. Ulveling and Fletcher [1970] estimated a functional form with the γ's but without the δ's or the θ's to measure returns to scale in U. S. agriculture. Antle [1987] used an approach similar to Ulveling and Fletcher to measure correlations between allocative efficiency and human capital in Indian agriculture.

The second exercise results in the regression of prices on factor shares: the estimation of a dual (factor shares) function. Mundlak [Mundlak 1989] shows that while estimation of a primal function is sometimes inconsistent, the estimation of a dual function is usually inefficient. Mundlak's proposal is a combination of the primal and dual estimators. Our choice of techniques specification is offered in that spirit.

Figure 2 illustrates Mundlak's argument. Each of two firms produces an output (Y) with an input (X). If the data available to the econometrician are points A and A', a regression line will identify the production function of neither firm. Observations such as C and B are needed to identify the production function of firm 2. In order to evaluate an estimation strategy, it is necessary to know what is causing the input variations which identify the production functions.

A dual estimator uses price variations to identify production functions. Mundlak argues that "Firms in a competitive industry all face the same prices and yet they differ considerably in their inputs and outputs."[3] Variations in inputs, possibly due to different attitudes towards risk, are not accounted for by dual estimators, and this accounting failure causes their inefficiency.

Factor Demand Elasticities

Every well specified production function has associated with it elasticities of factor demand. These are traditionally reported by researchers when characterizing a production technology. If the estimated functional form is a cost or a profit function, these elasticities are, by Shepard's lemma, simple functions of the estimated parameters. Since the approach in this study is to characterize technology by the estimation of a primal (production) function rather than a dual (cost or profit) function, computation of factor demand elasticities becomes more complicated. Because the chosen functional form is a translog production function, no closed form solution exists for the factor demand elasticities. Factor demand elasticities are obtained by numerical simulation.

To illustrate the solution techniques used in numerically simulating the factor demand elasticities, let there be two inputs and two state variables (the prices of these inputs). Normalize output price to unity. The production function with non changing returns to scale is:

3. Mundlak 1989, p. 4.

$$(7)\quad y = \Gamma(z_1, z_2, x_1, x_2) + \beta_1(z_1, z_2)\, x_1 + \beta_2\,(z_1, z_2)\, x_2$$

or equivalently:

$$(8)\quad Y = e^{\Gamma}\, X_1^{\beta_1}\, X_2^{\beta_2}$$

where $y = \ln(Y)$, $x_i = \ln(X_i)$ and $z_i = \ln(w_i)$

The profit maximization problem is:

$$(9)\quad \max_{X_1,\, X_2}\; Y - w_1 X_1 - w_2 X_2$$

with first order conditions:

$$(10)\quad \frac{\partial \pi}{\partial X_1} = \frac{\partial e^{\Gamma}}{\partial X_1} X_1^{\beta_1} X_2^{\beta_2} + \beta_1\, e^{\Gamma} X_1^{\beta_1 - 1} X_2^{\beta_2} - w_1 = 0$$

$$(11)\quad \frac{\partial \pi}{\partial X_2} = \frac{\partial e^{\Gamma}}{\partial X_2} X_1^{\beta_1} X_2^{\beta_2} + \beta_2\, e^{\Gamma} X_1^{\beta_1} X_2^{\beta_2 - 1} - w_2 = 0$$

Algebraic manipulation of (5) confirms that:

$$(12)\quad \frac{\partial e^{\Gamma}}{\partial X_1} = \frac{\partial \Gamma}{\partial x_1} \frac{e^{\Gamma}}{X_1} = \frac{e^{\Gamma}}{X_1}\left(\delta_{01}\, x_1 + \theta_{12}\, x_2 + \psi_{11}\, z_1\right)$$

$$(13)\quad \frac{\partial e^{\Gamma}}{\partial X_2} = \frac{\partial \Gamma}{\partial x_2} \frac{e^{\Gamma}}{X_2} = \frac{e^{\Gamma}}{X_2}\left(\delta_{02}\, x_2 + \theta_{12}\, x_1 + \psi_{22}\, z_2\right)$$

Substitution of (12) into (10) and of (13) into (11) yields:

$$(14) \qquad x_1 = \frac{1}{(\beta_1 - 1)} (z_1 - \beta_2 x_2 - \ln(\delta_{01} x_1 + \delta_{12} x_2 + \psi_{11} z_1 + \beta_1) - \Gamma)$$

$$(15) \qquad x_2 = \frac{1}{(\beta_2 - 1)} (z_2 - \beta_1 x_1 - \ln(\delta_{02} x_2 + \delta_{12} x_1 + \psi_{22} z_2 + \beta_2) - \Gamma)$$

Equations (14) and (15) represent a system of two equations for the two unknowns (x_1 and x_2) as functions of the parameters of the production technology. Since (14) and (15) are highly nonlinear in x_1 and x_2 their solution is obtained through numerical simulation.

Factor demand elasticities are calculated from the system (14) and (15). Define $\tilde{x}_1$ and $\tilde{x}_2$ as the x_1 and x_2 which solve (14) and (15) for an initial level of prices ($\tilde{z}_1$ and $\tilde{z}_2$). Generate another set of prices ($\hat{z}_1$ and $\hat{z}_2$) by $\hat{z}_1 = 1.01\ \tilde{z}_1$ and $\hat{z}_2 = 1.01\ \tilde{z}_2$. Define $\hat{x}_1$ and $\hat{x}_2$ as the x_1 and x_2 which solve (14) and (15) for level of prices ($\hat{z}_1$ and $\tilde{z}_2$) and $\bar{x}_1$ and $\bar{x}_2$ as the x_1 and x_2 which solve (14) and (15) for level of prices ($\tilde{z}_1$ and $\hat{z}_2$). Then factor demand elasticities are defined as:

$$\epsilon_{11} = \frac{\tilde{x}_1 - \hat{x}_1}{\tilde{z}_1 - \hat{z}_1} \qquad \epsilon_{12} = \frac{\tilde{x}_2 - \hat{x}_2}{\tilde{z}_2 - \hat{z}_2}$$

$$\epsilon_{21} = \frac{\bar{x}_1 - \hat{x}_1}{\bar{z}_1 - \hat{z}_1} \qquad \epsilon_{22} = \frac{\bar{x}_2 - \hat{x}_2}{\bar{z}_2 - \hat{z}_2}$$

where ϵ_{is} is the elasticity of demand for the i'th input with respect to changes in the price of the s'th input.

Output Elasticities

Elasticities in a choice of technique framework differ from elasticities in traditional production functions. Let the production function be defined by equations (4), (5) and (6). Then state variable elasticities are obtained by differentiating the production function with respect to a state variable:

$$(16) \quad \frac{\partial y}{\partial z_s} = \frac{\partial \Gamma}{\partial z_s} + \sum_{i=1}^{I} \frac{\partial \beta}{\partial z_s} x_i +$$

$$\sum_{i=1}^{I} \frac{\partial \Gamma}{\partial x_i} \epsilon_{is} + \sum_{i=1}^{I} \sum_{j=1}^{I} \frac{\partial \beta_i}{\partial x_j} \epsilon_{is} x_i +$$

$$\sum_{i=1}^{I} \beta_i \epsilon_{is}$$

The elasticity can be decomposed into three components. The term on the right hand side of the top line of (16) is the output elasticity holding inputs constant, but allowing implemented techniques to vary. The term on the bottom line of (16) is the output elasticity holding implemented techniques constant, but allowing inputs to vary. The term on the middle line of (16) is the contribution of the translog component of the production function and the contribution of changes in returns to scale to the output elasticity.

Production functions as traditionally estimated hold implemented techniques constant and only estimate the middle and bottom line of (16), misspecifying the response of output to changes in the economic environment.

A commonly estimated production function is (6) where the z's are restricted to linear and quadratic time trends. This approach is barely descriptive of the data, and the approach certainly fails if a goal of the model is to evaluate the effect on output of policies which change the environment (prices) in which agents make decisions.

Choice of Techniques and Induced Innovation

The induced innovation hypothesis of Hicks [1933], extended by Hyami and Ruttan [1972] is that relative prices help determine biases of technological change. Technological change, however, in models with linear / quadratic time trends is independent of changes in prices. The predictions of these models with respect to changes in technology will be valid only as long as the future is like the past. Policy analysis, however, asks what will happen if the future is made different, in some key way, from the past. Models with linear / quadratic technological change are thus ill suited to evaluate policy alternatives.

Choice of Technique and the Lucas Critique

This criticism is an application of the Lucas critique to production function estimation. In Robert Lucas' critique of econometric modeling for policy evaluation [Lucas 1973], he examines forecasting equations of the form:

$$(17) \quad y_t = \beta_1 x_t + \beta_2 z_t + \epsilon_t$$

where y_t is a policy goal, x_t is a vector of policy instruments, z_t are other variables, β_1 and β_2 are parameters and ϵ_t is a stochastic error. Optimal policy is found by choosing the x_t vector which yields the most desired y_t. Lucas objects to this procedure since strong theoretical reasons frequently exist for believing that the true form of the forecasting equation is instead:

$$(18) \quad y_t = \beta_1 x_t + \beta_2 z_t(x_t) + \epsilon_t.$$

Now, as the policy maker varies the policy instrument, the reaction of agents depends on the adjustments in the policy instrument. The antidote prescribed for econometricians involves models where z_t no longer depends on x_t. This insight spawned a new generation of econometric models where the z_t are the "fundamentals" of the economy: preferences, technology and endowments.

Thomas Sargent [Sargent 1981] calls for a change in the practice of dynamic econometrics so that it is consistent with the principle that people's rules of choice are influenced by their constraints. This will involve, Sargent says, a stricter definition of the class of parameters that can be regarded as "structural."

The goal of the choice of technique approach to production function estimation is to identify structural parameters in production functions.

Data

Data published by the U.S.D.A. are unsatisfactory for empirical analysis for several reasons. Among the reasons are:

U. S. D. A. quantity indices are Laspayres indices. Laspayres indices are exact indices for Cobb - Douglas production technologies. It is preferable to use indices which are exact for flexible functional forms

U. S. D. A. labor series are unadjusted for quality (human capital) changes

The input and output series do not balance. Profits are allocated neither as returns to capital nor land nor labor.

For further comments on U. S. D. A. data see Shumway [Shumway 1988a] and U.S.D.A. Technical Bulletin No. 1614. This analysis uses the data set prepared by Susan Capalbo and Trang T. Vo.

Susan Capalbo and Trang T. Vo [Capalbo and Vo, 1988] present data which they use [Capalbo 1988] to test the implications of using different cost, profit and production functions to measure technological change in U. S. Agriculture. The period of their sample is 1948 - 1983. They present divisia indices and implicit price indices for 7 output and for 9 input groups. In their empirical analysis these are further aggregated to either 1 or 2 output groups and 4 input groups. The Capalbo and Vo data has unallocated profits, but uses an index consistent with a flexible form, and uses quality adjusted labor data. In addition to expected input prices, normalized by output prices, we use the ratio of crop to livestock prices, a measure of price variability, and a measure of the economy's capital stock to characterize the state of the economy.

Since crop production and livestock production may be identified with different techniques, changes in their relative prices may induce changes in the implementation of different techniques. To capture this change, we use as a state variable the log of the ratio of crop prices to livestock prices, as reported by the U.S.D.A.

Different techniques may be associated with different risk attributes. A risk averse producer may implement different techniques as the riskiness of his economic environment changes. To capture these changes, we measure changes in riskiness by:

$$(19) \quad VAR = \frac{\max(p_{t-4}, p_{t-3}, p_{t-2}, p_{t-1} p_t) - \min(p_{t-4}, p_{t-3}, p_{t-2}, p_{t-1}, p_t)}{p_t}$$

where p_t is the ratio of output to input prices in year t, as reported by the U. S. D. A.

Finally, the implementation of new techniques may be constrained by the availability of capital. We capture this constraint by using as a state variable the log of per capita constant dollar GNP.

Results

The techniques we developed for empirical analysis suggested using the parameters of a Cobb - Douglas functions as dependant variables in regressions on variables which characterize the state of the economy so that observed technology changes as implemented techniques change, and on inputs so that the technology may approximate a functional form more general than Cobb - Douglas. With competitive input and output markets, the parameters of a Cobb - Douglas production function are equal to input factor shares. With unallocated profits, shares of revenue are different than shares of costs. It is also problematic to determine where the unallocated profit goes. The approach taken in this analysis is to allocate profit to the land input, and to recalculate the land price so that revenues collected in any year are equal to costs occurred in any year.

Capalbo reports results of several different functional forms fit to this data, including translog production, cost and profit functions, a generalized leontief cost function, multi - output cost and profit functions, and restricted cost and profit functions. In all her analyses, inputs are aggregated into 4 input groups and into either 1 or 2 output groups. We use the same aggregations. The input aggregations are:

Labor	= Hired Labor + Family Labor
Land	= Land + Structures
Capital	= Durable Equipment + Livestock
Raw Materials	= Energy + Fertilizer + Pesticides + Miscellaneous.

Output is a single aggregate.

Prices used as state variables are predicted values of vector autoregressions. The procedure is described in Chapter 3. The land price is not the land price as reported by Capalbo, but a land price calculated to equate costs and revenues.

The regressions were initially run using the Seemingly Unrelated Regression technique on the system:

$$(5) \qquad \Gamma(x^*,x,z) = \pi_{00} + \sum_{s=1}^{S} \pi_{0s} z_s + \sum_{i=1}^{I} (\delta_{0i} x_i^2 + \sum_{\ell \neq i} \theta_{i\ell} x_i x_\ell) + \sum_{i=1}^{I} \psi_{ii} z_i x_i$$

$$(6) \qquad \beta_k(x^*,x,z) = \pi_{k0} + \sum_{s=1}^{S} \pi_{ks} z_s + \sum_{i=1}^{I} \gamma_{ki} x_i \qquad k = 1,\ldots,I$$

with $\gamma_{ki} = 0$. The parameters estimated from this regression were used in the numerical simulation of the first order conditions to derive estimates of factor demand elasticities. Part of the simulation involves taking the log of a function of the parameters, inputs and state variables. The parameters obtained from estimating (5) and (6) alone generally resulted in negative values for this function. In order to obtain parameter estimates which are consistent with the first order conditions, the estimated system was expanded to include (5), (6) and the first order conditions:

$$(14)\quad x_k = \frac{1}{(\beta_k - 1)}\left(z_1 - \beta_2 x_2 - \ln\left(\delta_{0k} x_k + \sum_{\ell \neq k} \theta_{\ell k} x_\ell + \psi_{kk} z_k + \beta_k\right) - \Gamma\right)$$

The inclusion of (14) makes the estimation highly non - linear. Table 1 reports the results of the estimation of (5), (6) and (14) by SUR.

Each input price has been normalized by output price before expectations were calculated by ARIMA models. The four inputs and their notation are: 1 - Land, 2 - Capital, 3 - Raw Materials and 4 - Labor. Since the shares sum to one by the imposition of constant returns to scale, inclusion of all share equation in the estimation would make the covariance matrix singular. We exclude the labor equation. Asymptotic properties of the estimators are independent of the excluded share equation. Best results were obtained with ψ_{11} restricted to be zero.

State variables in the intercept (Γ) equation determine how the level of agricultural productivity is affected. Increasing either the capital stock, or the price of crops relative to the price of livestock increases the level of agricultural productivity (π_{0CAP} and $\pi_{0RCL} > 0$).

There are several curious results in Table 1. Increasing output price is equivalent to reducing each of the input prices (recall that input prices have been normalized by output prices). Because each of the input price coefficients in the intercept (Γ) equation are positive, this means that increasing output price decreases the level of agricultural productivity. An explanation for this may be that producers first utilize the most productive land and the most productive techniques, and that as increased output prices increase incentives to produce, less productive inputs and techniques are utilized.

Each of the share equations has a positive (and significant) coefficient in its own price (π_{11}, π_{22}, and $\pi_{33} > 0$). One would expect that as an input price increases, producers would shift to techniques which are intensive in other inputs, and that the k'th share would decrease as the k'th input price increases.

From the signs of state variables in the share equations, increases in the capital stock increase capital's share and decrease the share of raw materials while increases in the ratio of crop prices to livestock prices increase the capital share while reducing labor's share. Changes in the variance of prices does not affect the shares.

Table 2 displays the statistics of fit of the estimation. The system (5), (6) and (7) is solved simultaneously, so the r - square reported in Table 2 is a little different than the r-square from the estimation of the system. Each of the shares and each of the inputs, with the exception of land, is fit fairly well by the simulation. Adjusting the price of land, to reflect either costly adjustment, or smoothing its cyclicality induced by including profits (business cycle related) in its price, may improve the fit of the dynamic simulation.

Tables 3 through 6 report the factor demand elasticities which are obtained by the methodology of outlined earlier. Table 3 reports the elasticity of each of the factors with respect to changes in land prices. Table 4 reports the elasticity of each of the factors with respect to changes in capital prices. Table 5 reports the elasticity of each of the factors with respect to changes in raw material prices. Table 6 reports the elasticity of each of the factors with respect to changes in labor prices.

Encouraging is that each factor demand is downward sloping in its own price (ϵ_{11}, ϵ_{22}, ϵ_{33} and $\epsilon_{44} < 0$). This is in contradiction to the results obtained by Capalbo when fitting a translog production function with a linear and quadratic time trend to the same data. She reports that demand for capital is upward sloping in its own price.

Four of the factor demand elasticity series change signs. Raw materials are a complement to land ($\epsilon_{31}<0$) from 1949 through 1975. After 1975, raw materials become a substitute for land ($\epsilon_{31}>0$). Raw materials are also alternatively a substitute and complement for capital throughout the sample (ϵ_{32} is intermittently <0 and >0). Both land and capital change from complements to labor to substitutes for labor ($\epsilon_{14}<0$ from 1949 to 1960 and >0 thereafter and $\epsilon_{24}<0$ from 1949 to 1971 and >0 thereafter).

These sign changes have an induced innovation interpretation. Government policies increased, through commodity programs, the profitability of agriculture and land prices, but at the same time made land a scarce factor by imposing acreage restrictions a condition for participation in commodity programs. Producers had an incentive to find ways to expand output, and implementing techniques for which raw materials (a factor not restricted by commodity programs) was a substitute for land (a factor restricted by commodity programs) was their response.

Table 7 presents, for comparison, elasticities estimated in other studies. The results of two of Capalbo's models are most directly comparable with ours. Factor demand elasticities from estimations of a translog cost model and from a generalized leontief cost model are reported in Table 7. Also reported are elasticities from Eldon Ball's estimation of a restricted profit function, and Shumway's estimation of input demand equations implied by a quadratic profit model. Capalbo's elasticities are calculated for 1970. Shumway's are calculated for 1982. Shumway reports two sets of elasticities: those calculated directly from aggregated data, and those calculated from aggregation of elasticities from regional data. Table 7 reports elasticities from aggregated data. Ball does not report how his elasticities are calculated.

The largest elasticities are reported by Ball. His estimate (-1.500) of hired labor's own price elasticity stands out, and stands in contrast with the estimates of Capalbo (-.207) and of Shumway (-.100). (In comparing elasticities, remember that in Capalbo's and in our estimations, hired labor and family labor are aggregated, while Ball's and Shumway's estimations treat hired labor separately from family labor). Our estimates of labor's own price elasticity come closer to Ball's than to the other studies. Ball's other elasticities, however, still appear quite large. His estimate for durable equipment's own price elasticity (-1.271) appears several orders of magnitude larger than Capalbo's estimate for capital (-.146), than Shumway's estimate for machinery (-.105), and for our estimate for capital ($< |-.390|$).

An interesting comparison is the estimates of the elasticity of raw materials with respect to capital price (our estimates are reported as ϵ_{32} in Table 4). Capalbo reports an estimate of -.156 for this elasticity, while Shumway's estimate is .023. Capalbo's estimate was calculated in 1970, a year for which our estimate is negative (-.045), while Shumway's was calculated for 1982, a year for which our estimate is positive (.203). When the biases in technological change are large, reports of elasticities at a point in time as a summary of production relations are an imprecise characterization of these relations.

As a further illustration of these imprecisions, consider the elasticity of substitution of raw materials with respect to changes to land's price (our estimate is found as ϵ_{31} in Table 3). Capalbo's estimate of this elasticity is -.068, but her calculations were made for 1970. Examination of our estimates for this series indicate while this elasticity was negative in 1970, which agrees with Capalbo's estimate, in current production relations, perhaps induced by agricultural policies which made land an artificially scarce factor, raw materials and land are substitutes rather than complements, as implied by Capalbo's estimate for the elasticity.

Output elasticities with respect to each of the state variables are decomposed into three parts, as described earlier. The decomposition first holds inputs constant and allows implemented techniques to vary, then holds implemented techniques constant and allows inputs to vary, and finally accounts for a translog component. The output elasticity is the sum of these three components. These series are displayed for each of the input prices in Figures 3 through 7.

Figure 3 (titled "State Variable Elasticities"), presents the output elasticities with respect to each input price. Tables 4 through 7 present the decomposition of each elasticity into 3 parts: first holding inputs constant, next holding techniques constant, and finally allowing for a translog component. This decomposition illustrates the consequences and biases of the misspecification of estimations which hold implemented techniques constant.

In general, the elasticities are negative. Towards the end of the sample, however, they turn positive. This is a matter of some concern.

Looking at the decompositions, the elasticities holding techniques constant (the lines with *'s) are generally negative, which is expected. The elasticities holding inputs constant are generally positive, and the sum of the two elasticities (which more or less determines the sign of the overall elasticity, since the translog component is usually quite small), is occasionally positive. What this decomposition suggests is that estimations which do not allow for changes in implemented techniques are biased towards overestimating output elasticities with respect to input prices.

Since each input price is deflated by the aggregate output price, the output price elasticity may be constructed as a function (input share weight sum) of input price elasticities. The result is that output price elasticities tend also to be overestimated.

FIGURE 1

Choice of Techniques

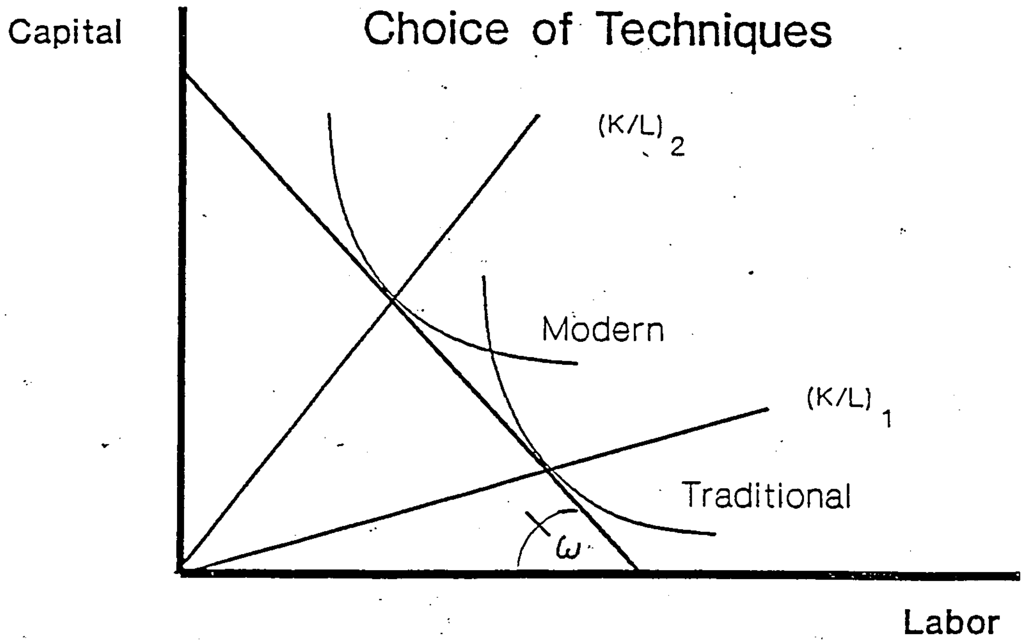


FIGURE 2

Estimation of Production Functions

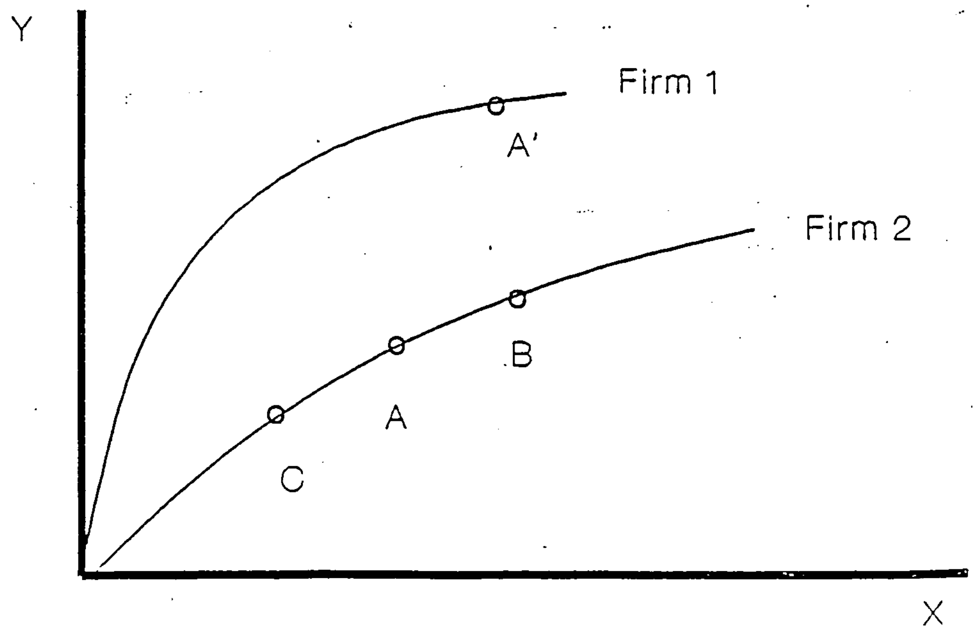


FIGURE 1

Choice of Techniques

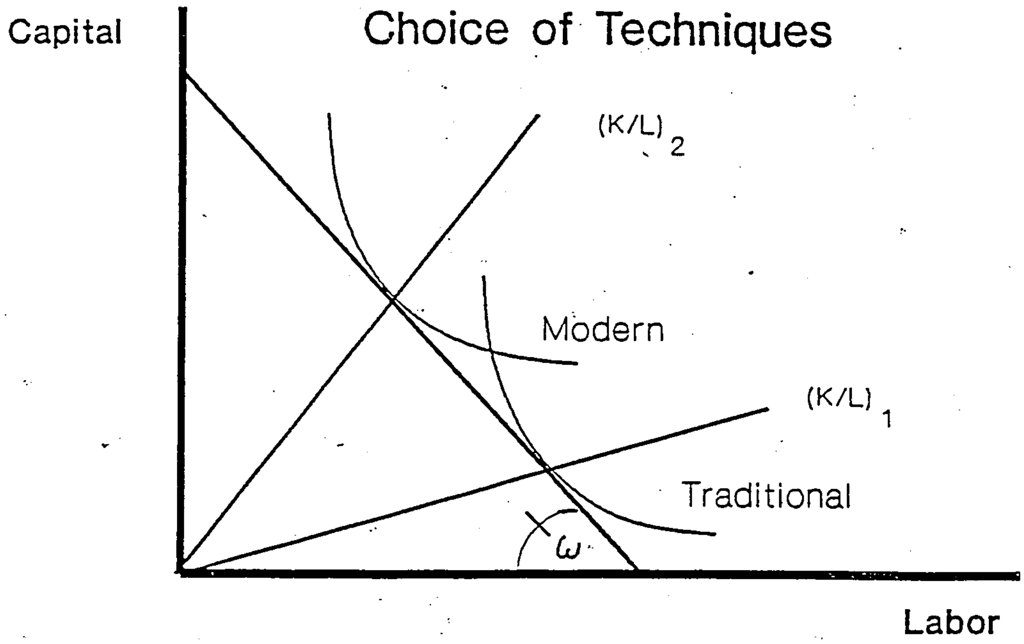
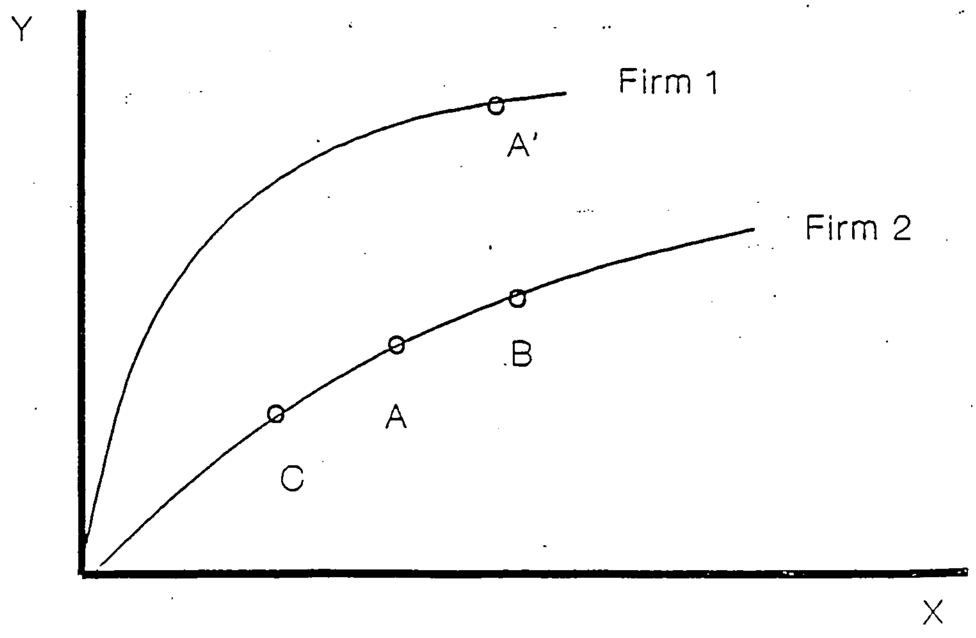
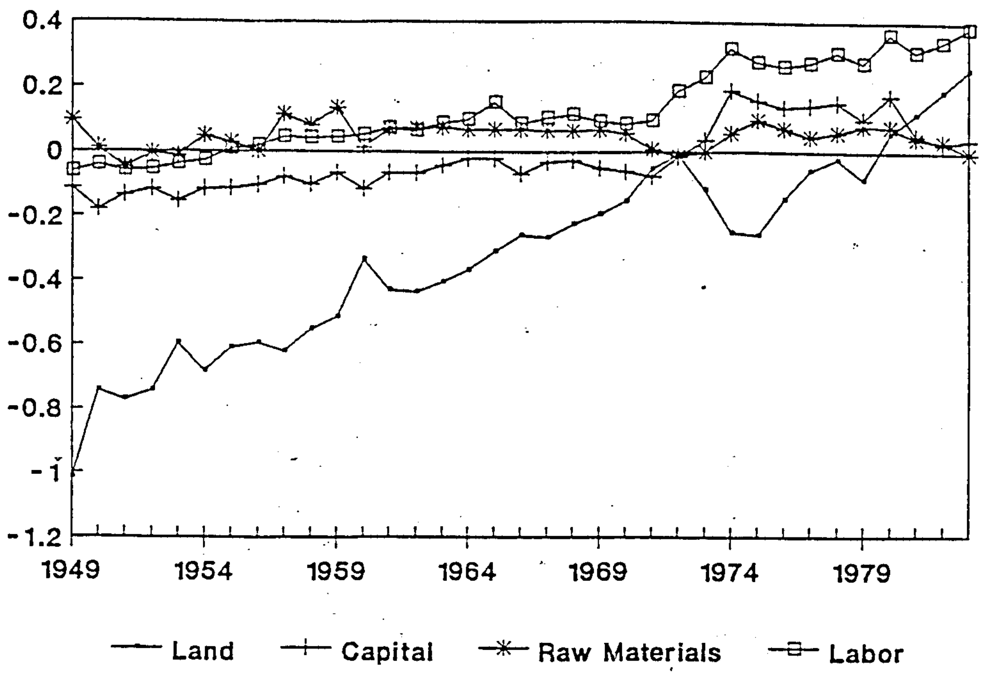


FIGURE 2

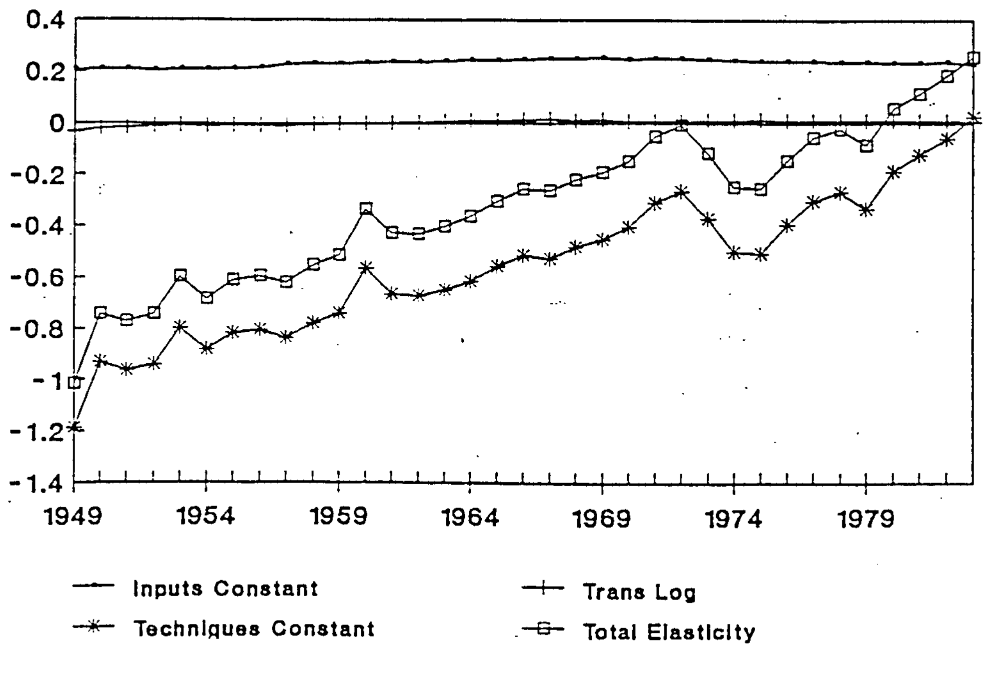
Estimation of Production Functions



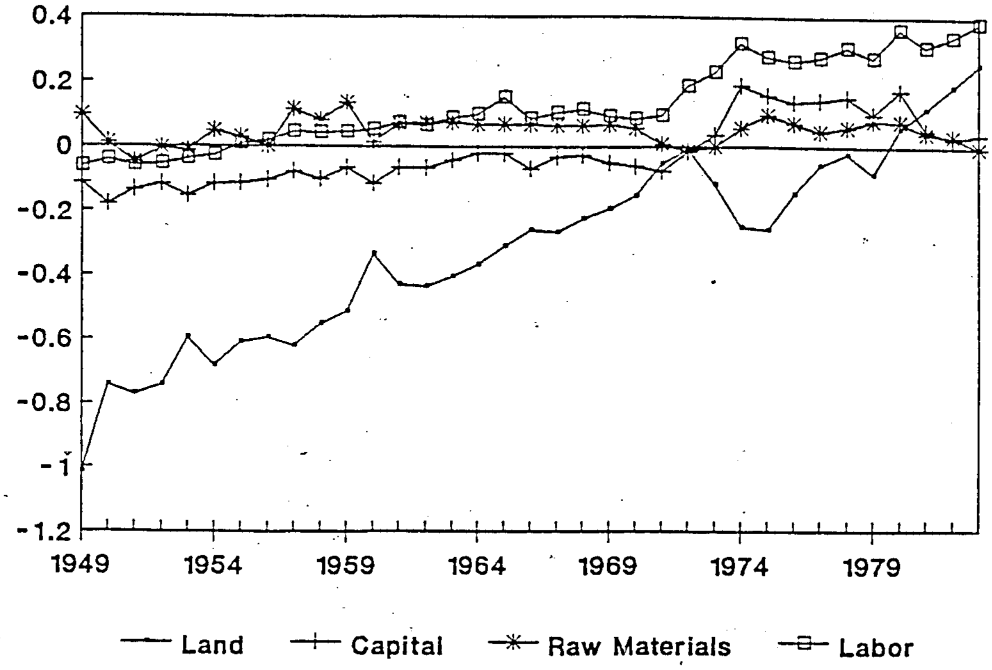
State Variable Elasticities



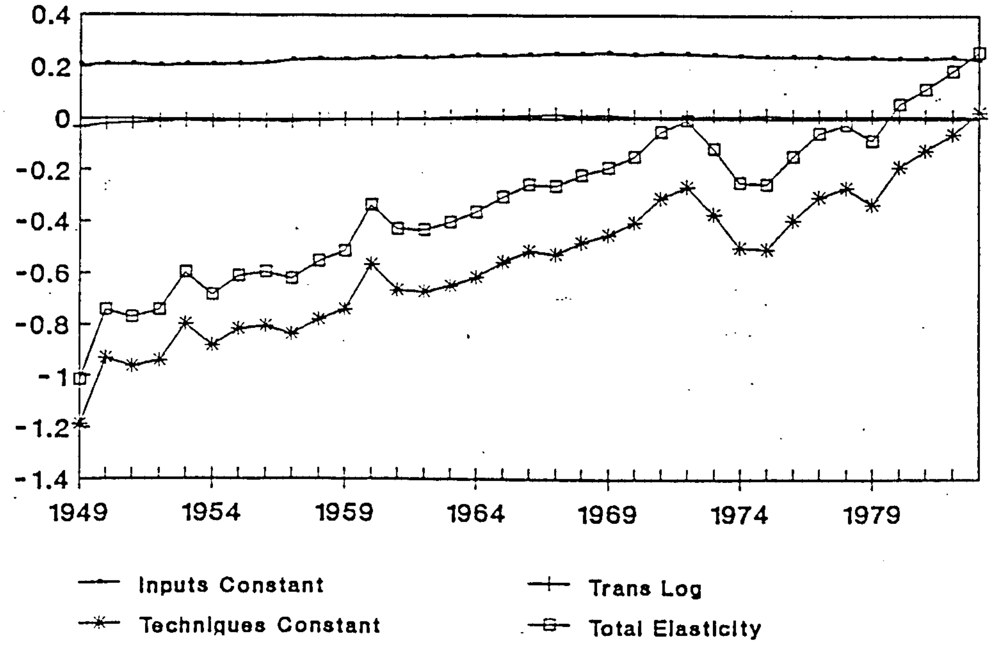
Land Price Elasticity Decomposition



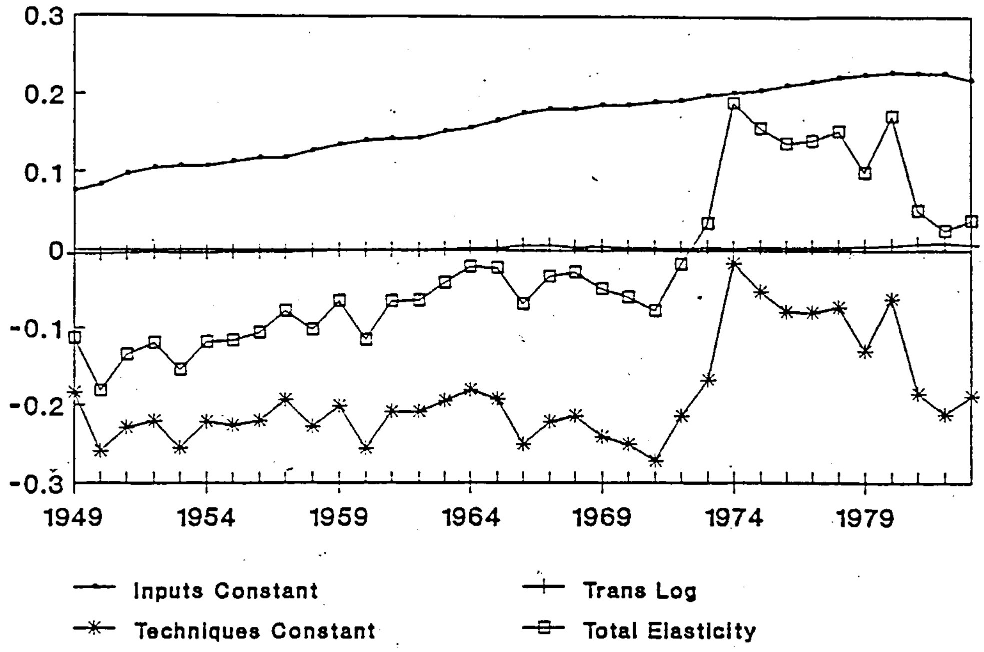
State Variable Elasticities



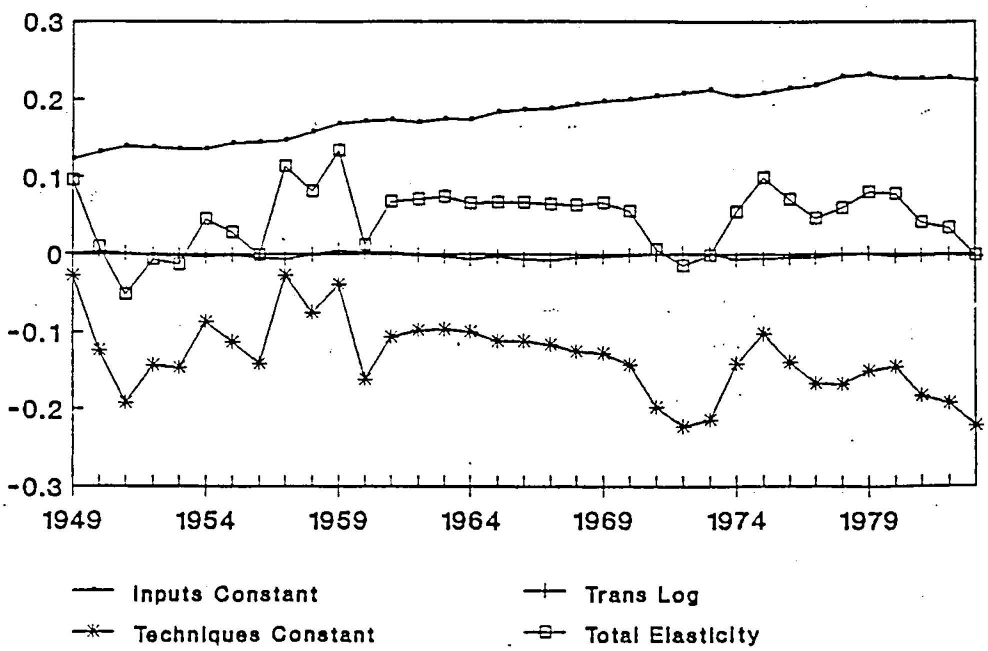
Land Price Elasticity Decomposition



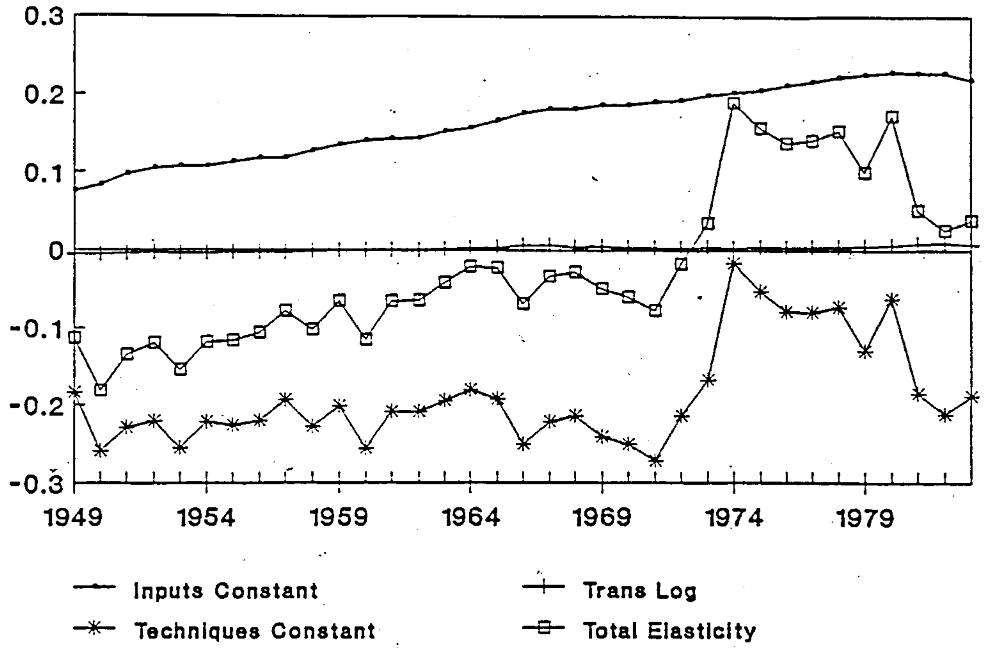
Capital Price Elasticity Decomposition



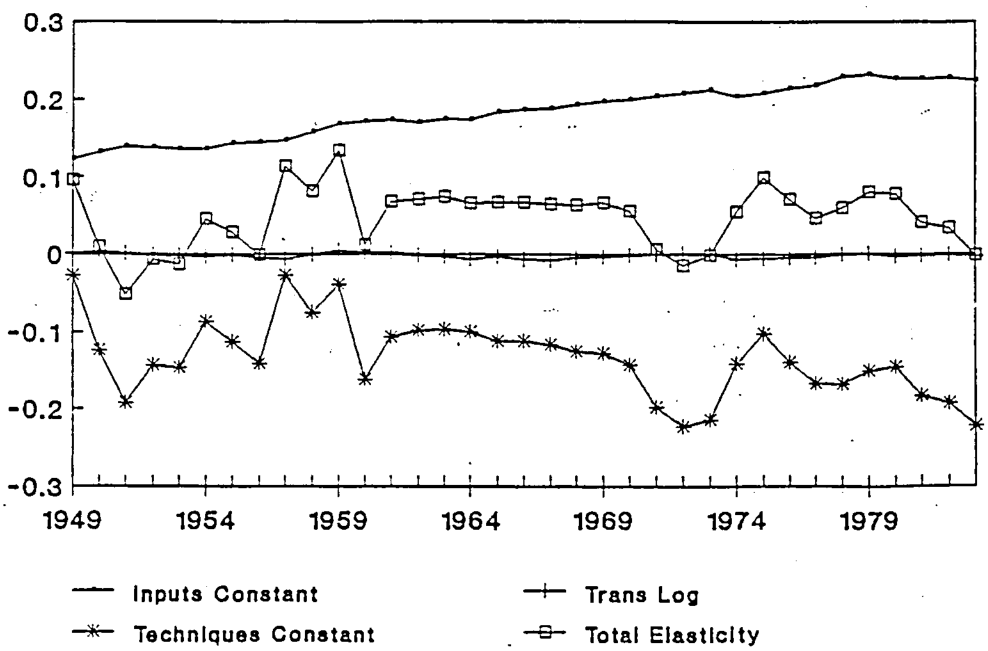
Raw Mat. Price Elasticity Decomposition



Capital Price Elasticity Decomposition



Raw Mat. Price Elasticity Decomposition



Labor Price Elasticity Decomposition

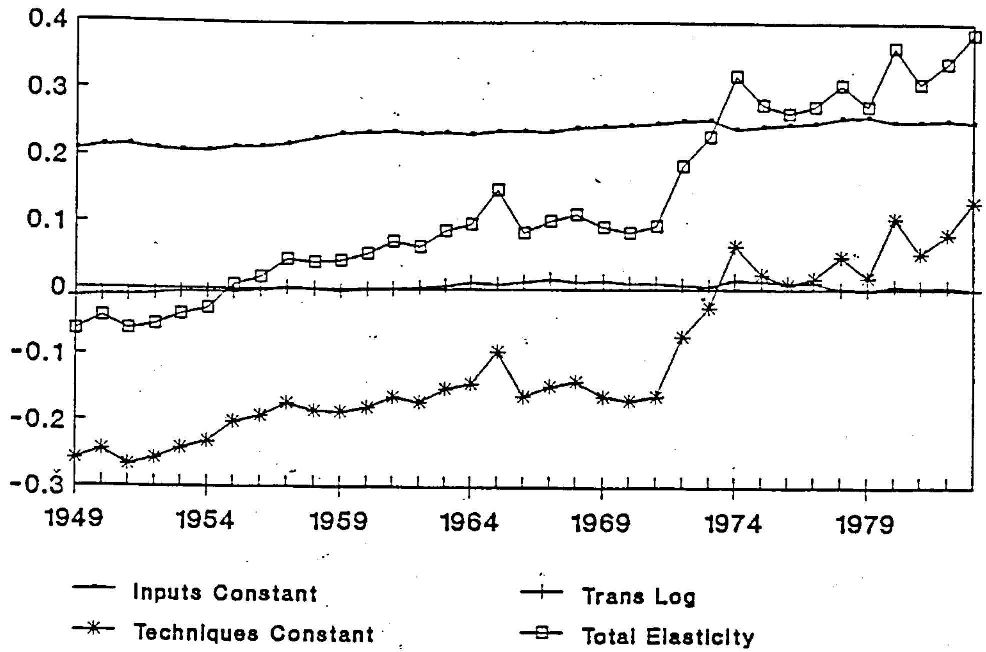


TABLE 1

Nonlinear SUR Parameter Estimates
Using Capalbo's Data

Parameter	Estimate	Approx. Std Error	't' Ratio	Approx. Prob > |t|
π_{00}	0.40848	0.74185	0.55	0.5877
π_{01}	0.24134	0.08956	2.69	0.0136
π_{02}	0.21664	0.06820	3.18	0.0046
π_{03}	0.21770	0.15897	1.37	0.1853
π_{04}	0.25004	0.04496	5.56	0.0001
π_{0VAR}	0.00038	0.00663	0.06	0.9544
π_{0RCL}	0.12235	0.04592	2.66	0.0145
π_{0CAP}	0.16929	0.08861	1.91	0.0698
δ_{01}	0.02464	0.09666	0.25	0.8007
δ_{02}	-0.03043	0.02287	-1.33	0.1945
δ_{03}	0.03972	0.01241	3.20	0.0035
δ_{04}	0.03515	0.00784	4.48	0.0001
ψ_{22}	0.00329	0.00367	0.90	0.3778
ψ_{33}	-0.00234	0.00306	-0.77	0.4506
ψ_{44}	0.00334	0.00154	2.17	0.0387
θ_{12}	-0.03502	0.08460	-0.41	0.6820
θ_{13}	-0.15557	0.05531	-2.81	0.0087
θ_{14}	-0.09076	0.03703	-2.45	0.0205
θ_{23}	0.00400	0.02331	0.17	0.8948
θ_{24}	-0.00138	0.02032	-0.07	0.9463
θ_{34}	0.06721	0.03149	4.98	0.0001

TABLE 1 (continued)

Parameter	Estimate	Approx. Std Error	't' Ratio	Approx. Prob > |t|
π_{10}	-0.26160	0.39221	-0.67	0.5104
π_{11}	0.14098	0.04571	3.08	0.0047
π_{12}	-0.09950	0.03425	-2.90	0.0072
π_{13}	-0.16063	0.07992	-2.01	0.0545
π_{14}	-0.09077	0.02681	-3.39	0.0022
π_{1VAR}	-0.00102	0.00331	-0.31	0.7607
π_{1RCL}	0.00734	0.02321	0.32	0.7540
π_{1CAP}	0.03797	0.04773	0.80	0.4333
π_{20}	-0.09630	0.28748	-0.33	0.7405
π_{21}	-0.08343	0.03290	-2.54	0.0173
π_{22}	0.15093	0.02520	5.99	0.0001
π_{23}	0.05046	0.05695	0.89	0.3834
π_{24}	-0.03495	0.01892	-1.85	0.0758
π_{2VAR}	0.00161	0.00234	0.69	0.4991
π_{2RCL}	0.00346	0.01653	0.21	0.8357
π_{2CAP}	0.08148	0.03532	2.31	0.0290
π_{30}	1.09481	0.25169	4.35	0.0002
π_{31}	0.03046	0.03067	0.99	0.3296
π_{32}	0.01512	0.02359	0.64	0.5271
π_{33}	0.10971	0.05509	1.99	0.0566
π_{34}	0.11593	0.01465	7.92	0.0001
π_{3VAR}	-0.00131	0.00230	-0.57	0.5735
π_{3RCL}	0.02753	0.01584	1.74	0.0937
π_{3CAP}	-0.06608	0.03009	-2.20	0.0368

Notes: Dependant Variable for parameters $\pi_{0.}$, δ, θ and ψ is Γ (the intercept term in the production function).

Dependant Variable for parameters $\pi_{i.}$ is β_i (the factor share of the i'th input: the exponent of the i'th input in a Cobb-Douglas production function.

Inputs are: 1 - Land, 2 - Capital, 3 - Raw Materials and 4 - Labor.

Additional state variables are: VAR - the variability of output prices, RCL- the ratio of crop prices to livestock prices, CAP - the economy wide percapita GNP.

See text for additional notes on estimation.

TABLE 2

Dynamic Simultaneous Simulation
Descriptive Statistics

Variable	#	Actual Mean	Actual Std. Dev	Predicted Mean	Predicted Std Dev.
x_1	35	0.0851	0.0651	0.0806	0.0691
x_2	35	-0.1370	0.1254	-0.1389	0.1423
x_3	35	-0.1308	0.1630	-0.1357	0.1771
x_4	35	0.3040	0.3014	0.3011	0.3041
β_1	35	0.3500	0.0594	0.3491	0.0537
β_2	35	0.2126	0.0529	0.2135	0.0501
β_3	35	0.2642	0.0339	0.2645	0.0301
β_4	35	0.1682	0.0333	0.1729	0.0326
Γ	35	-0.2152	0.1834	-0.2168	0.1867

Statistics of Fit

Variable	RMS Error	RMS % Error	r-square
x_1	0.05642	59315.65	0.2259
x_2	0.03555	42645.68	0.9172
x_3	0.05184	36822.58	0.8959
x_4	0.08023	6118.41	0.9270
β_1	0.03026	8.58879	0.7331
β_2	0.02061	10.96291	0.8436
β_3	0.01171	4.33100	0.8769
β_4	0.01258	8.94411	0.8530
Γ	0.03213	4456.32	0.9684

Notes: x_i is the factor demand for the i'th factor, solved for by numerical simulation of the system of equations as noted in the text.
β_i is the share of the i'th factor.
Factors are: 1 - Land, 2 - Capital, 3 - Raw Materials and 4 - Labor.

TABLE 3

Factor Demand Elasticities with respect to Land Price

YEAR	ϵ_{11}	ϵ_{21}	ϵ_{31}	ϵ_{41}
1949	-1.3767	-0.89039	-0.59257	-1.5643
1950	-0.8827	-0.78350	-0.65962	-1.3803
1951	-0.8354	-0.78363	-0.78216	-1.5644
1952	-0.8923	-0.77146	-0.66509	-1.4801
1953	-0.7840	-0.67890	-0.47541	-1.2324
1954	-0.8674	-0.72076	-0.53943	-1.3576
1955	-0.7429	-0.69769	-0.57834	-1.3552
1956	-0.7781	-0.68371	-0.51520	-1.3202
1957	-0.9775	-0.68889	-0.36369	-1.1967
1958	-0.7952	-0.66999	-0.45696	-1.2235
1959	-0.7457	-0.63154	-0.42730	-1.2349
1960	-0.4444	-0.52139	-0.38438	-1.0990
1961	-0.6315	-0.57566	-0.39131	-1.1925
1962	-0.5956	-0.57537	-0.41762	-1.2266
1963	-0.5451	-0.55704	-0.41797	-1.2609
1964	-0.5210	-0.52060	-0.36310	-1.2459
1965	-0.4562	-0.51861	-0.37858	-1.1984
1966	-0.3670	-0.48198	-0.32350	-1.0673
1967	-0.3497	-0.47591	-0.35371	-1.1610
1968	-0.3401	-0.42660	-0.27408	-1.1062
1969	-0.2765	-0.40557	-0.26283	-1.0520
1970	-0.1968	-0.35736	-0.21813	-1.0027
1971	-0.1081	-0.29267	-0.14147	-0.8780
1972	-0.1378	-0.25196	-0.07755	-0.9353
1973	-0.3599	-0.34626	-0.11620	-1.0177
1974	-0.6842	-0.41229	-0.01178	-1.0905
1975	-0.7233	-0.44233	-0.04808	-1.0224
1976	-0.5258	-0.34340	0.00784	-0.9983
1977	-0.3910	-0.25886	0.08316	-0.9744
1978	-0.3675	-0.22693	0.11507	-0.9502
1979	-0.4229	-0.30101	0.00762	-0.9432
1980	-0.3832	-0.16191	0.22351	-0.8859
1981	-0.2232	-0.11405	0.20646	-0.7899
1982	-0.1811	-0.03411	0.28973	-0.7416
1983	-0.1039	0.03219	0.35606	-0.7353

Notes:

ϵ_{ij} is the elasticity of demand for the i'th factor with respect to the j'th price.

Inputs are: 1 - Land, 2 - Capital, 3 - Raw Materials, 4 - Labor.

TABLE 4

Factor Demand Elasticities with respect to Capital Price

YEAR	ϵ_{12}	ϵ_{22}	ϵ_{32}	ϵ_{42}
1949	-0.35868	0.14882	0.15019	-0.38048
1950	-0.35796	-0.09041	0.01245	-0.45301
1951	-0.31866	0.03205	0.00940	-0.50389
1952	-0.31798	-0.04595	0.03831	-0.46901
1953	-0.35986	-0.21031	0.07578	-0.40677
1954	-0.27260	-0.08461	0.02282	-0.46024
1955	-0.25182	-0.08542	-0.03809	-0.51070
1956	-0.27666	-0.10965	0.02043	-0.46728
1957	-0.24397	-0.09636	0.04204	-0.43545
1958	-0.26517	-0.15783	-0.00921	-0.46937
1959	-0.25726	-0.16907	0.04019	-0.44150
1960	-0.32013	-0.28214	0.01374	-0.45709
1961	-0.28535	-0.21731	0.06541	-0.42223
1962	-0.24154	-0.18385	0.02141	-0.47171
1963	-0.19688	-0.14499	0.00070	-0.51276
1964	-0.18717	-0.14030	0.03158	-0.50278
1965	-0.16288	-0.17089	-0.05195	-0.56891
1966	-0.15171	-0.22888	-0.12291	-0.61925
1967	-0.14435	-0.19683	-0.07635	-0.59823
1968	-0.16908	-0.23080	-0.02142	-0.55618
1969	-0.17035	-0.27283	-0.05351	-0.57333
1970	-0.18223	-0.29492	-0.04591	-0.57059
1971	-0.24169	-0.35833	-0.03766	-0.54913
1972	-0.22546	-0.31998	0.03367	-0.53299
1973	-0.17615	-0.24177	0.06055	-0.52063
1974	-0.06456	0.00770	0.23664	-0.44372
1975	-0.06368	-0.04577	0.15936	-0.49332
1976	-0.09010	-0.10123	0.16205	-0.50994
1977	-0.09595	-0.10748	0.18258	-0.52746
1978	-0.09092	-0.12444	0.19415	-0.52932
1979	-0.12729	-0.20903	0.11419	-0.52687
1980	-0.14686	-0.16534	0.26875	-0.46284
1981	-0.26661	-0.32646	0.16652	-0.49480
1982	-0.34848	-0.39023	0.19392	-0.45132
1983	-0.33196	-0.36935	0.20390	-0.49184

Notes:

ϵ_{ij} is the elasticity of demand for the i'th factor with respect to the j'th price.

Inputs are: 1 - Land, 2 - Capital, 3 - Raw Materials, 4 - Labor.

TABLE 5

Factor Demand Elasticities with respect to Raw Materials Price

YEAR	ϵ_{13}	ϵ_{23}	ϵ_{33}	ϵ_{43}
1949	-0.44447	0.370493	0.07799	0.354935
1950	-0.43925	0.310445	-0.14527	0.218766
1951	-0.44615	0.265227	-0.23999	0.050123
1952	-0.42080	0.265409	-0.23158	0.102415
1953	-0.40468	0.265628	-0.26104	0.171872
1954	-0.41340	0.315292	-0.15546	0.283700
1955	-0.42899	0.312777	-0.18496	0.259452
1956	-0.42349	0.295029	-0.20394	0.239439
1957	-0.39351	0.368074	-0.06960	0.462978
1958	-0.39885	0.334552	-0.17190	0.336613
1959	-0.39684	0.319599	-0.19527	0.339093
1960	-0.42928	0.253144	-0.34883	0.170343
1961	-0.41024	0.288967	-0.25555	0.283547
1962	-0.42510	0.301562	-0.23639	0.314695
1963	-0.44187	0.307110	-0.22871	0.342501
1964	-0.44492	0.297014	-0.24704	0.344103
1965	-0.46110	0.312991	-0.24872	0.361219
1966	-0.49138	0.308931	-0.29104	0.333926
1967	-0.44919	0.291699	-0.31884	0.280741
1968	-0.44023	0.271717	-0.35280	0.256474
1969	-0.43676	0.265510	-0.38802	0.222676
1970	-0.42995	0.240606	-0.44021	0.150284
1971	-0.41979	0.202794	-0.51433	0.044351
1972	-0.41971	0.208318	-0.49087	0.087944
1973	-0.39687	0.242668	-0.42022	0.177030
1974	-0.34320	0.290949	-0.33936	0.330061
1975	-0.35444	0.311260	-0.30757	0.400529
1976	-0.38121	0.273042	-0.38393	0.298249
1977	-0.38504	0.250475	-0.43785	0.214461
1978	-0.38003	0.248684	-0.44989	0.217958
1979	-0.35437	0.257785	-0.43915	0.195894
1980	-0.34351	0.237852	-0.47563	0.165992
1981	-0.38238	0.196759	-0.53338	0.049832
1982	-0.39630	0.184200	-0.55325	0.053898
1983	-0.41159	0.175687	-0.56948	0.031558

Notes:

ϵ_{ij} is the elasticity of demand for the i'th factor with respect to the j'th price.

Inputs are: 1 - Land, 2 - Capital, 3 - Raw Materials, 4 - Labor.

TABLE 6

Factor Demand Elasticities with respect to Labor Price

YEAR	ϵ_{14}	ϵ_{24}	ϵ_{34}	ϵ_{44}
1949	-0.21126	-0.16708	0.535474	-1.0980
1950	-0.24577	-0.14071	0.509832	-1.0772
1951	-0.20991	-0.18871	0.420509	-1.2179
1952	-0.18742	-0.16523	0.418607	-1.1913
1953	-0.14621	-0.11722	0.385515	-1.1508
1954	-0.10699	-0.11520	0.389944	-1.1462
1955	-0.11346	-0.11707	0.384715	-1.1443
1956	-0.10492	-0.11318	0.377442	-1.1585
1957	-0.03573	-0.08363	0.355301	-1.1440
1958	-0.06471	-0.09194	0.343606	-1.1474
1959	-0.00915	-0.07652	0.306046	-1.1935
1960	-0.04200	-0.07877	0.289192	-1.1981
1961	0.00167	-0.06633	0.293442	-1.2095
1962	0.00469	-0.06676	0.299048	-1.2029
1963	0.02190	-0.06046	0.304607	-1.2055
1964	0.04722	-0.04499	0.307201	-1.2181
1965	0.03770	-0.05223	0.286857	-1.2096
1966	0.01708	-0.05501	0.273179	-1.1932
1967	0.05057	-0.04913	0.269275	-1.2290
1968	0.07825	-0.02877	0.265254	-1.2499
1969	0.08405	-0.03078	0.241753	-1.2586
1970	0.08263	-0.02626	0.243286	-1.2636
1971	0.06120	-0.02911	0.239501	-1.2627
1972	0.12017	0.01365	0.267083	-1.2903
1973	0.12470	0.01341	0.288810	-1.2806
1974	0.21831	0.07177	0.410442	-1.2627
1975	0.22590	0.05420	0.343225	-1.3008
1976	0.20745	0.07162	0.360706	-1.2907
1977	0.19957	0.08953	0.389015	-1.2862
1978	0.23011	0.11409	0.393116	-1.3066
1979	0.22297	0.07344	0.308165	-1.3335
1980	0.27442	0.18094	0.449837	-1.3278
1981	0.21713	0.13095	0.362338	-1.3426
1982	0.28701	0.19846	0.393155	-1.3912

Notes:

ϵ_{ij} is the elasticity of demand for the i'th factor with respect to the j'th price.

Inputs are: 1 - Land, 2 - Capital, 3 - Raw Materials, 4 - Labor.

TABLE 7

Other Estimated Factor Demand Elasticities

Capalbo's Translog Cost Model
Elasticity with Respect to Price of:

Input	Labor	Capital	Materials	Land
Labor	-.207	.097	.086	.033
Capital	.073	-.146	-.089	-.003
Materials	.113	-.156	-.068	.089
Land	.023	-.003	.046	-.193

(Source: Capalbo 1988, p. 183)

Capalbo's Generalized Leontief Cost Function
Elasticity with Respect to Price of:

Input	Labor	Capital	Materials	Land
Labor	-.120	-.083	.253	-.050
Capital	-.072	.038	.036	-.003
Materials	.169	.028	-.193	-.002
Land	-.037	-.002	-.002	.041

(Source: Capalbo 1988, p. 183)

Ball's Translog Restricted Profit Model
Elasticity with Respect to Prices of:

Input	Durable Equipment	Real Estate	Farm Durables	Hired Labor	Energy	Other Inputs
Durable Equipment	-1.271	-.192	-.228	-.443	-.321	-1.611
Real Estate	-.237	-.584	-.622	-.252	-.206	-1.186
Farm Durables	-.323	-.713	-1.162	-.242	-.219	-1.537
Hired Labor	-.674	-.310	-.260	-1.500	-.379	-2.099
Energy	-.647	-.336	-.312	-.503	-.941	-1.588
Other Inputs	-.564	-.336	-.379	-.483	-.276	-2.900

(Source: Ball 1988, p. 823)

Shumway, Saez, and Gottret's Demand Equations from a Quadratic Profit Model
Elasticity with Respect to Price of:

Input	Materials	Hired Labor	Machinery	Energy
Materials	-.075	.014	.023	.045
Hired Labor	-.084	-.100	-.162	.003
Machinery	.054	-.065	-.105	.002
Energy	.129	.001	.002	-.260

(Source: Shumway, Saez, and Gottret 1988, p. 336.)

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