A SIMULTANEOUS EQUATION APPROACH TO PRODUCTION RESPONSE: Delta Region

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Soybeans occupy the unique position of common denominator in crop production for much of the Eastern half of the U.S. The interdependence between the soybean economy and those of corn, cotton, and rice means that policy changes directed toward one crop can have very decided effects upon the others.

Effective policy and program decisions need continuing research as input in formulating and evaluating these decisions. Detailed analyses of inter- and intraregional interdependence among crops, and of production alternatives involving soybeans, are especially needed because it is no longer certain that an expanding demand will provide a safety valve for soybean and related commodity programs [4, 9].

This article reports an initial attempt to identify and estimate the underlying relationships between the production of soybeans and other crops and especially as influenced by consequences of alternative courses of policy action. A simultaneous equation system is specified and estimated for the Delta production region[1] in an attempt to measure the extent of interdependence amoung crops and the associated commodity policies. This approach contrasts with most previous studies which have employed single equation techniques on time series or have used the firm planning-aggregation approach to supply estimation.

ECONOMIC MODEL FORMULATION

We hypothesize that operators view decisions on the acreages to be planted in the current year in terms of adjustments from the previous year's operation in response to changes in expected relative profitability, acreage availability, and the Federal farm commodity programs [1].

This is expressed by four equations[2] in the model, with planted acreage response for soybeans, cotton, rice, and corn assumed to be jointly determined. The simultaneity occurs among acreages allocated to competing crops, given a fixed total acreage in any one year but not perfectly invariant among years. This contrasts with the usual market applications, where prices and quantities are assumed to be jointly determined.

Equation I. Acreage of Soybeans

Theory postulates that relative profitability influences enterprise selection. In order to obtain more detailed information, variables which represent the underlying components, i.e., own and competing crop expected prices, yields, and production costs, should be included. The acreage planted to soybeans in the previous year is a variable, since we seek to explain the current year's acreage as an adjustment from the previous year's acreage. It is argued that producers do not drastically alter their cropping pattern in one year (for reasons such as equipment peculiar to one enterprise in their machinery complement) but do it gradually over a period of years. The current year support price of soybeans is included, because it is known to producers and tends to be viewed as a "lower bound" when formulating production plans.

All of these variables (past and support prices,

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[1]The intent, if the results warrant, is to apply similar procedures for other regions, and to link these supply models with a set of demand relationships in a recursive system.

[2]A fifth equation, explaining the clearing of new land, was originally specified, and cleared land was included as a variable in the soybean equation. However, unavailability of any reasonably reliable information on clearing costs eventually forced us to eliminate the equation and variable. Information on acreages cleared will be furnished on request.

expected yields, and costs, as well as previous acreage and current support price) are considered predetermined or exogenous because of the length and segmentation of the production period in agriculture. The acreages of cotton, rice, and corn are included as endogenous variables because of the multidirectional causality assumed.

Equations II, III, IV. Acreages of Cotton, Rice, and Corn

The same rationale for components of relative profitability, lagged acreage, and the support price applies to the cotton, rice, and corn equations. The other variable included in these equations, and not appearing in Equation I, is the appropriate acreage allotment for the particular crop. Acreage allotments not only provide a limit on the acreage of the specific crop, but influence acreage planted to other crops.

THE ESTIMATED MODEL

The basic statistical model assumed that the acreages of the major crops are jointly determined in a supply sector that can be described by four simultaneous supply response equations involving lagged variables.

The variables in the estimated equations are as suggested by the economic model, with two exceptions. Production costs are not included, because empirical estimates or suitable proxies are not available for the historical period in question. The variables representing the yields of each crop are represented by a proxy variable. This was done because preliminary analysis indicated the yields varied together and the use of a single proxy helped maintain adequate degrees of freedom in a situation with a limited number of observations. The proxy variable is a yield index constructed from rice yields. Rice was chosen because of the constancy of the acreage base and land quality over time.

The pre-estimation identification properties of the model were examined and the system was found to be overidentified. The system was estimated by two stage least squares (2SLS).

The 2SLS technique yields second-stage estimators which are biased but consistent and asymptotically efficient, and the usual tests of significance on the coefficients, are not strictly valid. The coefficient of multiple determination, R^2, and interpretation of the coefficients[3] are also affected, as are elasticities derived from the equation. Although an unknown estimation bias exists, no better alternatives are available.

Annual observations for the time period 1947-1969 were chosen for analysis. This period was selected on the basis of continuity of data series and because it is generally recognized that structural changes in the soybean sector occurred in the mid and late forties, following World War II. All equations estimated were linear in actual values of the variables.

RESULTS

The parameter estimates (Table 1), in general, conform to a priori expectations. Though not all estimated coefficients were of acceptable magnitude relative to their standard error, the model does show considerable promise for further refinement. The magnitude of responses can be gauged by noting that price variables are in dollars and acreage in thousands of acres in Table 1.

The formulation of this model was based upon a hypothesized competitive relationship among the major crops for the available land. The results of the model estimation tend to bear out this contention. In most cases the competing acreage and price variables take on negative signs and own price and acreage variables carry positive signs. Soybeans exhibit a fairly strong competitive relationship with corn and cotton, and less so with rice. The results, in general, indicate the competitive relationship between rice and the other crops is not strong. Overall, the interdependence among crops tends to be reflected reasonably well by the simultaneous system.

For a closer examination of the estimates, and for clarity of discussion, the variables can be grouped into three categories: market price variables, yield and acreage variables, and policy variables.

In general, the own and competitive price variables conform to a priori expectations in sign, as mentioned above. Own price variable coefficients were expected to be positive and competing price variables negative, indicating competitiveness. Also, the own price variables tend to be stronger than competitive ones, as expected. In terms of magnitude, the soybean price variable exerts substantial effect on the acreages of all crops—more so than the other price variables. Thus, world market expectations for soybeans are crucially interdependent in setting necessary program variables for the other crops. The

[3]The usual single equation interpretation of the coefficients as the change in the endogenous variable associated with a unit change in an exogenous variable, all other variables invariant, is not appropriate with the appearance of more than one endogenous variable in an equation. Elasticity estimates computed from simultaneous systems also must be regarded with caution as the underlying ceteris paribus conditions are not strictly fulfilled.

TABLE 1. TWO-STAGE LEAST SQUARES ESTIMATES OF STRUCTURAL PARAMETERS AND STANDARD ERROR OF ESTIMATES (PRICES IN $, ACREAGES IN 000 ACRES)

Variables	Equation			
	Soybean	Cotton	Rice	Corn
Constant	2146.9 (1984.3)	–933.21 (5975.00)	2107.40 (762.00)	4797.70 (1898.30)
Soybean acreage (t)*		–0.128 (0.461)	–0.111 (0.059)	–0.546 (0.191)
Cotton acreage (t)*	–0.065 (0.106)		–0.177 (0.054)	0.126 (0.149)
Rice acreage (t)*	0.654 (0.517)	1.877 (1.035)		0.660 (0.659)
Corn acreage (t)*	0.063 (0.159)	0.570 (0.613)	–0.206 (0.063)	
Soybean acreage (t-1)	0.809 (0.153)			
Soybean support price (t)	216.18 (358.01)			
Soybean market price (t-1)	67.52 (588.98)	–567.65 (977.75)	–342.62 (179.07)	542.57 (746.26)
Cotton market price (t-1)	–49.99 (23.98)	1.786 (47.82)	2.869 (8.82)	–34.17 (29.92)
Rice market price (t-1)	–141.44 (186.53)	–59.15 (329.23)	116.85 (56.75)	–271.61 (234.38)
Corn market price (t-1)	405.07 (1027.30)	613.87 (1616.80)	220.84 (258.14)	–151.54 (1224.90)
Cotton support price (t)		37.62 (77.16)		
Cotton allotment (0, 1)		–1190.30 (316.60)		
Cotton acreage (t-1)		0.113 (0.233)		
Rice support price (t)			–438.56 (141.50)	
Rice allotment (0,1)			–906.57 (175.36)	
Rice acreage (t-1)			1.089 (0.210)	

TABLE 1. (continued)

Variables	Equation			
	Soybeans	Cotton	Rice	Corn
Corn support price (t)				–74.66 (60.92)
Corn acreage (t-1)				0.211 (0.065)
Yield index	7.61 (17.14)	20.42 (27.15)	10.12 (5.26)	1.545 (20.74)
$\bar{R}^2$	0.980	0.803	0.689	0.911

*Denotes endogenous variables.

Standard errors of estimates are in parentheses.

$\bar{R}^2$ is the coefficient of determination adjusted for degrees of freedom.

instances where the variables exhibit inconsistent signs or questionable magnitudes might be attributable to the measure of price used. The use of prices other than season average might possibly improve the results.

The coefficients of the lagged acreage variables were expected to be positive and of a magnitude less than 1.0. This was true for all except the lagged rice acreage variable, which was slightly greater than 1.0. A coefficient much larger than one would indicate an unstable and explosive year-to-year change and yield unacceptable elasticity estimates [7]. Since the lagged coefficients (except rice) were less than 1.0, this tends to support the year-to-year adjustment hypothesis. Also, the magnitude of the coefficients indicates the adjustment to changes in economic stimuli is more rapid for cotton and corn than for soybeans.

The yield index variable was positively related to increases in acreages, as would be expected. The magnitudes of the coefficients for this variable in the four equations suggest that effects of changes in yields have most affected cotton acreage, followed by rice, soybeans, and corn, in that order.

In addition to market prices and yields, the acreages of these crops and their interrelationships are strongly influenced by government commodity programs. The main policy variables presently available are price supports and acreage allotments. These variables were of primary concern in this analysis. Both support and market prices for the four commodities were included to determine response to these prices. Only the coefficients for soybeans and cotton support price were of the expected sign and both appeared to be somewhat stronger than the market price variable. One interpretation is that program dependence is high for cotton, and that soybean acreage expansion is keyed to removal of price uncertainty. However the relative sizes of these coefficients may be due to the market price measure used. Additional analysis should and will be directed toward obtaining adequate reflection of the role played by support prices.

Acreage allotments also play an important role in policy execution and are included in the model as zero-one variables in the cotton and rice equations. Both coefficients are of the expected sign. The coefficients indicate a reduction in acreage when allotments were imposed as expected and a study of the historical data shows the coefficients are not unrealistic. A less aggregate and more useful representation of allotments than zero-one formulations is desired for policy analyses and further work will be directed toward this end.

Acreage Supply Elasticities

For a clearer comparison of the relative size of price effects on soybean acreage (planted) independent of units of measurement, the relevant direct and cross shortrun elasticities of supply were computed at the data means.[4] They are shown in Table 2.

The elasticity estimates, while recognized as subject to estimation bias, do indeed suggest policy interdependence among the commodities. This is illustrated by noting that a 10 percent decrease in cotton market price has the same effect on soybean acreages (a 4.0 percent increase) as an approximate 33 percent increase in the soybean support price.

The elasticity estimate for soybean acreage with respect to soybean market price is larger than the estimate for the support price, as would be expected. From the above elasticities, it appears that cotton is the strongest competitor with soybeans.

The elasticities for both soybean support and market price are much lower than earlier estimates developed with single equation models for soybean acres harvested in the Delta region by Houck and Subotnik [6]. The cross-elasticity of soybean acreage with respect to cotton market price is of comparable magnitude to an earlier estimate by Houck and Subotnik, being only slightly larger. These elasticities are not comparable to the oft-quoted earlier regional estimates by Heady and Rao [3] as they used price-ratio variables rather than price variables.

Longrun elasticity estimates could be computed by dividing the shortrun estimates by $(1\text{-}C_i)$ where C_i is the estimated coefficient on the lagged acreage variable [7]. Since this region displays an upward trend in soybean acreage, the estimate of C_i is fairly large, which would make the longrun elasticity estimates much larger than those for the shortrun.

TABLE 2. COMPARISON OF RELATIVE SIZE OF PRICE EFFECTS ON SOYBEAN ACREAGE (PLANTED) INDEPENDENT OF UNITS OF MEASUREMENT

	With respect to							
Elasticities of	Soybean support price (t)	Soybean market price (t-1)	Cotton support price (t)	Cotton market price (t-1)	Rice support price (t)	Rice market price (t-1)	Corn support price (t)	Corn market price (t-1)
Soybean acreage planted	0.12	0.16		–0.40		–0.24		0.09
Cotton acreage planted		–0.38	0.24	0.36		0.11		0.11
Rice acreage planted		–0.55		–0.22	–1.269	0.14		0.34
Corn acreage planted		0.91		–0.81		–0.83	–0.04	–0.13

[4]The elasticity estimates were computed from the restricted reduced form, based on the estimated structure. This procedure is outlined below in matrix notation where the $\hat{\beta}$'s and $\hat{\Gamma}$'s are the estimated structural coefficients of the endogenous (Y) and exogenous (Z) variables, respectively, and ϵ is elasticity.

$$\hat{\beta}Y + \hat{\Gamma}Z = U$$
$$\hat{\beta}Y = -\hat{\Gamma}Z + U$$
$$\tilde{Y} = -\hat{\beta}^{-1}\Gamma Z + \hat{\beta}^{-1}U \quad \text{or} \quad \tilde{Y} = \tilde{\pi}Z \quad \text{where } \tilde{\pi} = -\hat{\beta}^{-1}\hat{\Gamma}$$
$$\tilde{\epsilon} = \frac{\partial \tilde{Y}}{\partial Z} \cdot \frac{\bar{Z}}{\bar{Y}} \quad \text{or} \quad \tilde{\epsilon} = \tilde{\pi} \cdot \frac{\bar{Z}}{\bar{Y}}$$

POLICY IMPLICATIONS OF THE STRUCTURAL ESTIMATES

There are two major policy variables presently available to the Federal government in the soybean supply sector. They are (1) the price support loan rate for soybeans themselves, and (2) the price support-acreage restriction mix for crops which compete with soybeans for available acreage. Other policy variables might be available in the future as Federal farm programs and legislation evolve. For example, an acreage or marketing restriction might be added on the soybean supply side. It is precisely the effects of such alternative courses of action which more refined structural parameter estimates from analyses such as this can assist in evaluating.

A realistic example might be a situation where the Commodity Credit Corporation finds itself accumulating soybean stocks at a rapid rate (as in 1968) because the soybean support price tends to be above market price. A decrease in soybean production (given demand) is called for. What is the most efficient method for accomplishing this? Should the support price be lowered and if so, how much? Could cotton or rice acreages be expanded, their support levels changed, etc?

An examination of the direct and cross-elasticities from an analysis such as this would suggest that a 10 percent decrease in the soybean support price would yield a 1.2 percent decrease in the soybean acreage planted. A 10 percent increase in the cotton market price would result in a 4.0 percent decrease (opposite direction) in soybean acreage planted. However, it should be noted that changes in the cotton price have ramifications for rice and corn acreages, as well as adjusting soybean acreage. This simple example suggests that by formulating, identifying, and estimating structural equations, the effect of alternative courses of policy actions can be evaluated and the uncertainty as to the consequences of these actions reduced. The same type of procedure could be applied to a situation where expanded soybean acreage is being encouraged, such as 1971. But even if the main value of the estimates is in describing what has taken place in a consistent fashion, we believe the exercise has been worthwhile.

POTENTIAL REFINEMENTS

Although estimates obtained in this analysis are quite crude, there appears to be considerable promise in the simultaneous approach. After the experience gained from specification and estimation of this model, several areas are suggested for possible improvement:

(1) Rather than using planted acreages of the crops, farmers planting intentions, as announced on March 1 of each year, could offer an improvement.

(2) The support price for soybeans does not seem to enter very prominently in producers decisions. A subsequent reformulation of this model might include two price variables for soybeans. One might be the average of the January-February price and the other an indication of whether last year's price was up or down from the January-February price.

(3) Consideration of a more homogeneous area appears to have considerable merit. For the region considered here, the use of county data would make possible consideration of the 20-25 counties, considered Delta proper, rather than using data for the whole of the States. Data for an entire State may tend to mask certain relationships present in a homogeneous area.

(4) While gross returns (price x yield) with improved price data appear to represent relative profitability fairly well, the construction of a production cost per acre data series for each crop would make calculation of net returns possible. Inclusion of net returns into the analysis would probably improve the model considerably.

Colyer [2] has pointed out that although the single equation approach is less complicated, current knowledge allows relatively easy computation of systems of equations, and improved data sources still offer considerable promise in the study of supply. Our results so far suggest that there is economic payoff in considering simultaneous techniques for isolating relationships from supply data.

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