July 1991 No. 328

A MULTI-MARKET BOUNDED PRICES MODEL UNDER RATIONAL EXPECTATIONS: THE CASE OF CORN AND SOYBEANS

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Abstract

The bounded prices model under rational expectations is extended to a multi-market setting. Because the resulting rational expectations model is highly nonlinear, Fair and Taylor's iterative procedure is employed in conjunction with the multi-market framework to obtain maximum likelihood estimates of a supply-demand model for corn and soybeans. The estimated model is then used to simulate the market equilibrium effects associated with removing price support and acreage set-aside programs over the sample period. Among other things, the results reveal that acreage set-asides have dominated the induced supply effects of price support programs for corn.

Keywords: bounded price variation, corn and soybeans, multi-market model, price supports, rational expectations, set-asides.

Analyzing market disequilibrium and its various economic implications has been the focus of much research (Ziemer and White; Quandt and Rosen, 1986; Portes et al.). Although several types of disequilibrium models have been employed (e.g., Maddala and Nelson; Laffont and Garcia; Bowden), a version receiving recent attention is Maddala's bounded price variation model (BPVM). The BPVM differs from traditional disequilibrium models in that rationing occurs only upon occasion. That is, a market with bounded prices will be in equilibrium until price reaches an exogenously set upper or lower limit, at which time rationing occurs and the market is in disequilibrium.

Although the BPVM is appropriate in a variety of settings, it seems especially suited for analyzing agricultural markets where guaranteed price supports are offered to producers. In the U.S., for instance, price supports are available for a number of commodities. These support levels are typically enforced by the government's commitment to purchase stocks (i.e., excess supplies) at the announced support price. Empirical applications of the BPVM to agricultural markets have been reported by Shonkwiler and Maddala, Holt and Johnson, and Liu et al.

The studies by Shonkwiler and Maddala and Holt and Johnson are also unique in that the basic BPVM was extended to include rational price expectations. The resulting model is more complicated than traditional linear rational expectations models since price supports truncate the equilibrium price distribution. Even though the resulting model is highly nonlinear, full information maximum likelihood (FIML) estimates of the structural equations can still be obtained using Fair and Taylor's iterative solution-estimation procedure.

While previous studies have highlighted the potential for modeling agricultural markets in a bounded prices framework, more work is required.

Specifically, previous research has been conducted in a single-market context, thus ignoring potentially important cross-price effects. Inter-market linkages are important since agricultural supply decisions are often made jointly and because many agricultural commodities are related in consumption. Any complete analysis of government intervention should incorporate relevant market feedbacks.

Considering the above, the objective of this article is to estimate a multi-market BPVM for the U.S. corn and soybean markets that (1) includes cross-price linkages in the supply and demand equations and (2) incorporates the truncation effects associated with government price support programs in a rational expectations framework. Previous research has shown that corn and soybean supply decisions are made jointly (Gallagher; Lee and Helmberger; Chavas and Holt); however, these joint decisions have not been modeled in a rational expectations context. Consequently, this paper goes beyond the recent studies by Shonkwiler and Maddala and Holt and Johnson, which focused only on the corn market, and provides the first application of a multi-market bounded prices model under rational expectations.

The plan of the paper is as follows. In the next section, a framework for estimating a multi-market BPVM under rational expectations is presented. A multi-market model is specified for the corn and soybeans markets in the U.S. FIML estimates of the structural equations, obtained using Fair and Taylor's procedure, are then reported for the 1950-85 period. The model is used to simulate the results of a "free market" regime enforced over the sample period.

A Bounded Prices Model with Rational Expectations

This section focuses on the BPVM applied to a situation where there is a floor under the market price and where producers form price expectations rationally. In what follows, it is assumed that two commodities compete for the same resources in production and are related in consumption.

Consider the following multi-market supply-demand model for two commodities with exogenously set support prices $\bar{P}_{1t}$ and $\bar{P}_{2t}$:

$$D_{1t} = \underline{\alpha}_1' \underline{X}_{1t} + \alpha_2 P_{1t} + \alpha_3 P_{2t} + u_{1t} \tag{1}$$

$$D_{2t} = \underline{\beta}_1' \underline{X}_{2t} + \beta_2 P_{1t} + \beta_3 P_{2t} + u_{2t} \tag{2}$$

$$S_{1t} = \underline{\gamma}_1' \underline{X}_{3t} + \gamma_2 P^e_{1t} + \gamma_3 P^e_{2t} + u_{3t} \tag{3}$$

$$S_{2t} = \underline{\nu}_1' \underline{X}_{4t} + \nu_2 P^e_{1t} + \nu_3 P^e_{2t} + u_{4t} \tag{4}$$

$$Q_{1t} = D_{1t} = S_{1t} \quad \text{if } P_{1t} \geq \bar{P}_{1t} \tag{5}$$

$$Q_{1t} = D_{1t} < S_{1t} \quad \text{if } P_{1t} < \bar{P}_{1t} \tag{6}$$

$$Q_{2t} = D_{2t} = S_{2t} \quad \text{if } P_{2t} \geq \bar{P}_{2t} \tag{7}$$

$$Q_{2t} = D_{2t} < S_{2t} \quad \text{if } P_{2t} < \bar{P}_{2t} \tag{8}$$

where D_{it} is quantity demanded, i=1,2, S_{it} is quantity supplied, i=1,2, P_{it} is the market clearing price, i=1,2, and P^e_{1t} and P^e_{2t} denote the rational expectations of prices P_{1t} and P_{2t}, respectively.[1/] Terms $\underline{X}_{1t}$ and $\underline{X}_{2t}$ are vectors of demand shifters and $\underline{X}_{3t}$ and $\underline{X}_{4t}$ are vectors of supply shifters. Also, $\underline{u}_t = (u_{1t}, u_{2t}, u_{3t}, u_{4t})'$ denotes a vector of joint normally distributed random variables with mean vector zero and variance-covariance matrix Σ.

With observations on P_{1t}, P_{2t}, $\bar{P}_{1t}$, and $\bar{P}_{2t}$, the data points belonging to equilibrium and those associated with excess supply can be identified. Unlike the single-market case, however, the model in (1)-(8) is associated with four regimes. Let ψ_1 denote the observations where $\bar{P}_{1t} \geq P_{1t}$ and $\bar{P}_{2t} \geq P_{2t}$, ψ_2 the years where $P_{1t} < \bar{P}_{1t}$ and $P_{2t} \geq \bar{P}_{2t}$, ψ_3 the points for which $P_{1t} \geq \bar{P}_{1t}$ and $P_{2t} < \bar{P}_{2t}$, and ψ_4 the points where $P_{1t} < \bar{P}_{1t}$ and $P_{2t} < \bar{P}_{2t}$.

For $t \in \psi_1$, both markets are in equilibrium and we have a simultaneous system given by (1)-(5), and (7). Alternatively, for $t \in \psi_2$, the first market is in disequilibrium and the second market is not. In this case the market price for the first commodity is $\bar{P}_{1t}$, but both D_{1t} and S_{1t} are observed since the amount produced and the amount purchased by the government under the price support program are known. The market for the second good remains in equilibrium with the sub-system consisting of equations (2), (4), and (7) determining D_{2t}, S_{2t}, and P_{2t} endogenously. Similar results hold when $t \in \psi_3$, except now D_{1t}, S_{1t}, and P_{1t} are determined endogenously and the market for the second commodity is in disequilibrium. Lastly, when $t \in \psi_4$, both markets are in disequilibrium, prices equal their respective support rates, and quantities demanded and supplied are determined from (1)-(4).[2/][3/]

The model in (1)-(8) represents a market for a pair of commodities where price supports truncate the equilibrium price distribution and where producers form expectations about P_{1t} and P_{2t} in accordance with the rational expectations hypothesis. Under a linear rational expectations setup, reduced form equations for P_{1t} and P_{2t} are derived, the expectation operator applied, and the solutions for P^e_{1t} and P^e_{2t} obtained. The resulting closed-form expressions for P^e_{1t} and P^e_{2t} are then substituted into the supply equations to obtain an estimable structural form with nonlinear cross-equation restrictions. See, e.g., Wallis or Shonkwiler and Emerson for details.

The above procedures cannot be applied in the present case, though, since price supports truncate the distributions of expected prices. This truncation process must be incorporated when solving for the expected prices in the BPVM under rational expectations.

The multi-market rational expectations model with price supports is obtained as follows. The restricted reduced form price equations from (1)-(5) and (7) are:

$$P_{1t} = (\alpha_2\beta_3 - \alpha_3\beta_2)^{-1}[\beta_3\underline{\gamma}_1'\underline{X}_{3t} - \alpha_3\underline{\nu}_1'\underline{X}_{4t} + (\beta_3\gamma_2 - \alpha_3\nu_2)P^e_{1t}$$
$$+ (\beta_3\gamma_3 - \alpha_3\nu_3)P^e_{2t} - \beta_3\underline{\alpha}_1'\underline{X}_{1t} + \alpha_3\underline{\beta}_1'\underline{X}_{2t} + \beta_3(u_{3t} - u_{1t}) - \alpha_3(u_{4t} - u_{2t})] \tag{9}$$

and

$$P_{2t} = (\alpha_2\beta_3 - \alpha_3\beta_2)^{-1}[\alpha_2\underline{\nu}_1'\underline{X}_{4t} - \beta_2\underline{\gamma}_1'\underline{X}_{3t} + (\alpha_2\nu_2 - \beta_2\gamma_2)P^e_{1t}$$
$$+ (\alpha_2\nu_3 - \beta_2\gamma_3)P^e_{2t} - \alpha_2\underline{\beta}_1'\underline{X}_{2t} + \beta_2\underline{\alpha}_1'\underline{X}_{2t} + \alpha_2(u_{4t} - u_{2t}) - \beta_2(u_{3t} - u_{1t})]. \tag{10}$$

Taking conditional expectations of (9) and (10), we obtain the expected market prices (i.e., expected prices before truncation) as:

$$P^*_{1t} = (\alpha_2\beta_3 - \alpha_3\beta_2)^{-1}[\beta_3\underline{\gamma}_1'\underline{X}^e_{3t} - \alpha_3\underline{\nu}_1'\underline{X}^e_{4t} + (\beta_3\gamma_2 - \alpha_3\nu_2)P^e_{1t}$$
$$+ (\beta_3\gamma_3 - \alpha_3\nu_3)P^e_{2t} - \beta_3\underline{\alpha}_1'\underline{X}^e_{1t} + \alpha_3\underline{\beta}_1'\underline{X}^e_{2t}] \tag{11}$$

and

$$P^*_{2t} = (\alpha_2\beta_3 - \alpha_3\beta_2)^{-1}[\alpha_2\underline{\nu}_1'\underline{X}^e_{4t} - \beta_2\underline{\gamma}_1'\underline{X}^e_{3t} + (\alpha_2\nu_2 - \beta_2\gamma_2)P^e_{1t}$$
$$+ (\alpha_2\nu_3 - \beta_2\gamma_3)P^e_{2t} - \alpha_2\underline{\beta}_1'\underline{X}^e_{2t} + \beta_2\underline{\alpha}_1'\underline{X}^e_{2t}] \tag{12}$$

where $[\underline{X}^e_{1t}, \underline{X}^e_{2t}]$ and $[\underline{X}^e_{3t}, \underline{X}^e_{4t}]$ denote, respectively, expectations of the exogenous variables in the demand and supply equations. Rational expectations P^*_{1t} and P^*_{2t} are appropriate when price supports do not truncate producers' price expectations. Without price supports, $P^*_{it} = P^e_{it}$, i=1,2, (11) and (12) could be solved for the rational price expectations, P^e_{it}, i=1,2.

In the present case, however, $P^*_{it} \neq P^e_{it}$, i=1,2, since the latter is formed after including the truncation effects implied by $\bar{P}_{1t}$ and $\bar{P}_{2t}$. These truncation effects are incorporated, in turn, by accounting for the probability that each market price will fall below its respective support price. Given the joint normality of the error vector $\underline{u}_t$ and the linear equation specifications in (1)-(4), it follows that the market (e.g., untruncated) price distributions are also normal. Using standard results for truncated normal distributions, it can be shown (see, e.g., Holt and Johnson) that the expectations prior to truncation in (11) and (12) are related to the price expectations after truncation as follows:

$$P^e_{1t} = \bar{P}_{1t}\Phi(K_{1t}) + \sigma_1(2\pi)^{-1/2}\exp(-K^2_{1t}/2) + P^*_{1t}[1 - \Phi(K_{1t})], \tag{13}$$

and

$$P^e_{2t} = \bar{P}_{2t}\Phi(K_{2t}) + \sigma_2(2\pi)^{-1/2}\exp(-K^2_{2t}/2) + P^*_{2t}[1 - \Phi(K_{2t})], \tag{14}$$

where,

$$K_{1t} = [\bar{P}_{1t} - (\alpha_2\beta_3 - \alpha_3\beta_2)^{-1}[\beta_3\underline{\gamma}_1'\underline{X}^e_{3t} - \alpha_3\underline{\nu}_1'\underline{X}^e_{4t} + (\beta_3\gamma_2 - \alpha_3\nu_2)P^e_{1t} + (\beta_3\gamma_3 - \alpha_3\nu_3)P^e_{2t} - \beta_3\underline{\alpha}_1'\underline{X}^e_{1t} + \alpha_3\underline{\beta}_1'\underline{X}^e_{2t}]/\sigma_1, \tag{15}$$

$$K_{2t} = [\bar{P}_{2t} - (\alpha_2\beta_3 - \alpha_3\beta_2)^{-1}[\alpha_2\underline{\nu}_1'\underline{X}_{4t}^e - \beta_2\underline{\gamma}_1'\underline{X}_{3t}^e + (\alpha_2\nu_2 - \beta_2\gamma_2)P_{1t}^e + (\alpha_2\nu_3 - \beta_2\gamma_3)P_{2t}^e - \alpha_2\underline{\beta}_1'\underline{X}_{2t}^e + \beta_2\underline{\alpha}_1'\underline{X}_{2t}^e]/\sigma_2, \tag{16}$$

$$\sigma_1^2 = (\alpha_2\beta_3 - \alpha_3\beta_2)^{-2}\text{var}[\beta_3(u_{3t} - u_{1t}) - \alpha_3(u_{4t} - u_{2t})], \tag{17}$$

$$\sigma_2^2 = (\alpha_2\beta_3 - \alpha_3\beta_2)^{-2}\text{var}[\alpha_2(u_{4t} - u_{2t}) - \beta_2(u_{3t} - u_{1t})], \tag{18}$$

and $\Phi(\cdot)$ denotes the distribution function of the standard normal. Here $1 - \Phi(K_{it})$ denotes the probability the ith support price, i=1,2, is not effective (e.g., the observed market price is above the support price).

With price supports, the rational price expectations P_{1t}^e and P_{2t}^e are obtained by solving simultaneously equations (11)-(18). This system of equations is highly nonlinear and closed form expressions for the rational price predictors cannot be obtained. Several instrumental variables methods have been proposed for generating proxies for the unobservable price expectations in the bounded prices model (Shonkwiler and Maddala). But the full impact of the rational expectations hypothesis can only be evaluated if <u>all</u> cross-equation restrictions resulting from the simultaneous solution of (11)-(18) are used in estimation.

To obtain FIML estimates of the model incorporating all information implied by rationality, the iterative simulation-estimation procedure described by Fair and Taylor is used. With starting values for parameter vector $\underline{\omega} = (\underline{\alpha}', \underline{\beta}', \underline{\gamma}', \underline{\nu}', \text{vech}(\Sigma)')$, the system in (11)-(18) can be solved numerically using the Gauss-Seidel algorithm. Resulting values for P_{1t}^e and P_{2t}^e will embody all information implied by rational expectations, just as they would if analytical solutions could be obtained. The simulated values for P^e_{1t} and P^e_{2t} are then used to evaluate the likelihood function and obtain updated estimates of parameter vector $\underline{\omega}$. The entire procedure is repeated iteratively until convergence is achieved.[4/].

The Model

A structural model is specified for the U.S. corn and soybean markets that consists of four behavioral equations: one each for aggregate corn and soybean demand and one each for aggregate corn and soybean production. The model is closed by assuming that producers form price expectations rationally.

Demand Equations

Relatively simple demand equations are used to keep the empirical model tractable. Each demand equation is hypothesized to be a function of corn and soybean prices, the price of livestock, exports, and a time trend.

The following demand equations are specified:

$$QCD_t = \alpha_0 + \alpha_1 PC_t + \alpha_2 PS_t + \alpha_3 LP_t + \alpha_4 CXP_t + \alpha_5 t + u_{1t} \tag{19}$$

and

$$QSD_t = \beta_0 + \beta_1 PC_t + \beta_2 PS_t + \beta_3 LP_t + \beta_4 SXP_t + \beta_5 t + u_{2t}. \tag{20}$$

where QCD_t is total annual disappearance of corn in all uses, QSD_t is total annual disappearance of soybeans in all uses, PC_t is farm price of corn, PS_t is farm price of soybeans, LP_t is an index of prices received for livestock, CXP_t is commercial corn exports, SXP_t is commercial soybean exports, t is a time trend, and u_{1t} and u_{2t} are random error terms.

Corn and soybean exports are included to reflect export growth over the sample period. The livestock price index reflects profitability associated with feeding livestock. Trend variables are also included as proxies for omitted variables--such as growth in livestock populations, inflation, and other demand factors--that are correlated with time.

Supply Equations

Corn and soybean supply decisions are interrelated since corn and soybeans are produced using many of the same resources (Gallagher; Lee and Helmberger; Chavas and Holt). Government price support programs have also been implemented for both commodities, thus creating the potential for cross-market price and quantity reactions induced by government intervention.

The supply equations are specified as:

$$QCS_t = \gamma_0 + \gamma_1 PC_t^e + \gamma_2 PS_t^e + \gamma_3 CWI_t + \gamma_4 DA_t + \gamma_5 D83_t + \gamma_6 t + u_{3t} \qquad (21)$$

and

$$QSS_t = \nu_0 + \nu_1 PC_t^e + \nu_2 PS_t^e + \nu_3 SWI_t + \nu_4 D83_t + \nu_5 t + u_{4t} \qquad (22)$$

where QCS_t is total corn production, QSS_t is total soybean production, PC_t^e is the rational expectation of the effective producer price for corn, PS_t^e is similarly defined for soybeans, DA_t is corn acres diverted, CWI_t and SWI_t are respectively seasonal growing condition indices for corn and soybeans, $D83_t$ is a binary variable equaling 1 only during 1983, and u_{3t} and u_{4t} are random error terms.

Growing conditions indices CWI_t and SWI_t are constructed by regressing observed yields on a trend variable and evaluating the ratio between observed and predicted yields.[5/] Trend variables are included in (20) and (21) as a proxy for technological change that has occurred in corn and soybean production. Total corn acres diverted are included in the corn supply equation to capture effects of set-aside programs.[6/] Dummy variable $D83_t$ is used to discount effects of the payment-in-kind (PIK) program and the severe drought that occurred in 1983.

Exogenous Processes

It is necessary also to specify how expectations of the exogenous variables LP_t, CXP_t, SXP_t, CWI_t, and SWI_t are formed. For simplicity, we assume LP_t, CXP_t, and SXP_t follow a first-order vector autoregressive process:

$$\underline{X}_t = \underline{\phi}_0 + \phi_1 \underline{X}_{t-1} + \underline{\phi}_3 t + \underline{u}_t \tag{23}$$

where $\underline{X}_t = (CXP_t, SXP_t, LP_t)'$, $\underline{\phi}_0$ and $\underline{\phi}_3$ are (3 x 1) parameter vectors, $\underline{\phi}_1$ is a (3 x 3) parameter matrix, and $\underline{u}_t = [u_{5t}, u_{6t}, u_{7t}]'$ is a (3 x 1) vector of serially uncorrelated random variables. Conditional expectations of the exogenous variables are then given by:

$$\underline{X}_t^e = \underline{\phi}_0 + \phi_1 \underline{X}_{t-1} + \underline{\phi}_3 t. \tag{24}$$

In the Fair-Taylor iterations, the right-hand side of (24) is substituted for $[X_{1t}^e, X_{2t}^e]$ and $[X_{3t}^e, X_{4t}^e]$ when solving equations (11)-(18). Less information is available for predicting seasonal growing conditions. Hence, expected values for CWI_t and SWI_t are determined by a simple three-year moving average.

Closing Identities

A key assumption of the model is that both corn and soybean markets are occasionally in disequilibrium. Prices and quantities are determined during equilibrium periods ($t \in \psi_1$) by the intersection of supply and demand. The identities:

$$QCD_t = QCS_t + CSTK_{t-1} \tag{25}$$

and

$$QSD_t = QSS_t + SSTK_{t-1}, \tag{26}$$

where $CSTK_{t-1}$ and $SSTK_{t-1}$ denote respectively beginning stocks of corn and soybeans are used when $t \in \psi_1$. During periods when both markets are in disequilibrium ($t \in \psi_4$), (25) and (26) are modified to account for stocks placed under government reserve. Specifically, the identities used when $t \in \psi_4$ are:

$$QCD_t = QCS_t + CSTK_{t-1} - GCSTK_t \tag{27}$$

and

$$QSD_t = QSS_t + SSTK_{t-1} - GSSTK_t, \tag{28}$$

where $GCSTK_t$ is the amount of corn placed under government reserve by the loan program and $GSSTK_t$ is similarly defined for soybeans. For $t \in \psi_2$ or ψ_3 (i.e., one market is in disequilibrium but the other is not), closing relations (25) and (28) or (26) and (27) apply respectively.

Data and Estimation Issues

The above model is estimated using annual data for the 1950-85 period. Data on production, disappearance, beginning stocks, government removals, exports, and corn and soybean prices were obtained from annual issues of Agricultural Statistics, as were support prices for both corn and soybeans. The livestock price index was obtained from various annual supplements of Livestock and Meat Statistics. Yield data used to construct the growing condition indices were also obtained from Agricultural Statistics.

As is common practice, the market price is set equal to the support price during periods when market price fell below support price. The result is that twenty-two observations were associated with equilibrium for both markets ($t \in \psi_1$), ten were associated with disequilibrium in the corn market only ($t \in \psi_2$), one was associated with disequilibrium in the soybean market only ($t \in \psi_3$), and three observations were associated with disequilibrium in both markets ($t \in \psi_4$).

Support price data for corn were also modified to incorporate the target price when determining expected producer prices in the Fair-Taylor iterations. Prior to 1963, corn producers participating in government programs were eligible to receive only price support loans. Following 1963, participating corn producers could also receive a deficiency payment if subsequent market prices did not exceed the target price (target price always exceeds the loan rate). To more fully reflect this additional source of support, the government price used to determine effective producer corn prices after 1963 was the target price itself.[7/]

Estimation Results

Parameter Estimates

With the above data, FIML estimates of the corn and soybeans rational expectations model were obtained. The truncation effects associated with the corn and soybean price support programs were incorporated by embedding Fair and Taylor's algorithm in the FIML estimation procedure to solve equations (11)-(18) for the expected price variables PC_t^e and PS_t^e. Preliminary results also revealed serial correlation in the error terms of (19)-(22). An AR(1) error processes was subsequently included for each of these equations, with autocorrelation parameters denoted by ρ_1, ρ_2, ρ_3, and ρ_4, respectively. In this estimation, (19)-(22) were quasi-first-differenced and the structural parameters were estimated jointly with the autocorrelation coefficients. FIML estimates of the multi-market system in (19)-(28) with bounded prices and rational expectations are reported in table 1.

In the corn demand equation, the estimated value of α_1 implies an own-price elasticity of demand of -0.696, an estimate similar to the one reported by Shonkwiler and Maddala. The cross-price elasticity of corn demand with respect to soybean price is small and negative (-0.057) and the cross-price coefficient α_2 is not statistically significant. The estimated livestock price coefficient on α_3 is positive with an elasticity of 1.003. Corn export coefficient α_4 is also positive, although its point elasticity of elasticity of 0.09 is rather small.

Turning to the soybean demand equation, estimated value of β_2 is negative and significant, implying an own-price elasticity of -1.015. While this estimate appears somewhat high, it is not unreasonable given the aggregate nature of the soybean demand equation. Interestingly, corn cross-price coefficient β_1 is positive and significant, with an associated elasticity of 0.719. Hence, it appears that corn is a substitute for soybean consumption. The elasticity of soybean demand with respect to livestock price is 0.145, implying soybean usage is less responsive to livestock prices than corn demand; however, the elasticity of soybean demand with respect to exports is 1.019, indicating soybean demand is more responsive than corn demand to exports.

Results for the corn supply equation also appear satisfactory in terms of signs, significance, and magnitude. The estimated value for γ_1 is positive and significant and implies a short-run supply elasticity of 0.223. This elasticity estimate is reasonable and within range of those reported by Chambers and Just, Lee and Helmberger, Chavas and Holt, and others. Similarly, the γ_2 estimate is negative and significant, implying a short-run corn supply response elasticity of -0.076 with respect to expected soybean price.[8/] As expected, estimated coefficient γ_4 of acres diverted is negative and significant, with an implied short-run elasticity of -0.076. The γ_5 estimate shows that in 1983 corn supplies fell significantly; estimate of coefficient γ_6 indicates corn production has trended upward over time.

Results for the soybean supply equation also are favorable. The estimated value of ν_2 is positive and significant, indicating a short-run own-price elasticity of supply of 0.378. Likewise, the cross-price elasticity with respect to expected corn price is -0.160. These elasticity estimates are well within range of those reported elsewhere (e.g., Gardner; Chambers and Just; Chavas and Holt). Remaining coefficient estimates in the soybean supply equation are significant as well, and have plausible signs and magnitudes.

Model Evaluation

In addition to assessing the economic plausibility of estimated parameters, it is useful to determine (1) how well the model "explains" historical time-series data, (2) whether the rational expectations assumption is appropriate, and (3) whether it is useful to estimate corn and soybean models in a multi-market context. Each of these issues is addressed in turn.

First, the model was simulated historically by solving for the relevant endogenous variables in order to evaluate goodness of fit.[9/] Several measures of simulation performance are reported in table 2. Results indicate the estimated model does a reasonable job of replicating historical movements in the endogenous variables. All simulation R^2's are greater than 0.85, and the mean absolute percent error in each behavioral equation is below 12%. The estimated model also predicts turning points accurately, as indicated by the consistently low values of Theil's U-statistics.

Although the estimated model fits the data well, simulation results say nothing about the validity of the rational expectations hypothesis. To assess the relevance of the rational expectations approach, an alternative model was estimated in which expected corn and soybean prices, before truncation, were determined using second-order AR models. Generating expected prices in this manner is consistent with producers forming "economically" rational expectations. Parameter estimates compared favorably with those reported in table 1, and the value of this model's log likelihood function (-290.814) was slightly smaller than that of the rational expectations model (-289.902). Thus, the rational expectations hypothesis is no less appropriate for characterizing corn and soybean producer expectations than is less restrictive price expectations process.

Finally, the hypothesis that corn and soybean markets are unrelated can be tested (Quandt and Rosen, 1989). If these markets are not linked, cross-price terms in the supply and demand equations will be zero. Hence, the assumption of independent markets implies $\alpha_2 = \beta_1 = 0$ and $\nu_1 = 0$. Absence of linkage also implies error terms in the corn equations will be uncorrelated with those in the soybean equations; that is, $\text{cov}(u_{1t}, u_{2t}) = \text{cov}(u_{1t}, u_{4t}) = \text{cov}(u_{2t}, u_{3t}) = \text{cov}(u_{3t}, u_{4t}) = 0$. A likelihood ratio test of the constraints implied by this independent markets assumption resulted in a test statistic of 35.67. The critical value for $\chi^2(7)$ at a 0.05 significance level is only 14.01. Thus, restrictions implied by the hypothesis of no linkages between corn and soybean markets are rejected by the data.

Policy Simulation Results

To illustrate the estimated model's potential for policy analysis, is was simulated over the historical sample period after removing price support and acreage diversion effects. In this way it is possible to predict time-paths for the endogenous variables in the absence of government intervention. Unlike models based on naive producer response, the simulations reported here allow all expected prices to adjust to their new equilibrium levels. Hence, feedbacks incorporated in this analysis are more complete than those in models based on naive behavior or in models without cross-price effects.

The procedure was to perform repeated dynamic stochastic simulations of the structural equations after setting all support prices to zero. Specifically, the model was solved repeatedly (100 times) under the assumption that a "free-market" regime prevailed each period. Simulation results for selected years are reported in tables 3 and 4.

As expected, impacts of removing support prices are larger in the corn market than in the soybean market. For example, during 29 of the 35 sample periods the simulated corn price was below observed market price, and during 12 of these periods the fraction of simulated prices falling below the observed price exceeded 0.90.[10/] Results show corn prices would have been well below observed market prices during most of the mid and late 1950s, throughout most of the 1960s and early 1970s, and again during most of the early 1980s. Simulated average corn prices also were lower for all 13 periods in which the corn market was effectively in disequilibrium.

Simulated means corn production means were above observed production levels during 23 sample periods. In fact, simulated corn production was above actual production over 90% of the time during 16 of these periods. Moreover, in the absence of government programs corn production would have been notably higher than observed values throughout the 1960s and early 1970s. These results appear counterintuitive since under a free-market regime farm prices would also have been substantially lower than observed prices during much of this same period. However, corn acreage set-aside programs were employed during 14 of the years in which simulated corn production was higher than observed production. Not surprisingly, acreage set-asides historically have had an important impact on corn production, and set-aside effects may have dominated price support effects in the corn market.[11/] Similar results for corn (e.g., lower prices, higher production) were reported by Johnson et al. in their analysis of a "free-market" regime for U.S. agriculture.

The simulation results also reveal that average corn disappearance under a free market scenario would have been above observed levels during 29 of the 35 periods studied. For 25 of these periods, simulated disappearance was higher than actual disappearance over 90% of the time. These results seem consistent given that (1) average production tended to be higher in the absence of government programs, and (2) surplus production would no longer be purchased by the government under a free market. Substantial increases in simulated corn use occurred during each period in which the corn market was in disequilibrium. Not surprisingly therefore, government stock operations have had an important effect on corn usage.

Impacts of eliminating government programs are less pronounced for soybeans than for corn (table 4). Simulation results put average free-market soybean prices below observed prices for 27 of the 35 periods. During nine of these periods, the fraction of simulated soybean prices falling below observed soybean prices exceeded 0.90. Moreover, impacts of removing government programs on soybean production and disappearance were relatively minor; average free-market production differed substantially from observed production for only four years and average disappearance deviated meaningfully from actual disappearance during only five years.

Interestingly, of the nine years in which the fraction of free-market simulated soybean prices falling below observed soybean prices exceeded 90%, seven coincided with periods in which the fraction of simulated corn prices falling below actual corn prices exceeded 90%. Among other things, this result highlights the potential importance of "spillover" effects in policy analysis of corn and soybean markets.

Conclusions

Previous applications of the BPVM to agricultural markets have been conducted in a single-market framework. While this simplification has facilitated model specification and estimation, it is made at the expense of important additional information. A major focus of the present study was to model price support programs in the U.S. corn and soybean markets with a multi-market endogenous switching model. The model was closed by assuming that producers form price expectations rationally. While previous studies have estimated corn and soybean supply decisions in a systems framework, this is the first attempt to do so with the rational expectations hypothesis. Since price support programs make rational expectations models nonlinear, Fair and Taylor's iterative procedure was used to obtain FIML estimates. Resulting parameter estimates appear reasonable and the estimated model provides a good fit to the historical data.

The model provides a rich framework for conducting policy analysis. It was used, for example, to assess the possible effects of eliminating price support and acreage diversion programs. Results suggested corn prices would have been lower and, due to set-aside programs, corn production higher over much of the 1950-85 sample period. Effects on the soybean market were less pronounced, although there were apparent "spillovers" from the corn to the soybean market. Analysis of government intervention in corn and soybean markets appears to be well served by a model that incorporates cross-market linkages.

While this study illustrates the feasibility of modifying a "bare bones" rational expectations version of the BPVM to a multi-market setting, more work is required. For instance, it would be interesting to include other potentially important markets in the analysis. It would also be desirable to have separate structural equations for each disappearance category. In particular, future research should address the relationship between private stockholding and government programs. Finally, analysis could be expanded to include risk terms in the supply equations since recent research has illustrated that government price support programs can affect higher moments of price distributions (Chavas and Holt).

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Table 1. Maximum Likelihood Estimates of U.S. Corn and Soybean Supply-Demand Parameters, 1950-85.

	Coefficients	t-values		Coefficients	t-values
α_0	26.5966	19.1426	ν_4	-0.2482	1.9539
α_1	-22.8639	21.4614	ν_5	0.4800	5.9683
α_2	-0.8530	0.4586	ϕ_{10}	3.7476	2.3954
α_3	4.0786	7.5866	ϕ_{11}	0.9623	6.1767
α_4	0.5807	1.2676	ϕ_{12}	1.0742	1.7706
α_5	0.6222	2.2101	ϕ_{13}	-0.3916	2.6586
β_0	1.4384	0.4006	ϕ_{14}	-0.0786	0.6267
β_1	4.8876	5.0941	ϕ_{20}	0.6136	0.7124
β_2	-3.1210	4.5218	ϕ_{21}	0.1591	2.9523
β_3	0.1224	0.7853	ϕ_{22}	0.4852	2.6167
β_4	3.2440	1.9998	ϕ_{23}	-0.1046	1.7212
β_5	0.0067	0.0188	ϕ_{24}	0.0777	1.5255
γ_0	-39.3769	18.2143	ϕ_{30}	3.9498	3.7140
γ_1	5.8814	4.2022	ϕ_{31}	0.3258	2.8309
γ_2	-0.9492	1.6617	ϕ_{32}	0.5045	1.7784
γ_3	5.8164	17.1739	ϕ_{33}	0.5227	5.6309
γ_4	-0.4094	6.3389	ϕ_{34}	-0.0856	1.1762
γ_5	-0.9903	3.3564	ρ_1	0.2749	1.5505
γ_6	1.4508	13.4619	ρ_2	0.2404	1.1903
ν_0	-9.1320	6.0552	ρ_3	0.3817	1.7788
ν_2	1.0658	2.8890	ρ_4	0.3467	1.6556
ν_3	0.8708	6.4694			

Likelihood Value = -289.902

Table 2. Goodness-of-Fit and Theil's Statistics for Endogenous Variables.

Endogenous Variable	Actual[a/] Average	RMSE	RMSPE	MAE	MAPE	R^2	Theil's U
QCD_t	5.859	0.100	0.083	0.414	0.068	0.942	0.049
QCS_t	4.902	0.036	0.043	0.168	0.034	0.985	0.021
PC_t[b/]	2.074	0.048	0.158	0.198	0.112	0.856	0.074
QSD_t	1.212	0.023	0.149	0.102	0.108	0.969	0.048
QSS_t	1.101	0.016	0.121	0.073	0.090	0.975	0.038
PS_t[b/]	4.147	0.082	0.121	0.364	0.092	0.935	0.055
CXP_t	0.931	0.030	0.290	0.120	0.178	0.943	0.075
SXP_t	0.380	0.010	0.362	0.047	0.214	0.951	0.066
LP_t[b/]	1.442	0.019	0.077	0.088	0.063	0.967	0.036

Note: RMSE denotes root mean square error, RMSPE denotes root mean square percent error, MAE is mean absolute error, MAPE denotes mean absolute percent error, and R^2 is the square of the simple correlation coefficient between observed and simulated values.

a/ QCD_t, QCS_t, QSD_t, QSS_t, CXP_t, and SXP_t are measured in billion bushels, PC_t and PS_t are measured in dollars per bushel, and LP_t is an index, 1967 = 1.0.

b/ Simulated values for PC_t and PS_t were computed using their respective unconditional expectations.

Table 3. Simulated Effects of Removing Government Price Supports and Acreage Diversions on the U.S. Corn Market for Selected Years.

	Price			Production			Disappearance		
Year	Actual	Simulated	Frac.	Actual	Simulated	Frac.	Actual	Simulated	Frac.
1951	1.66	1.49	0.76	2.63	2.48	0.18	3.37	3.22	0.18
1955	1.58	1.27	0.86	2.87	2.59	0.08	3.09	3.63	0.99
1957	1.40	1.00	0.88	3.05	3.08	0.56	3.36	4.50	1.00
1959	1.12	0.98	0.74	3.83	3.45	0.08	4.06	4.97	1.00
1961	1.20	0.53	0.98	3.60	4.10	1.00	4.73	6.11	1.00
1963	1.11	0.75	0.93	4.02	4.57	1.00	5.38	5.94	1.00
1965	1.16	0.75	0.95	4.10	5.02	1.00	5.25	6.17	1.00
1967	1.05	0.88	0.78	4.86	5.47	1.00	5.21	6.30	1.00
1969	1.16	0.75	0.95	4.69	5.78	1.00	5.81	6.90	1.00
1971	1.08	1.06	0.54	5.65	6.04	0.95	6.31	6.71	0.95
1973	2.55	1.72	1.00	5.67	6.26	0.98	6.38	6.97	0.98
1975	2.54	1.93	0.97	5.84	6.20	0.94	6.40	6.76	0.94
1977	2.02	2.25	0.21	6.51	6.47	0.43	7.64	7.61	0.43
1979	2.48	2.29	0.75	7.93	7.73	0.17	9.64	9.44	0.17
1981	2.47	2.88	0.06	8.12	7.99	0.28	9.51	9.38	0.28
1983	3.21	2.92	0.85	4.18	5.13	1.00	7.70	8.65	1.00
1985	2.55	2.15	0.93	8.88	8.44	0.02	9.42	10.08	1.00

Note: In the case of Price, Frac. denotes the fraction of times the simulated price was at or below the observed price. Similarly for Production and Disappearance, Frac. denotes the fraction of times the simulated values were equal to or above the observed values.

Table 4. Simulated Effects of Removing Government Price Supports and Acreage Diversions on the U.S. Soybean Market for Selected Years.

	Price			Production			Disappearance		
Year	Actual	Simulated	Frac.	Actual	Simulated	Frac.	Actual	Simulated	Frac.
1951	2.73	2.43	0.73	0.28	0.21	0.16	0.30	0.22	0.16
1955	2.22	2.27	0.51	0.37	0.31	0.31	0.40	0.34	0.31
1957	2.97	1.82	0.97	0.48	0.50	0.50	0.52	0.54	0.50
1959	1.96	1.69	0.63	0.53	0.53	0.48	0.62	0.62	0.48
1961	2.30	1.16	0.99	0.68	0.68	0.54	0.65	0.71	0.72
1963	2.51	1.79	0.87	0.70	0.76	0.73	0.75	0.80	0.73
1965	2.54	2.12	0.75	0.85	0.89	0.60	0.88	0.92	0.60
1967	2.50	2.14	0.77	0.98	0.92	0.32	0.93	1.01	0.79
1969	2.35	1.26	0.97	1.13	1.04	0.22	1.46	1.37	0.22
1971	3.03	2.54	0.79	1.18	1.23	0.72	1.28	1.33	0.72
1973	5.68	4.54	0.99	1.55	1.46	0.21	1.61	1.52	0.21
1975	4.92	3.71	1.00	1.55	1.50	0.37	1.74	1.68	0.37
1977	5.88	5.20	0.88	1.77	1.81	0.66	1.87	1.91	0.66
1979	6.28	6.10	0.57	2.26	1.96	0.00	2.44	2.14	0.00
1981	6.04	6.92	0.04	1.99	1.97	0.48	2.30	2.29	0.48
1983	7.91	7.89	0.53	1.64	1.66	0.56	1.98	2.01	0.56
1985	5.19	4.12	0.97	2.10	2.07	0.39	2.42	2.39	0.39

Note: See table 3.

Footnotes

*/ Matthew T. Holt is an assistant professor, Department of Agricultural Economics, University of Wisconsin-Madison. Helpful comments from Mario Miranda, Jean-Paul Chavas, Peter Helmberger, Jung-sup Choi, and two anonymous referees are gratefully acknowledged.

1/ Quantity demanded, D_{it}, i=1,2, denotes total quantity demanded. For storable commodities, equations (1) and (2) represent the combined demands for: (1) feed and food use; (2) exports; and (3) private inventories.

2/ An important issue is the conditions under which the multi-market endogenous switching model in (1)-(8) is "coherent". Necessary and sufficient conditions for the present model to be coherent are that $\alpha_1\beta_2 - \alpha_2\beta_1 > 0$. See Gourieroux, Laffont, and Monfort for details.

3/ In practice government stocks are released back onto the market once pre-established "release" prices are encountered. However, upper price limits are not incorporated presently because they do not represent a true price ceiling; once government stocks are exhausted, release price need not hold. To include release prices it would be necessary to treat both private and government stock holding decisions using a more complicated structure as in, e.g., Miranda and Helmberger.

4/ Details on likelihood function specification details will be furnished upon request.

5/ Given that dependent variables QCS_t and QSS_t are the product of yield and harvested acres, it follows that including growing conditions indices as explanatory variables introduces simultaneous equations bias. Several attempts were made to generate suitable instruments for CWI_t and SWI_t; however, none were satisfactory. The analysis thus proceeds using growing conditions indices computed from observed yields, but realizing that the empirical results must be interpreted with some caution.

6/ Including diverted acres in the corn supply equation is not fully desirable since set-aside decisions are implicit in commodity program participation decisions. It would be more appropriate to model participation decisions directly; however, the econometric complications associated with modeling participation rates are formidable since price supports have not always been tied to set-asides. Rather than ignore the effects of set-asides on corn production, we follow Garst and Miller, Taylor and Talpaz, and others in including acres diverted as an explanatory variable in the corn supply equation.

7/ This corn support price modification only affects the solution of the rational expectations model. Importantly, loan rates are still used in lieu of market prices in demand equations during periods of disequilibrium.

8/ Initial estimates indicated supply equation cross-price effects were nearly symmetric. A likelihood ratio test of the restriction $\gamma_2 = \nu_1$ yielded a test statistic of 0.049 with one degree of freedom. The critical value for $\chi^2(1)$ at the 0.05 level is 3.841, indicating symmetry cannot be rejected. Correspondingly, all reported results are for the model where symmetry is imposed.

9/ The model was simulated by obtaining reduced form equations for PC_t and PS_t and then computing unconditional price expectations from:

$$E(P_{it}) = \Phi(\cdot)E(P_{it}|P_{it} < \bar{P}_{it}) + [1 - \Phi(\cdot)]E(P_{it}|P_{it} \geq \bar{P}_{it}),$$

i=1,2. Resulting unconditional price expectations were then used to predict consumption levels for both corn and soybeans.

10/ The simulation results may overstate price impacts associated with removing price supports. This is because historically private stockholding has been "crowded-out" by government stockholding. Thus, private storage activities may have prevented prices from dropping as low as that indicated in the reported free-market simulations. However, it should be emphasized the simulations do incorporate government stocks into aggregate demand. Hence, simulated prices reflect that with a free-market, government stocks would have been allocated to other uses.

11/ To further explore the hypothesis that set-aside effects historically dominated price support effects in the corn market, simulations were repeated assuming price supports were not available, but that set-aside programs were still in force. This exercise revealed average free-market corn production would have been higher than observed values during only 12 years. Only during three of these 12 years would simulated free-market production levels have been higher than observed quantities 90% of the time. At the same time, simulated free-market prices would have been below observed levels 90% of the time during six sample periods.