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Acreage Response, Expected Price Functions, and Endogenous Price Expectations

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Taking the price of futures as a proxy for expected price, this article treats acreage planted to soybeans, the price of futures, and other variables as jointly dependent. A futures price equation is embedded in a simultaneous equations model along with the consumption demand and acreage response. The model is estimated using both ordinary and three-stage least squares. Estimated price elasticities for consumption demand, demand for stocks, and acreage response equal, respectively, −.5, −1.8, and +.2 (short run) and +.59 (long run).

Key words: acreage response, consumption demand, expectations, futures price, soybeans, stocks, storage demand.

Introduction

The estimation of supply functions for farm products has occupied researchers for many decades, with one of the results being a kit of research tools that has become ever larger and more sophisticated. It was recognized early on that production lags necessitated the modeling of price expectations, and from the beginning to the present time researchers have relied on simple cobweb theory, taking the price in period t as a proxy for the expected price in period $t + 1$. A plethora of finite and infinite distributed lag models now exists that draws upon past prices in modeling price expectations. As an alternative to using past price(s), Gardner advanced the idea of using the futures price as a measure of expected price, arguing that "the price of a futures contract for next year's crop reflects the market's estimate of next year's cash price" (p. 81). Eales et al. have recently provided important support for the view that the futures price is an appropriate proxy for subjective price expectations. In his research, Gardner treated the futures price as an exogenous variable; many researchers have followed his lead.

A more recent approach is based on the hypothesis of rational expectations (see, e.g., Shonkwiler and Emerson, Shonkwiler and Maddala, and Holt and Johnson). The starting point in this approach is a structural model that includes a supply equation containing expected price. Let P_t^e equal expected price. According to Holt and Johnson (p. 606), "In linear rational expectation models, the restricted reduced form of the structural system is solved for in terms of expected price and then substituted for P_t^e in the supply equation." This involves finding the reduced form for price (treating, momentarily, the expected price as exogenous), taking the conditional expectation of both sides of this reduced form, and then equating the mathematical expectation of price with P_t^e. Fair and Taylor suggest an algorithm for solving and estimating nonlinear rational expectations models. A central contention of the literature on rational expectations is that expected price is an endogenous variable (Sheffrin). This raises important questions in regard to Gardner's suggested use of the futures price. If the futures price is an appropriate proxy for expected price, then

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why should it be supposed that the futures price is exogenous? Does treating the futures price as exogenous in the estimation of farm supply (acreage response) equations give rise to simultaneous equations bias?

This article explores an approach to the estimation of acreage response in which acreage planted and the futures price for next year's crop are treated as jointly dependent variables. The theoretical basis for the empirical analysis comes from a recent model of pricing and storage in which acreage response is but one of several behavioral relations. In addition to planted acreage and expected price, other endogenous variables include current price, consumption, and ending inventory. A key feature of our empirical analysis is the estimation of an expected price function using econometrics instead of the numerical methods proposed by Lowry et al. and Miranda and Helmberger. The simultaneity of current and futures prices, emphasized by Working, is brought into sharp relief. The resulting estimates appear to be plausible and the estimated system, though simple, tracks history rather well. Although storage theory holds that acreage planted and the expected price are jointly determined, our empirical results suggest otherwise. The results also suggest that econometrics might be a good substitute for the numerical methods that have been used recently to estimate expected price functions.

Theoretical Considerations

The theoretical model that guides our econometric analysis is taken from the quarterly model of soybean pricing and storage set forth by Lowry et al. Our interest centers on their model of the third quarter (March, April, and May), when acreage planting decisions are made. A somewhat modified version of this model is as follows:

(1) $D_{t3} = D(P_{t3}, X_{t3})$ demand for crush plus exports,
(2) $A_{t3} = A[E_{t3}(P_{t+1,1}), Z_{t3}]$ acreage supply function,
(3) $E_{t3}(P_{t+1,1}) = g(I_{t3}, A_{t3}, W_{t3})$ expected price function,
(4) $E_{t3}(P_{t4}) = f(I_{t3}, A_{t3}, W_{t3})$ expected price function,
(5) $E_{t3}(P_{t4}) = (P_{t3} + K_{t3})(1 + i_{t3})$ arbitrage condition,
(6) $C_{t3} = a + bA_{t3}$ seed use,

and

(7) $D_{t3} + I_{t3} + C_{t3} = I_{t2}$ market clearing condition.

The variables D, P, A, and I equal, respectively, consumption, farm-level price, acreage planted, and inventory; E is the expectation operator. The subscript ti indicates quarter i of year t. The variables or vectors X, Z, and W are exogenous shifters. Examples include exchange rates and the price of fertilizer, with W equaling the expected values of these demand and supply shifters for future periods. The per unit storage cost, rate of interest, and soybeans used for seed are given by K, i, and C. The aggregate demand for soybeans for both domestic consumption and exports and the acreage response function are conventional formulations and require no elaboration. The arbitrage condition given by equation (5) assumes that keen competition in the storage industry drives expected profits to zero where industry profit equals $(P_{t4} - P_{t3} - iP_{t3} - K - iK)I_{t3}$. Storers may be assumed to be risk-neutral or, alternatively, to have access to a futures market that allows the avoidance of risk through hedging. For simplicity, the model assumes that the marginal cost of operating or renting bin space, K, is constant.

The article by Lowry et al. provides, along with references to the more technical literature, an intuitive explanation of the derivation of the expected price functions on the basis of rational expectations. Worth emphasizing is the need for two expected price functions, one for the price expected in the fourth quarter, $E_{t3}(P_{t4})$, and the other for the price expected to prevail at harvest time, $E_{t3}(P_{t+1,1})$. The first is required for the proper modeling of storage for fourth-quarter consumption and the eventual carryout of old crop, if any; the second is required in order to explain acreage planted.

Using the arbitrage condition allows elimination of $E_{t3}(P_{t4})$ from the system. Current price becomes the left-hand side of equation (4), which may then be viewed as the demand for stocks. This possibility establishes the close linkage between an expected price function and the demand for stocks.

Expected price functions play a crucial role in models of pricing and storage, as in the model given above, and in empirical applications, these functions have been estimated using numerical methods. Although such methods have much to commend them, three limitations make the search for an alternative worthwhile. First, computational cost rises rapidly with the number of endogenous variables entering the function(s) and soon becomes prohibitive. Second, numerical methods are difficult to apply in other than a time-stationary setting. Finally, expected price functions and other behavioral relationships should be estimated simultaneously in order to avoid biased estimates of structural parameters. In short, there are good reasons for exploring econometrics as an alternative to numerical methods in the estimation of expected price functions.

Fashioning an econometric model that captures the essence of a theoretical model, equations (1)–(7) in the present case, involves subjective judgments on how best to proceed. Some of the problems that arise in this regard are addressed briefly here. First, there is the question of a suitable measure of price expectations. In what follows, we adopt Gardner's suggestion of using the price of futures for the next year's crop as a proxy for the expected price at planting time. The efficient market hypothesis, that an efficient futures market should provide an unbiased estimate of the actual price at contract maturity, has been tested repeatedly with mixed results (see Tomek and Gray; Just and Rausser; Martin and Garcia; and Eales et al.). This is not the place to attempt to resolve the basic issues. We do note, however, that those who argue econometric or ARIMA models can be constructed that are more efficient than futures markets face an uphill battle since futures markets will surely take advantage of superior models as they are developed.

Second, there are intractable issues arising out of government programs that idle acres, constrain acreages planted to program crops, and support market prices through commodity storage and disposal. These issues have been considered elsewhere by many writers, including Houck et al., Lee and Helmberger, and Burt and Worthington. Since our interest is centered on the endogeneity of price expectations, we analyze the soybean market both in order to minimize complications caused by farm programs and because soybeans is the most important nonprogram crop.

Third, hypothesizing that price of harvest futures, planted acreage, and other variables are interdependent calls attention to interdependence among crops, a phenomenon recently emphasized by Chavas and Holt. To cope with this problem, consider a generalization of the model specified in equations (1)–(7) that would allow for two crops, soybeans and all "other crops" taken together. A partially reduced form model that excludes all endogenous other crop variables would contain a residue of exogenous variables one might not expect to find in a soybean model. Importantly, and in contrast to several previous studies, the futures price of corn would not be included in the acreage response function for soybeans. More on this later.

A final problem concerns the expectations of exogenous demand and supply shifters for future periods that appear in expected price functions. Since the model given by equations (1)–(7) contains no structural information on how the values of exogenous variables are determined, first-order autoregressive processes are assumed for most exogenous variables. This procedure is similar to that used by Shonkwiler and Emerson, and Holt and Johnson.

The Econometric Model

The estimated structural parameters for a third-quarter model of the U.S. soybean market are given in table 1. The variables are defined in table 2. All quantity variables except acreage and soybean seed are expressed on a per capita basis. The variables without

Table 1. Estimated Structural Parameters for a Third-Quarter Model of the U.S. Soybean Market, Based on Time Series for 1961–88

Variate	OLS	3SLS
	(8) Demand for Consumption: Q_{t3}	
CON1*	+1.932	+3.444
	(2.419)	(4.104)
P_{t3}	−.040	−.145
	(1.412)	(4.389)
ES	−.013	−.016
	(3.357)	(4.151)
XF	−11.337	−24.743
	(.878)	(2.022)
RPI	+.131	+.069
	(2.704)	(1.398)
R^2	.869	.781
	(9) Demand for Storage: P_{t3}	
CON2	+15.670	+17.981
	(3.472)	(5.482)
I_{t3}	−1.621	−1.418
	(3.809)	(4.754)
A_{t3}	−.029	−.074
	(.757)	(2.860)
ES	−.063	−.057
	(5.951)	(3.394)
XF	+15.296	−66.332
	(.182)	(1.119)
RPI	+.158	+.786
	(.330)	(2.300)
LYS	−.226	−.237
	(1.199)	(1.994)
R_{t3}	−.183	−.143
	(1.161)	(2.111)
R^2	.718	.593
	(10) Expected Price Function: F_{t3}	
CON3	+19.170	+19.404
	(8.486)	(11.635)
I_{t3}	−.918	−.800
	(4.675)	(5.383)
A_{t3}	−.013	−.055
	(.636)	(4.049)
ES	−.063	−.067
	(5.951)	(8.170)
XF	−.284	−43.604
	(.008)	(1.552)
RPI	−.039	+.201
	(.162)	(1.159)
LYS	−.192	−.172
	(2.016)	(2.771)
R^2	.833	.780
	(11) Acreage Response: A_{t3}	
CON4	−40.208	−34.969
	(2.185)	(2.290)
F_{t3}	+2.329	+2.014
	(3.492)	(3.209)
TA	+.133	+.120
	(3.757)	(4.203)
D	−8.022	−7.153
	(5.825)	(6.352)
EC	−.128	−.117
	(1.886)	(2.078)

Table 1. Continued

Variate	OLS	3 SLS
RPI	+1.740	+1.563
	(1.998)	(2.180)
$A_{t-1,3}$	+.633	+.660
	(6.341)	(8.097)
R^2	.983	.982
	(12) Seed Use: C_{t3}	
CON5	+13.740	+14.634
	(7.490)	(8.108)
A_{t3}	+.771	+.759
	(22.348)	(22.777)
R^2	.950	.950

* CON_i is a constant term, $i = 1, 2, 3, 4$, and 5.
Notes: Numbers in parentheses are asymptotic t-ratios. R^2 is the coefficient of multiple determination.

subscripts are annual averages, in most instances lagged one year. The model was estimated using time series for 1961–88 and three-stage least squares (3SLS); asymptotic t-ratios are given in parentheses. For comparative analysis, all parameters also were estimated using ordinary least squares (OLS). Each of the equations given in table 1 will be discussed in turn except for the seed equation, which requires no comment. The discussion centers on 3SLS estimates unless specifically stated otherwise.

The first equation in table 1, equation (8), is the third-quarter demand for soybeans for consumption. The estimated elasticity of consumption Q_{t3} with respect to current price P_{t3}, evaluated at the means, equals $-.5$. This estimate is consistent with those of previous researchers (Houck, Ryan, and Subotnik; Lowry et al.). The signs of the coefficients for the lagged exchange rate for soybeans *ES* and lagged rest-of-world exports of fishmeal *XF* are negative, as expected. The sign of the coefficient for real per capita income *RPI* is consistent with expectations but the standard error is relatively large. Turning to the OLS estimates, we note that the estimated coefficient for price P_{t3} is small relative both to its standard error and to its 3SLS counterpart.

The demand for third-quarter ending stocks is given by equation (9), table 1. The theoretical foundation for this equation consists of equations (4) and (5) as noted above. Both ending stocks I_{t3} and planted acreage A_{t3} are negatively related to current price. (According to the OLS estimates, increased acreage planted decreases the demand for third-quarter stocks, but the effect is small and statistically insignificant.) The estimated elasticity of the demand for stocks with respect to price equals -1.8. Elastic stock demand is consistent with recent research on storage. For example, using numerical analysis, Glauber et al. estimated that the elasticity of the third-quarter demand for soybean stocks equaled -1.3. The elasticity of the total third-quarter demand for soybeans, estimated as a weighted average of the elasticities for consumption, stocks, and seed (with the latter equaling zero) equals -1.2. Inelastic demand is often claimed to be the cause of price and market instability (see, e.g., Cochrane). The above results, together with those of Lowry et al., Glauber et al., and Wright and Williams, point to the crucial role of stockholding as a source of demand elasticity and market stability, phenomena that, we believe, have received inadequate attention in agricultural economics research.

The exchange rate, rest-of-world exports of fishmeal, and real per capita income, all lagged, are inserted in this equation as proxies for the expected values of these demand shifters for future years. All estimated coefficients have the correct signs, but the fishmeal coefficient is insignificant. A three-year moving average of past soybean yields *LYS* is included as a proxy for future technological change. The real rate of quarterly interest exerts a negative and significant effect on the demand for stocks, as expected.

Equation (10) is the futures price function corresponding to equation (3) of the theoretical

Table 2. List of Variables

Variables		Description
Endogenous Variables:		
Q_{t3}	=	Total soybean consumption for the third quarter, i.e., total disappearance minus seed, million bushels.
P_{t3}	=	Soybean farm price for the third quarter deflated by the index of prices paid by farmers, dollars per bushel.
I_{t3}	=	Soybean stocks at June 1, million bushels.
A_{t3}	=	U.S. acreage planted to soybeans, million acres.
F_{t3}	=	Futures price of soybeans, average price of the 15th and the last day (or nearest market day) of March, April, and May for November delivery, deflated by the index of prices paid by farmers, dollars per bushel.
S	=	Soybeans used for seed, million bushels.
Predetermined Variables:		
ES*	=	Exchange rate weighted by exports to foreign soybean markets.
XF*	=	Fishmeal exports by the rest-of-world, million metric tons.
RPI*	=	Per capita disposable personal income deflated by GNP deflator.
LYS	=	Lagged three-year moving average of soybean yields, bushels per acre.
R_{t3}	=	Quarterly PCA loan rate adjusted by the index of prices paid by farmers, percent.
TA	=	Total acreage planted to major crops, million acres.
D	=	A dummy variable representing corn diversion programs, 0 for corn program years and 1 for "free" market years.
EC*	=	Exchange rate weighted by exports to foreign corn markets.
LAS	=	Lagged U.S. acreage planted to soybeans, million acres.

* Annual data for previous calendar year.
Note: The data set with sources is available upon request from the junior author.

model. The elasticities of the harvest futures price F_{t3} with respect to I_{t3} and AS are, respectively, $-.3$ and $-.5$. Further, the futures price falls, *ceteris paribus,* with (*a*) the strengthening of the dollar, (*b*) increased foreign exports of fishmeal, and (*c*) increased soybean yields. These results, together with those discussed above in connection with equation (9), lend support to rational expectations in that the futures price appears to depend on what speculators think the future demand and supply conditions will be. According to the OLS estimates, increased acreage planted lowers the price of harvest futures F_{t3} but, in contrast to the 3SLS estimates, the effect is small and insignificant.

The acreage response function is given by equation (11), table 1. The 3SLS and OLS estimates are virtually identical. This suggests that the standard procedure of treating the price of harvest futures as an exogenous variable in acreage response studies does not risk serious simultaneous equations bias. Further work on this issue might, of course, lead to a different conclusion. In any event, the similarity of OLS and 3SLS results invites a statistical test for simultaneity between acreage planted and the futures price. The reduced form equation for the futures price, with the futures price expressed as a function of all exogenous variables, was first estimated using OLS.[1] The residual between the actual futures price and the OLS estimate from the estimated reduced form equation was then added as an explanatory variable in the acreage response equation, which was then estimated using OLS. The t-ratio for the estimated coefficient for the futures price residual, which is the appropriate test statistic, was .072 with 20 degrees of freedom. Clearly, the results of this test do not support the claim of simultaneity.

Returning to the 3SLS estimates in table 1, we note that the short-run elasticity of A_{t3} with respect to F_{t3} equals .2. This estimate may seem low relative to those of Chavas and Holt (.44) and Gardner (.45–.61), but it must be emphasized that our estimate is based on a formulation that does not hold constant the expected prices of corn and other crops. Lagged soybean acreage *LAS* is included on Nerlove's partial adjustment hypothesis. Its t-ratio equals 8.1, and its estimated coefficient yields a long-run elasticity of acreage response equal to .59.

Total acreage planted to principle crops A is included to take account of government intervention in agriculture since variation in A reflects mainly the extent of acres idled under farm programs for feedgrains, wheat, cotton, and rice. The dummy variable D equals one during "free" market years and zero during years when corn acreage controls (allotments) are in effect. The effect of government programs on soybean acreage and futures prices will be taken up later in a simulation analysis.

The elimination of the expected prices of other crops, most notably corn, from the structural model explains why the weighted exchange rate for corn *EC* and real per capita income *RPI* were included as exogenous variables in the acreage response function. Instead of including expected prices of other crops, we included exogenous variables that affect those expectations. Because the reduced form parameters for *EC* and *RPI* represent complex combinations of structural parameters, the a priori signs of their estimated coefficients are not apparent. Both are significant, however, at the 1% level using two-tailed t-tests.[2]

In terms of consistency with theory and levels of statistical significance, 3SLS appears to outperform OLS by a considerable margin. The signs of the 3SLS estimated coefficients for all endogenous variables are in accord with a priori expectations and the associated asymptotic t-ratios equal or exceed 2.9. In contrast, and excluding the seed equation, three out of the seven coefficients for endogenous variables estimated using OLS have t-ratios less than 1.5. The signs of the 3SLS estimated coefficients for exogenous and predetermined variables also are consistent with a priori expectations in those instances where the expectations are themselves not ambiguous. Only four of the 17 estimates for exogenous variables have t-ratios less than 2.0.

The question remains, however, whether the model as a whole is a plausible quantitative representation of the third-quarter market for soybeans. In order to address this question further, the 3SLS estimates were used to simulate dynamically the performance of the market over the sample period using the actual values of all exogenous variables. Actual acreage planted in 1960 is used as a start-up variable, but the subsequent lagged acreages are simulated values. The actual and the simulated values for the price of the harvest futures are shown in figure 1. Except for the tumultuous years following the Russian grain deal (1973–77), the model appears to track the market for futures quite closely. Of the 27 year-to-year changes in the price of futures, 13 changes were negative and the remaining 14 were positive. The model correctly simulated the signs of the year-to-year changes in 24 cases. The mean absolute percentage error for the simulated harvest futures price is 6.6%. The corresponding figures are: for current price, 12.1%; planted soybean acreage, 4.5%; consumption, 5.8%; end-of-May stocks, 5.3%; and seed, 6.5%.

The OLS estimates also were used in a dynamic simulation of the performance of the soybean market over the sample period. The mean absolute percentage errors are: for the harvest futures price, 8%; current price, 13.8%; planted soybean acreage, 4.4%; consumption, 6.8%; end-of-May stocks, 5.3%; and seed, 6.0%. Comparing these figures with those given in the previous paragraph for the 3SLS estimates supports the conclusion, we believe, that the 3SLS estimates outperform those based on OLS. However, both sets of estimates track the history of planted soybean acreage equally well.

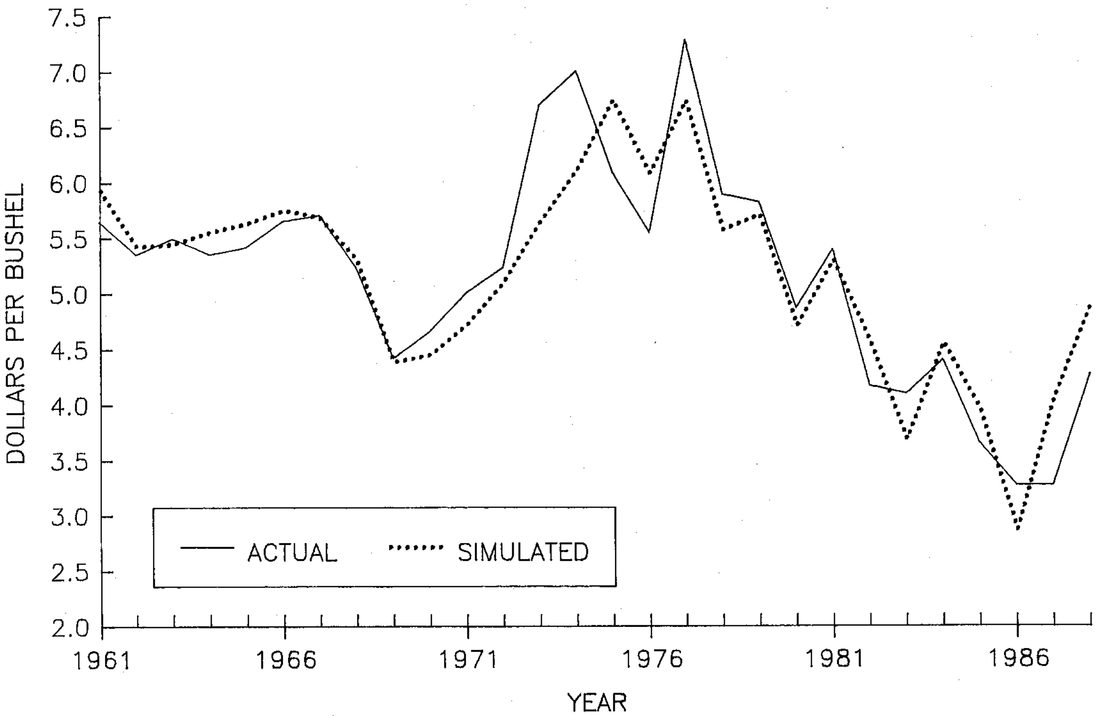

Figure 1. The price of harvest futures for soybeans

Experiments with the Model

Two simulation experiments are reported that shed new light on the quantitative effects of farm programs and of changes in the exchange rate on the performance of the soybean market. An important question is how land diversion programs affect prices of and acres planted to nonprogram crops. Of the nonprogram crops, soybeans is easily the most important both in terms of sales value and acreage planted.

To assess the effects of farm programs on the soybean market, we use the 3SLS estimates to simulate performance of the market under 1988 economic conditions with and without farm programs. In order to simulate the market in the absence of government intervention, the acreage planted to principal crops in 1988 is increased by 54.2 million acres, the acres idled under farm programs. In addition, D is changed from zero to one. All exogenous variables are held constant at their 1988 values.

Based on 3SLS estimates, the steady-state (long-run) soybean acreage equals 66.4 million acres with farm programs and 64.9 million acres without farm programs. The corresponding estimates for the third-quarter real price are \$5.13, and \$5.21 with and without programs, respectively. These estimates indicate that the 1988 land diversion program in the long run would have increased soybean acreage by 2.3% above the competitive level; price would have been lower by 1.5%.

A plausible explanation for these results is as follows: Farm programs that simply idle land likely decrease acreages planted to all crops. Farm programs that use acreage allotments, i.e., that impose upward limits on acreages planted, likely shift acres from program to nonprogram crops. Our findings suggest that in the case of the most important of the nonprogram crops, soybeans, the negative idled acre effect is more than offset by the positive allotment effect. Importantly, however, the net effect on soybean acreage, although positive, is rather small.

Turning to exchange rates, we note that with the increased importance of farm exports following the 1972 Russian grain deal, the strength of the dollar has become an important shifter of the demands for crops. To assess the effect of changes in exchange rates, we use the 3SLS estimates model to simulate the long-run performance of the soybean market under 1988 conditions, with farm programs in place, and assuming a *ceteris paribus* 10% increase in the weighted exchange rates for both soybeans and corn. The results of this simulation are then compared with the baseline simulation with exchange rates held at their 1988 values. We find that the strengthening of the dollar, as specified, causes the steady-state third-quarter real farm price to fall from \$5.13 per bushel to \$4.91 per bushel, a 4.3% decline. Steady-state soybean acreage declines by 6.9%, from 66.4 to 61.8 million acres. Since total acres planted to principal crops is held constant, a decrease in soybean acreage suggests increases in the production of other crops, but the increase for any one competing crop likely would be modest.

Summary

Recent developments in the theory of storage clearly suggest that acreage planted and the price expected to prevail at the time of harvest should be viewed as jointly dependent variables. In order to explore this issue empirically, we estimated an econometric model that contained several behavioral relationships including an acreage response function for soybeans and an expected price function that heretofore has been estimated using numerical methods.

Little empirical support was found for the view that in estimating acreage response functions, the expected price, as measured by the futures price, should be viewed as an endogenous rather than an exogenous variable. Ordinary and three-stage least squares estimates of the acreage response function were essentially the same.

Including an expected price (futures price) function in the econometric model of the market for soybeans along with the demands for consumption and stocks appears to have been successful both in terms of generating estimates of important elasticities and in tracking the history of market performance over the sample period. Simulation experiments were reported that show the usefulness of the model in examining the effects of exogenous shocks. These experiments indicate that the land idling programs of 1988 had a long-run tendency to increase acreage planted to soybeans, but the effect was rather small, in the order of 2 to 3% of the competitive level. Another experiment indicated that under the economic conditions of 1988, a 10% increase in the exchange rates for both soybeans and corn decreases the price of soybeans by 4.3% in the long run.

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Notes

[1] We are indebted to the editor, Jeffrey LaFrance, for suggesting this test.

[2] To take risk behavior into consideration, the lagged three-year moving average of the variance of the difference between the futures price and the subsequent cash price of soybeans was included in the acreage equation. The corresponding variance for corn and the covariance for corn and soybeans were also included. According to the Wald chi-square test statistic, the joint null hypothesis that all coefficients of the variances and covariance are zero was accepted.

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