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RISK BEHAVIOR AND RATIONAL EXPECTATIONS IN THE U.S. BROILER MARKET

Satheesh V. Aradhyula and Matthew T. Holt

I. Introduction

The production of most agricultural commodities occurs in an environment which is unique from that of any other industry. The presence of time lags in the production process implies that firms make their decisions on the basis of expected or anticipated prices. Similarly, the demands for many agricultural products are highly inelastic, suggesting that prices can be extremely volatile. The random influences of weather, export markets, government policy, and other institutional and environmental factors also adds a further dimension of uncertainty to most agricultural markets.

These unique aspects of agricultural markets have led to a number of important theoretical and empirical developments. For instance, agricultural economists have made significant contributions to the price expectations literature. Important examples include Ezekiel's cobweb model and the adaptive expectations hypothesis, first considered in an agricultural context by Nerlove. Although both models are based on the simple premise that expectations are extrapolative--i.e., conditioned only on past prices--their operational simplicity and optimal prediction properties have led to wide professional acceptance (Askari and Cummings).

More recently, attention has begun to focus on the implications of Muth's Rational Expectations Hypothesis (REH) for supply modeling. The fundamental assumption underlying the REH is that agents make informed predictions about the future. That is, expectations are formed in a manner which is consistent with the underlying market structure. The theoretical appeal of the REH is that it provides a consistent framework for reconciling the subjective expectations formed by agents with observed market phenomena. Recent applications of the REH in supply estimation include Goodwin and Sheffrin, Shonkwiler and Emerson, and Shonkwiler and Maddala.

Another area where important gains have been made is with respect to the effects of uncertainty on production decisions. Numerous studies, including those by Binswanger, and Moscardi and de Janvry, have established that agricultural producers exhibit a distaste for risk. Recognizing this, Behrman, Just, Traill, Hurt and Garcia, and others have examined the implications of price and yield uncertainty in aggregate models of crop and livestock supply response. In all instances, risk was found to be an important explanatory variable. These studies are, however, limited in that uncertainty is viewed as a passive process. In other words, the models considered by these authors treat risk as a moving weighted average of past deviations between observed prices and their respective expectations. Although this approach is consistent with the distributed lag mechanism frequently used to estimate expected price, it unfortunately ignores currently available information which could be used by agents to determine subjective variance estimates.

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Only now are attempts being made to examine the linkages between the Rational Expectations Hypothesis and uncertainty theory. The theoretical foundations necessary for combining these theories have been considered by Newberry and Stiglitz (1979, 1981), Wright and Williams, and Choi and Johnson. The basic concept is that in the presence of uncertainty, producers must form rational expectations with respect to all moments of the equilibrium price distribution. Although the theory of rational expectations in the presence of uncertainty is emerging, there have only been a few attempts to empirically implement and test such models (e.g., Antonovitz and Roe, Antonovitz and Green).

The objective of this paper then is to examine the empirical implications of extending the REH to include higher-order moments of price in aggregate supply response relationships. The approach used generalizes the REH to include risk in the supply component of a quarterly model of the U.S. broiler industry. The broiler market seems to be a particularly promising area for isolating the effects of price risk on production decisions since output uncertainty is typically negligible (Lasley). Previous studies have also found that broiler producers behave in a manner which is consistent with the rationality hypothesis (e.g., Goodwin and Sheffrin, Huntzinger).

Broiler supply is specified as a function of expected price, expected variance of price, and other relevant exogenous variables. The model is then solved in the rational expectations framework for the mean and variance of the equilibrium price distribution. The rational predictors for the first and second moments of price are functions of the expected mean and variance of exogenous variables, as well as model disturbance terms. Although Antonovitz and Green used a similar approach to estimate supply response in the fed beef market, they ignored the disturbance terms associated with the structural equations, thus omitting a potentially important source of uncertainty.

The paper is organized as follows. Section II presents the model and discusses the issues involved in an econometric implementation of the REH in an uncertainty framework for the U.S. broiler industry. Econometric estimates of the time series and structural models is the focus of section III, along with discussion of the results. A test of the REH is the subject of section IV followed by several concluding comments and observations in section V.

II. Model Specification

We consider a standard supply and demand model for the U.S. broiler market. The model consists of two behavioral equations and a closing identity. The behavioral equations explain the demand for and supply of broilers in a competitive framework. All price and income variables included in the behavioral equations are deflated by the consumer price index.

The supply function of broilers is specified as

$$\begin{aligned} QBP_t = & a_1 D_{1t} + a_2 D_{2t} + a_3 D_{3t} + a_4 D_{4t} + a_5 PBF_{t-1} + a_6 QBP_{t-4} \\ & + a_7 WPB_t^e + a_8 WPB_t^v + u_{1t} \end{aligned} \quad (1)$$

where

QBP_t = broiler production in period t , billion pounds,
 D_{jt} = seasonal dummy variable for j^{th} quarter $j = 1, 2, 3, 4$
 PBF_{t-1} = price of broiler feed in period $t-1$, dollars per cwt
 WPB_t^e = the expected wholesale price of broilers in time t , viewed from $t-1$, dollars per cwt, and
 WPB_t^v = the anticipated variance of wholesale price of broilers in time t , viewed from $t-1$.
 u_{1t} is normally distributed with $E(u_{1t}) = 0 \forall t$ and $E(u_{1t}^2) = \sigma_{11} \forall t$.

The biological production lag for broilers is approximately two months (eight weeks), suggesting that current-quarter production is conditioned on the expectations formed by producers in the previous quarter. The decision to produce broilers is, of course, made under uncertainty. Assuming that broiler producers exhibit risk-averse behavior, it is necessary to consider moments of the probability distribution of price other than the mean. In the present case, the variance of price is hypothesized to influence production decisions. Ignoring the potential effects of third and higher-order moments implies that producers behave in a manner consistent with the E-V framework. However, the additional complexities added by considering these other moments would unduly burden the model. Although the model is specified in a manner consistent with E-V framework, this is still a considerable generalization over considering the mean alone in a rational expectations framework.

The only input price we included is the price of feed, which is a weighted average of the prices of corn and soymeal. In this high-variable cost industry, feed accounts for nearly 74 percent of all production costs, while another 16 percent is accounted for by baby chicks (Benson and Witzig). Baby chick production, in turn, is largely determined by feed costs. So the feed price coefficient should capture most of the short-run costs associated with broiler production.

Finally, broiler producers may not be able to fully adjust production to a desirable level in any given quarter. This could be due to capacity constraints, adjustment costs, or mistakes in decision making. To account for these factors, a lagged dependent variable was included in the supply specification. As Kennan has shown, the partial adjustment framework in a rational expectations model is consistent with the notion that agents possess a quadratic loss function which includes both disequilibrium and adjustment costs. On the basis of previous research (Chavas and Johnson), a four-quarter lag was considered for the dependent variable. This is compatible with the assumption that broiler producers adjust production capacity and make capital investments on an annual basis.

The demand for broilers is assumed to depend on their price, the price of substitutes, and personal disposable income. Also, demand has a seasonal pattern. We specify that

$$\begin{aligned} WPB_t = & b_1 D_{1t} + b_2 D_{2t} + b_3 D_{3t} + b_4 D_{4t} + b_5 QBD_t + b_6 RPB_t \\ & + b_7 RPP_t + b_8 RPT_t + b_9 RDI_t + u_{2t} \end{aligned} \quad (2)$$

where

WPB_t = wholesale price of broilers, dollars per cwt,
 QBD_t = quantity of broilers consumed, ready to cook, bil. pounds,
 RPB_t = retail price of beef, dollars per cwt,
 RPP_t = retail price of pork, dollars per cwt,
 RPT_t = retail price of turkey, dollars per cwt, and
 RDI_t = real disposable personal income, dollars.
 u_{2t} is normally distributed with $E(u_{2t}) = 0 \forall t$, $E(u_{2t}^2) = \sigma_{22}$ and
 $E(u_{1t}, u_{2t}) = \sigma_{12} \forall t$.

A few words are in order about the formulation of the demand function. Note that (2) does not represent a consumer demand curve; it is the derived demand of profit maximizing retailers and food processors. Profit maximization compels demanders to be cognizant of the factors affecting consumer demand for broilers (Goodwin and Sheffrin). Previous studies have established that beef, pork, and turkey are substitutes in consumption for broilers, while demand for all meats are sensitive to income. Additionally, there is a seasonal pattern to consumer demand as reflected by the inclusion of quarterly slope shifters. The essential difference between this demand curve and consumer demand is that we have employed wholesale price for broilers. The coefficients should be interpreted accordingly. We choose to use wholesale price, rather than retail price, because earlier studies (e.g., Chavas) have shown that price determination in the broiler market takes place at the wholesale level. That is, wholesale prices tend to lead retail prices. This may be a result of vertical integration and the concentration of power at the wholesale level (Chavas).

Finally, the model is closed with the following identity:

$$QBP_t = QBD_t + QOD_t \quad (3)$$

where QOD represents other demand for broiler meat. This includes net export demand and net stock demand. Since these are a small part of the market, they are left exogenous in the model.

The model, as given by equations (1)-(3), can not be estimated directly since data on producers' subjective expectations of mean (WPB_t^e) and variance (WPB_t^v) of broiler price are not available. The REH may be used to endogenously determine expressions for these two variables. In its most general form, the rational expectations interpretation of expected price, WPB_t^e , is the mathematical expectation of WPB_t conditioned on the information

available at the time the expectation was formed. That is, $WPB_t^e = E_{t-1}(WPB_t | \Omega_{t-1})$ where Ω_{t-1} is the information set available at time $t-1$. The rational expectations interpretation of price variance is defined analogously. In particular, $WPB_t^v = VAR_{t-1}(WPB_t | \Omega_{t-1})$ where VAR is the variance operator. In a structural econometric model, the information set Ω_{t-1} consists of the model's predetermined variables and the reduced-form parameters (Wallis). In the present case, Ω_{t-1} is expanded to include information pertaining to the forecast errors of exogenous variables as well as the error process associated with the structural econometric model.

The price and variance predictors are now obtained by solving the model presented in equations (1) through (3) and for the reduced-form of price. Substituting equations (1) and (3) into (2) gives:

$$\begin{aligned} WPB_t = & \sum_{j=1}^4 b_j D_{jt} + b_5 \left\{ \sum_{j=1}^4 a_j D_{jt} + a_5 PBF_{t-1} + a_6 QBP_{t-4} \right. \\ & + a_7 WPB_t^e + a_8 WPB_t^v + u_{1t} - QOD_t \left. \right\} + b_6 RPB_t + b_7 RPP_t \\ & + b_8 RPT_t + b_9 RDI_t + u_{2t}. \end{aligned} \quad (4)$$

Taking conditional expectation (E_{t-1}) of both sides of equation (4), and recognizing that REH implies $E_{t-1}(WPB_t) = WPB_t^e$, yields:

$$\begin{aligned} WPB_t^e = & \sum_{j=1}^4 b_j D_{jt} + b_5 \left\{ \sum_{j=1}^4 a_j D_{jt} + a_5 PBF_{t-1} + a_6 QBP_{t-1} \right. \\ & + a_7 WPB_t^e + a_8 WPB_t^v - QOD_t^e \left. \right\} + b_6 RPB_t^e + b_7 RPP_t^e + b_8 RPT_t^e \\ & + b_9 RDI_t^e. \end{aligned} \quad (5)$$

We assume the seasonal components are known with certainty; i.e., $D_{jt}^e = D_{jt}$ for all j . Note that among other things, the rational predictor for price is a function of the the variance term WPB_t^v .

To find the rational expectation of the variance of broiler price, subtract equation (5) from (4) to get:

$$\begin{aligned} WPB_t - WPB_t^e = & b_5 \{ u_{1t} - (QOD_t - QOD_t^e) \} + b_6 (RPB_t - RPB_t^e) \\ & + b_7 (RPP_t - RPP_t^e) + b_8 (RPT_t - RPT_t^e) \\ & + b_9 (RDI_t - RDI_t^e) + u_{2t}. \end{aligned} \quad (6)$$

Squaring and taking the conditional expectations (E_{t-1}) of both sides of equation (6) and again, recognizing that the REH implies $E(WPB_t - WPB_t^e)^2 = WPB_t^v$, gives:

$$\begin{aligned} WPB_t^v = & b_5^2 \sigma_{11} + b_5^2 QOD_t^v + b_6^2 RPB_t^v + b_7^2 RPP_t^v + b_8^2 RPT_t^v + b_9^2 RDI_t^v \\ & + \sigma_{22} + 2b_5 \sigma_{12}. \end{aligned} \quad (7)$$

Equation (7) is the reduced-form for the rational expectation of price variance. Importantly, the expectation of variance is a function of the variance of the model's exogenous variables, denoted by a superscript v , and the structural parameters, including the variance and covariance terms associated with the structural equations. We assume the expectations of exogenous variables are generated by independent stochastic processes. Thus, the covariance among the exogenous variables are zero.

Substituting the expression for the rational expectation of variance in (7) into (5) yields the reduced-form rational predictor for the mean of wholesale broiler price. That is,

$$\begin{aligned} WPB_t^e = & \sum_{j=1}^4 b_j D_{jt} + b_5 \left\{ \sum_{j=1}^4 a_j D_{jt} + a_5 PBF_{t-1} + a_6 QBP_{t-4} \right. \\ & + a_8 (b_t^2 \sigma_{11} + b_5^2 QOD_t^v + b_6^2 RPB_t^v + b_7^2 RPP_t^v + b_9^2 RDI_t^v + \sigma_{22} \\ & + 2b_5 \sigma_{12}) - QOD_t^e \} + b_6 RPB_t^e + b_7 RPP_t^e + b_8 RPT_t^e \\ & \left. + b_9 RDI_t^e \right\} / (1 - b_5 a_5). \end{aligned} \quad (8)$$

Equations (8) and (7) are expressions for rational predictors of the mean and variance of wholesale broiler price, respectively. In particular, note that the expected price in (8) depends on predetermined exogenous variables, the expected values of current exogenous variables, the forecast variance of current exogenous variables, and the variance-covariance terms associated with equations (1) and (2). In addition, information is processed in a manner consistent with the REH as indicated by the fact that WPB_t^e is a function of the structural model's parameters. Substituting these expressions into the equation (1) gives the following estimable form of the supply equation:

$$\begin{aligned} QBP_t = & \sum_{j=1}^4 a_j D_{jt} + a_5 PBF_t + a_6 QBP_{t-4} + a_7 \sum_{j=1}^4 b_j D_{jt} \\ & + b_5 \left\{ \sum_{j=1}^4 a_j D_{jt} + a_5 PBF_t^e + a_6 QBP_{t-4} + a_8 (b_5^2 QOD_t^v \right. \\ & + b_6^2 RPB_t^v + b_7^2 RPP_t^v + b_8^2 RPT_t^v + b_9^2 RDI_t^v + \sigma_{22} + 2b_5 \sigma_{12}) \\ & \left. - QOD_t^e \right\} + b_6 RPB_t^e + b_7 RPP_t^e + b_8 RPT_t^e + b_9 RDI_t^e \\ & (1 - b_5 a_5)^{-1} + a_8 (b_5^2 \sigma_{11} + b_5^2 QOD_t^v + b_6^2 RPB_t^v + b_7^2 RPP_t^v \\ & + b_8^2 RPT_t^v + b_9^2 RDI_t^v + \sigma_{22} + 2b_5 \sigma_{12}) + u_{1t}. \end{aligned} \quad (9)$$

By combining the coefficients of the common elements, equation (9) may be rearranged to obtain:

$$\begin{aligned}
 QBP_t = & \sum_{j=1}^4 \{a_j + (a_7b_j + a_7b_5a_j)/(1 - b_5a_5)\} D_{jt} \\
 & + \{a_6 + a_7b_5a_6/(1 - b_5a_5)\} QBP_{t-4} \\
 & + \{a_5 + a_7b_5a_5/(1 - b_5a_5)\} PBF_{t-1} + \{-a_7b_5/(1 - b_5a_5)\} QOD_t^e \\
 & + \{a_7b_6/(1 - b_5a_5)\} RBP_t^e + \{a_7b_7/(1 - b_5a_5)\} RPP_t^e \\
 & + \{a_7b_8/(1 - b_5a_5)\} RPT_t^e + \{a_7b_9/(1 - b_5a_5)\} RDI_t^e \\
 & + \{(a_7b_5a_8b_6^2)/(1 - b_5a_5) + a_8b_6^2\} RPB_t^v \\
 & + \{(a_7b_5a_8b_7^2)/(1 - b_5a_5) + a_8b_7^2\} RPP_t^v \\
 & + \{(a_7b_5a_8b_8^2)/(1 - b_5a_5) + a_8b_8^2\} RPT_t^v \\
 & + \{(a_7b_5a_8b_9^2)/(1 - b_5a_5) + a_8b_9^2\} RDI_t^v \\
 & + \{(a_7b_5^3a_8)/(1 - b_5a_5) + a_8b_5^2\} QOD_t^v \\
 & + \{(a_7b_5^3a_8)/(1 - b_5a_5) + a_8b_5^2\} \sigma_{11} \\
 & + \{(2a_7b_5^3a_8)/(1 - b_5a_5) + 2a_8b_5\} \sigma_{12} \\
 & + \{(a_7a_8)/(1 - b_5a_5) + a_8\} \sigma_{22} + u_{1t}.
 \end{aligned} \tag{10}$$

The rational expectations model as given by equations (10), (2), and (3) can now be estimated by using suitable instruments for the expected mean and variance of the exogenous variables.

Time series analysis is used to generate the expected means of exogenous variables. To obtain forecasts of the variances of exogenous variables, a simple three-period moving average of past deviations between observed values and their respective expectations was utilized. Thus our econometric procedure treats the means and the variances of exogenous variables as data; as if they are given to the producers by a forecasting service. In so doing, we forego some potential gains in efficiency that could be obtained by jointly estimating the structural equations and time series models used to forecast the means and variances of exogenous variables. However, joint estimation is computationally more burdensome and the resulting gains in efficiency were not considered to be worth the additional effort. The sample period extends over years 1967-1984.

III. Econometric Estimates of the Model

The econometric procedure first requires the forecasts of the exogenous variables. The ARIMA estimates along with the associated Box-Pierce "Q" statistics, appear in Table 1. These statistics indicate that the fitted models have a reasonable amount of explanatory power. These fitted time series models were then used to generate the optimal one-quarter-ahead forecasts needed for the estimation of the structural model. Variances of the exogenous variables are obtained by taking moving averages of the square of the three past quarters' deviations between observed values and their respective expectations. Additionally, some method is needed to estimate the variances and covariance terms σ_{11} , σ_{22} , and σ_{12} associated with structural equations (1) and (2). Several options are available, such as estimating the variance-covariance terms of the structural equations simultaneously with other model parameters by maximum likelihood estimation. This would also allow us to generalize the variance-covariance terms to be functions of other exogenous variables (i.e., a generalized heteroscedasticity framework). However, to reduce computational expense, a simpler procedure was used in the present study. The initial estimate of the covariance matrix was set equal to the identity matrix. A set of parameter estimates were then generated by estimating equations (2), (3), and (10) which incorporated all the cross-equation restrictions implied by the REH. The resulting estimate of the variance-covariance matrix was then computed and substituted into the full model for a second round of estimation. By using this iterative estimation method, we are able to incorporate information about the structural equation variance-covariance terms. This approach is conceptually less appealing than that of simultaneously estimating the structural parameters and equation variance-covariance terms by maximum likelihood procedures. However, it was felt that the present method represented a reasonable compromise between using the more complex procedure outlined above and simply ignoring the reduced-form variance terms, as has been the case in previous studies.

Under the REH, the system is highly nonlinear in the parameters, in addition to having a number of cross-equation restrictions. The model considered here also has more nonlinearities and restrictions than the typical rational expectations model because of the incorporation of the rational expectation of variance. Although limited information methods such as two-stage least squares could be used to estimate each equation, the appearance of cross-equation restrictions makes this approach undesirable. Under rational expectations, it is desirable to use a full information estimation procedure such as three-stage least squares or full information maximum likelihood (FIML). In the present case, the parameter estimates were obtained by FIML estimation. The assumption is that the disturbance terms in (1) and (2) follow a joint normal distribution.

The maximum likelihood parameter estimates of the rational expectations model are presented in Table 2. With the exception of turkey price and

Table 1. Time series models fitted for the exogenous variables

Price of Beef (R_{PB_t})

$$\begin{array}{ccccccc} (1 + 0.034B - 0.736B^2) & \text{RPB}_t & = & 0.889 + & (1 + 0.999B + 0.177B^3) & \epsilon_{1t} \\ (0.238) & (0.222) & & (0.032) & (0.255) & (0.134) \end{array}$$

$$Q = 11.58 \quad \chi^2_{.05}(13) = 22.36$$

Price of Pork (RPP_t)

$$\begin{matrix} (1 - 0.146B^4 + 0.525B^5) & \nabla RPP_t = & (1 - 0.210B^3) & \varepsilon_{2t} \\ (0.101) & & (0.099) & \\ & & (0.118) & \end{matrix}$$

$$Q = 22.62 \quad \chi^2_{.05}(15) = 25.00$$

Price of Turkey (RPT_t)

$$\begin{matrix} (1 - 0.584B - 0.247B^2) & \text{RPT}_t = 0.417 + (1 + 0.787B + 0.547B^3) & \epsilon_{3t} \\ (0.227) & (0.220) & (0.031) \quad (0.197) \quad (0.108) \end{matrix}$$

$$Q = 8.50 \quad \chi^2_{.05}(13) = 22.36$$

Personal Income (RDI_t)

$$\frac{(1 - 0.815B)}{(0.218)} \nabla RDI_t = \frac{(1 - 0.643B)}{(0.282)} \epsilon_{4t}$$

$$Q = 18.06 \quad \chi^2_{.05}(16) = 26.30$$

Broiler, Other Demand (QOD_t)

$$\frac{(1 + 0.906B)}{(0.137)} QOD_t = \frac{(1 + 0.785B)}{(0.197)} \varepsilon_{5t}$$

$$Q = 6.52 \quad \chi^2_{.05}(16) = 26.30$$

Notes: B is the lag operator, $B^s X_t = X_{t-s}$ and $\nabla = 1 - B$. Figures in parentheses are approximate standard errors.

Table 2. FIML estimates of the structural model

$$\begin{aligned}
 QBP_t &= 285.720 D_{1t} + 309.600 D_{2t} + 306.630 D_{3t} + 360.170 D_{4t} \\
 &\quad (110.540) \quad (100.480) \quad (99.707) \quad (90.778) \\
 &\quad -1111.500 PBF_{t-1} + 0.911 QBP_{t-4} + 607.180 WBP_t^e - 11.008 WBP_t^v \\
 &\quad (15.810) \quad (0.041) \quad (23.191) \quad (1.007) \\
 \\
 WPB_t &= 0.017 D_{1t} + 0.033 D_{2t} + 0.036 D_{3t} + 0.004 D_{4t} - 0.0001 QBD_t \\
 &\quad (0.051) \quad (0.050) \quad (0.051) \quad (0.051) \quad (0.00002) \\
 &\quad + 0.055 RPB_t + 0.124 RPP_t + 0.058 RPT_t + 0.002 RDI_t \\
 &\quad (0.036) \quad (0.036) \quad (0.070) \quad (0.001) \\
 \\
 R^2 &= 0.999 \qquad \log\text{-likelihood} = -272
 \end{aligned}$$

Note: Figures in parentheses are approximate standard errors.

seasonal coefficients in the price equation, all parameter estimates are statistically significant at the 5 percent level.

In a systems framework common measures of individual equation explanatory power, such as R^2 , have little meaning. An overall goodness-of-fit measure useful in these instances is the "generalized R^2 ", which was originally proposed by Baxter and Cragg. The generalized R^2 gives an indication of the goodness of fit of the entire system and is defined by

$$\tilde{R}^2 = \{1 - \exp[2(L_0 - L_{\max})/K]\}$$

where L_0 is the value of the log-likelihood function obtained when all parameters are set at zero, L_{\max} is the maximum value of the log-likelihood function when all parameters are allowed to vary, and K is the total number of observations. The \tilde{R}^2 coefficient was 0.99, indicating that the goodness of fit is extremely high.

In addition to these quantitative measures of performance, the estimates of the structural parameters have, in every case, signs which are consistent with theory and a priori intuition. In particular, the coefficients on the expected price and variance terms in the supply equation are positive and negative, respectively. The negative sign associated with the variance expectation conforms with our working hypothesis that broiler producers are risk averse. Also, the signs on the estimated cross-price and income coefficients in the demand equation are all positive, indicating that pork, beef, and turkey are substitutes in consumption for chicken and that poultry meat is a normal good.

IV. Test of REH

A likelihood ratio test is used to test the REH. In order to perform the test, an unconstrained model is estimated first by maximum likelihood. The unconstrained model includes equations (2), (3) and the following supply equation:

$$\begin{aligned} QBP_t = & \sum_{j=1}^4 \alpha_j D_{jt} + \alpha_5 PBF_{t-1} + \alpha_6 QBP_{t-4} + \alpha_7 QOD_t^e + \alpha_8 RBP_t^e \\ & + \alpha_9 RPP_t^e + \alpha_{10} RPT_t^e + \alpha_{11} RDI_t^e + \alpha_{12} QOD_t^v + \alpha_{13} RPB_t^v \\ & + \alpha_{14} RPP_t^v + \alpha_{15} RPT_t^v + \alpha_{16} RDI_t^v + u_{1t}. \end{aligned} \quad (11)$$

This unconstrained model (equations (2), (3), and (11)) has 25 parameters. Formally, the restrictions tested are:

$$\begin{aligned} \alpha_j = & \{a_j + (a_7 b_j + a_7 b_5 a_j)/(1 - b_5 a_5)\} \\ & + \{(a_7 b_5^3 a_8)/(1 - b_5 a_5) + a_8 b_5^2\} + \{(2a_7 b_5^2 a_8)/(1 - b_5 a_5) \\ & + 2a_8 b_5\} + \{(a_7 a_8)/(1 - b_5 a_5) + a_8\} \quad j = 1, 2, 3, 4 \end{aligned} \quad (12)$$

$$\alpha_5 = a_5 + a_7 b_5 a_5 / (1 - b_5 a_5)$$

$$\alpha_6 = a_6 + a_7 b_5 a_6 / (1 - b_5 a_5)$$

$$\alpha_7 = -a_7 b_5 / (1 - b_5 a_5)$$

$$\alpha_k = (a_7 b_{k-2}) / (1 - b_5 a_5) \quad k = 8, 9, 10, 11,$$

$$\alpha_{12} = (a_7 b_5^3 a_8) / (1 - b_5 a_5) + a_8 b_5^2$$

$$\alpha_\ell = (a_7 b_5 a_8 b_{\ell-7}^2) / (1 - b_5 a_5) + a_8 b_{\ell-7}^2 \quad \ell = 13, 14, 15, 16.$$

These restrictions reduced the dimension of parameter space by 8. The test results did not lead to rejection of the null hypothesis that the nonlinear constraints (12), implied by the REH, were valid. The key statistic is minus twice the difference of the constrained and unconstrained log likelihoods. The calculated test statistic was 7.78 which is well below the appropriate χ^2 statistic for 8 degrees of freedom at the .01 confidence level (20.09). Thus, the model passes the likelihood test, implying that in the U.S. broiler market, rational expectations with respect to both the mean and variance of price does characterize producer behavior.

V. Conclusions

The primary goal of this paper has been to extend the rational expectations framework to include price uncertainty. The biological lags inherent in many agricultural production processes, coupled with the fact that producers typically exhibit risk avoiding behavior, suggest that it is meaningful to consider higher-order moments of the price distribution in applied supply analysis. Previous studies of aggregate supply response have used ad hoc representations of the risk variables. The most common approach is to approximate risk terms by a distributed lag relationship. In marked contrast to this approach, the rational expectations specification assumes that producers use all currently available information to form expectations of the mean and variance of price. Producers then adjust their expectations on the basis of this information and in accordance with the structure as reflected in the supply and demand model.

The dual assumptions of risk averse behavior and rational expectations were subsequently examined with a model of the U.S. broiler industry. Among other things, the results indicate that price variance is an important determinant of broiler supply. A formal test also indicated that the restrictions implied by the REH could not be rejected. This result is important because of given the additional restrictions and nonlinearities implied by the assumption of risk averse behavior. In summary, the results reported here, although preliminary, are encouraging. In particular, it seems that more sophisticated approaches to rational expectations modeling can be fruitfully applied.

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