Rationally Expected Livestock and Poultry Price Forecasts and Meat Price Predictions from a Livestock and Meat Sector Model

by

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Forecasting livestock and meat prices is a problem of enduring importance, both because of the magnitude of the livestock industry and because of apparent technical problems involved in making these forecasts. Many forecasts in the 1980s have tended to over-estimate livestock prices (Conway, et al.) so that much effort has gone into attempts to improve their quality. Some of these efforts have invoked structural change in meat demand while others have emphasized improvements in forecasting methods. Examples of studies concerning structural change in meat demand include Chavas, Nyankori and Miller, Moschini and Meilke, and, most recently, Choi and Sosin. Examples of the second approach are in Conway, Elitzak and Blisard, and in the demand system approach of Huang.

This paper follows the methods improvement approach, but it uses the structural change motif as a means of evaluating the quality of predictions. A recursive model is developed in this analysis in which quantities of meats supplied within a given quarter are in part determined by previously held expectations of livestock prices. Retail prices are in turn determined by these quantities. The system is driven by livestock price expectations, which are developed here as quarter-ahead rational expectations of prices for beef cattle, hogs, broilers, and turkeys.

RATIONAL EXPECTATIONS and their ESTIMATION

Muth's paradigm of rational expectations suggests that the optimal forecasts for profit-maximizing producers working within a competitive market structure are those implied by market equilibrium. This is usually expressed as

$$P^*_t = E(P_t | \ Z_{t-s}), \qquad (1)$$

which is the expected value of the equilibrium price in period t, given the information set Z available s periods prior to t. It is possible for Z to contain any number of variables and relationships. However, Wallis has proposed limiting the set to the variables specified in a structural model of the market in question. Wallis' general model is as follows:

$$\Gamma Y_t = \beta Y1^*_t + \Theta X_t + \epsilon_t \qquad (2)$$

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where Y_t = a K x T matrix of endogenous variables,
$Y1^*_t$ = an M x T matrix of expectations of endogenous variables, $M \leq K$,
X_t = an N x T matrix of exogenous variables,
ϵ_t = a K x T matrix of disturbances, and
Γ, β, and Θ are structural parameter matrices. The reduced form of this model can be partitioned into functions for those variables having expectations counterparts (Y1) and those which do not (Y2):

$$Y1_t = \pi_{11}Y1^*_t + \pi_{21}X_t + U1_t \tag{3}$$

$$Y2_t = \pi_{12}Y1^*_t + \pi_{22}X_t + U2_t \tag{4}$$

in which the πs are matrices of reduced form coefficients. Taking expectations on equation (3) yields

$$E(Y1_t|Z_{t-s}) = \pi_{11}E(Y1_t|Z_{t-s}) + \pi_{21}E(X_t|Z_{t-s}) + U1_t. \tag{5}$$

Coefficient matrix π_{11} is an M x M matrix. Assuming it is of full rank, equation (5) can be rewritten as

$$E(Y1_t|Z_{t-s}) = (I - \pi_{11})^{-1} \pi_{21} E(X_t|X_{t-s}) + (I - \pi_{11})^{-1}U1_t \tag{6}$$

which in turn can be written as an estimating equation for the expectations:

$$Y1^*_t = b_1 X^{**}_t \tag{7}$$

where X^{**}_t are predicted values for all the exogenous variables in the model. Substituting equation (7) into equations (3) and (4) yield the following reduced-forms:

$$Y1_t = (\pi_{11}b_1)X^{**}_t + \pi_{21}X_t + V1_t \tag{8}$$

$$Y2_t = (\pi_{12}b_1)X^{**}_t + \pi_{22}X_t + V2_t \tag{9}$$

Wallis' results indicate that, given estimates of the reduced-form parameter matrix b_1 and s step-ahead predictions of the exogenous variables, estimates of the rationally-expected variables $Y1^{*t}$ can be obtained. The reduced-form of the structural model resolves to a set of functions on predicted and observed values of the exogenous variables. Obtaining predictions of the exogenous variables is of course a problem. Wallis suggests using time series techniques to estimate the X^{**}s. Shonkwiler and Emerson used recursive functions to predict exogenous variables in their application of Wallis' procedures to tomatoes. A combination of time series estimates and lags are used here. However, even with the best of predictions for the exogenous variables, the rational expectations estimates can never be exactly equal to actual equilibrium values. Recent work by Spear indicates that exact estimates are not computable except under very limiting cases.

THE LIVESTOCK SECTOR MODEL

A short-run livestock sector model is specified for the purposes of this analysis. In this model quarter-ahead livestock price expectations and other variables affect per capita quantities supplied for beef and veal, pork, chicken, and turkey. These quantities in turn affect retail prices in a set of normalized demand functions. This specification is as follows:

$$Q_{1t} = f_1(FP^{*}_{1t},\ PLCMNTS_{t-2},\ CAFCRP_{y-1},\ CAFSLTR_t,\ CATWT_t,\ PC_t,\ PSYML_t) \tag{10}$$

$$Q_{2t} = f_2(FP^{*}_{2t},\ FWRNGS_{t-2},\ PC_t,\ PSYML_t) \tag{11}$$

$$Q_{3t} = f_3(FP^{*}_{3t},\ HATCH^{*}_{t},\ PC_t,\ PSYML_t,\ FCRB_t) \tag{12}$$

$$Q_{4t} = f_4(FP^{*}_{4t},\ POULTS_{t-2},\ PC_t,\ PSYML_t,\ FCRT_t) \tag{13}$$

$$RP_{it} = g_i(Q_{it},\ RP_{jt},\ PDI_t),\ i = 1,2..,4,\ j<>i \tag{14}$$

$$FP_{it} = MM_{it}RP_{it},\ i = 1,2..,4 \tag{15}$$

where Q_{it} and RP_{it} are per capita quantities supplied and retail prices for beef, pork, chicken, and turkey, and FP_{it} are farm-level prices for the corresponding livestock classes: beef cattle, hogs, broilers, and turkeys. Rational expectations for livestock prices are represented by FP^{*}_{it}.

Livestock supply relationships are greatly simplified in this model. Thirteen-state feedlot placements ($PLCMNTS_{t-2}$), the previous year's calf crop ($CAFCRP_{y-1}$), commercial calf slaughter ($CAFSLTR_t$), slaughter cattle dressed weights ($CATWT_t$), ten-state farrowings ($FWRNGS_{t-2}$), and turkey poult hatchings ($POULTS_{t-2}$) are treated as predetermined, when in a longer-run model they might become endogenous. The rational expectation for broiler hatchings ($HATCH^{*}_{t}$) is included in the model in recognition of the fact that broilers can be raised and marketed within a quarter. However, the corresponding explanatory function for hatchings is omitted. Short-run cold storage activities, acknowledged to be important, especially for pork and turkey, are also omitted from the model. Corn meal (PC_t) and soymeal ($SYML_t$) prices are used to specify feeding costs, and changes in feeding technology are represented by feed conversion ratios for broilers ($FCRB_t$) and turkeys ($FCRT_t$). The price of cornmeal is used instead of corn to pick up any effects of changes in milling margins over time. Percentage marketing margins (MM_{it}) are calculated from observed prices as the ratios of farm-level livestock prices to retail prices. Retail prices themselves are monetized in cents per pound of retail weight from BLS retail price index numbers.

Equation (14) represents a set of normalized demand equations in which retail prices are jointly determined with quantities predetermined by supply. The demand functions are specified as static so that any secular shifts in demand, such as health-consciousness-induced shifts from red meats to poultry, will tend to show up as trends in residuals. Equation (15) consists of a set of price linkage equations in which the margin variables are the linkages.

Application of Wallis' procedures to this model yields a great deal of information. In addition to rational expectations of livestock prices, the model can yield estimates of quantities supplied, livestock prices received, and retail meat price predictions. Both reduced-form and structural parameters estimates are obtainable, although estimating structural parameters in the presence of rational expectations is a formidable task (Brown and Brandt). There is more here than can be covered in this paper, so the focus is on the endpoints: the rational expectations of livestock that initiate the model's sequence of events and the retail price relationships at the other end of them.

REDUCED-FORM MODEL ESTIMATION

Exogenous Variable Prediction

Before reduced-form estimates of the functions generating rational expectations of livestock prices can be obtained, predictions of contemporaneous exogenous variables in the model are required. A trend-adjusted autoregressive time series approach is used to predict calf slaughter, dressed weights for cattle, feed prices, the feed conversion ratios for broilers and turkeys, and personal disposable income. Predictive models are fitted on quarterly data for years 1960-87, the results of which are shown in Table 1. Efforts to predict marketing margins by time series were unsuccessful. Instead, current margins are used as expectations of margins in the next quarter, although these are still not particularly good predictors, particularly for turkey.

Rational Expectations of Livestock Prices

Equation (7) is fitted for rational expectations of livestock prices and broiler hatchings on quarterly data for 1964-87, using observed variables for lagged feeder placements, farrowings, and poult hatchings, and predicted values for the contemporaneous exogenous variables. Parameter estimates for these functions are given in Table 2. The R^2 measures show goodness-of-fit with observed livestock prices over the sample period. Not too much should be made of individual coefficients since they are in reduced-form. However, they do indicate that price expectations for beef cattle and hogs are inversely related to corn prices, whereas poultry prices are not. All price expectations respond positively to income. All prices are responsive to the poultry feed conversion ratios. The implication is that long-run improvements in poultry feed conversion ratios have driven down expectations for all livestock prices. All prices except turkey respond strongly to indicated increases in percentage margins at the farm level. The weak response for turkey price may be due more to the poor predictive performance of lagged margins for turkeys than to lack of a causal relationship.

Reduced-Form Function Estimates for Quantities and Prices

Direct estimation of equations (8) and (9) is accomplished by regressing actual livestock prices, quantities of meat supplied, and retail meat prices on the set of regressor variables, which is composed of the predetermined variables, quarter-ahead predictions of contemporaneous exogenous variables, and observed values for these variables. Parameter estimates and prediction diagnostics for these functions are available from the authors, but they are not reproduced here. Before going on to consider the demand equations, however, it should be noted that predicted values of retail prices generated from equation (9) are good candidates for the instrumental variables needed to estimate the demand equations and are used as such.

STRUCTURAL ESTIMATES OF DEMAND FUNCTIONS

The normalized demand functions represented by equation (14) are estimated by a two-stage procedure to account for simultaneity in retail price determination and first-order autocorrelation in the residuals. Price predictions from equation (9) are used as instrumental variables in the first stage, as noted above, together with observed per capita quantities and disposable personal income. Autocorrelation estimates generated in the first stage are used as inputs into generalized least-squares estimates of the demand equations' parameters in the second stage. These equations were also fit on quarterly data for 1964-87. Table 3 shows parameter estimates, standard errors, and price flexibilities measured at sample means for these equations.

Results for these normalized demand functions are peculiar in the sense that they yield much lower own-price flexibilities than do inverse demand systems (Huang). Taken on their own merits, however, these results give a coherent account of what has been taking place at the retail level, which is prolonged and severe price competition from poultry meats. Own-price flexibilities for beef and pork are exceeded in absolute value by at least one of the poultry meat cross-price flexibilities. This is to say that the price-increasing effect of a one percent decrease in per capita quantity supplied of beef or pork can be more than offset by a corresponding one percent decrease in chicken or turkey price. Likewise, the effects of the positive income flexibilities for beef and pork can also be offset by declining poultry prices. Chicken is not exempt from this competitive pressure, as indicated by the large cross-price flexibility with turkey.

The persistence of trends in poultry prices and per capita consumption can lead to anomalous results, as may be the case for the income parameter for turkey, and they make it very difficult to separate effects of health-consciousness from price competition. A look at the predictive performance of the model may give some indication whether this separation really matters from the standpoint of price forecasting.

PREDICTIVE CAPABILITIES

Predictive capabilities of the model are evaluated for rational expectations of livestock prices and for retail prices predicted from structural parameters of the demand sector. Both in-and out-of-sample comparisons are made. The out-of-sample period is from 1988 through the third quarter of 1989, for a total of seven quarters. Prices are expressed in 1988 dollars.

Table 4 shows root mean square errors (RMSE), actual and predicted means, and mean absolute percentage errors (MAPE) of forecasts from the rational expectations livestock price functions. It can be seen that out-of-sample performances for beef cattle, hogs, and broilers are not much different from in-sample results. Out-of-sample RMSEs are equal or smaller than in-sample values, and only for beef cattle price is the out-of-sample MAPE larger than its in-sample counterpart. However, while the in-sample forecast performance for turkey price is comparable to the other livestock classes, out-of-sample results are greatly inferior. The predicted mean price overstates the actual mean price of turkey in this period by 11.3 cents per pound, or 30 percent. This was a relatively consistent bias, because variations of actual and predicted out-of-sample turkey prices around their respective means were nearly equal. Nevertheless, a substantial prediction error occurred, possibly due to a structural shift.

Comparison of mean absolute percentage errors (MAPEs) between in-sample results for livestock prices in Table 4 and their retail counterparts in Table 5 indicate very similar performances. The principles of price relationships between different levels of a marketing system indicate that this should be so in the long run. In the out-of-sample period, prediction performance at the retail level seems to be at least as good as in the sample for all meats, including turkey. Except for turkey, out-of-sample performances for the livestock prices and their retail counterparts are quite similar. It is interesting to note that the poor forecasting performance for live turkeys at the farm level in 1988-89 does not extend to the retail level. Retail price predictions for turkeys are as good out-of-sample as within it. These results suggest that, if structural change is taking place for turkeys, as was mentioned above, it is more likely occuring in turkey supply than in turkey demand.

CONCLUDING REMARKS

Wallis' approach seems to hold a lot of promise for livestock price analysis, but there are many aspects of it yet to be explored. Rational expectations forecasts can only be as good as the forecasts of the exogenous variables on which they are based. The stability of the time series models used to generate these forecasts needs to be looked into before making serious out-of-sample forecasts. Other aspects of forecasting errors need to be investigated. How much is attributable to prediction errors in the exogenous variables and how much to specification errors in the model? How will the model perform if we try to forecast six months ahead?

The demand segment of this model seems to work quite well as a retail price prediction mechanism, but there is legitimate reason to wonder if it represents the "true" demand structure. Conventional wisdom holds that health-consciousness has shifted meat demands, and that may indeed be so. If it is, then the present specification may attribute too much to price competition. However, from the point of view of price analysis, it is interesting to see that old-fashioned price competition can go a long way towards explaining what has been happening in meat demand.

Table 1. Trend-Adjusted Autoregressive Functions for Exogenous Variables.[a]

Variable	CAFSLTR	CATWT	PCM	PSYML	FCRB	FCRT	PDI
Constant	1833.1	599.65	3.78	5.75	2.03	3.34	2343.02
Trend	-11.72	.432	-.011	-.008	-.004	-.012	13.90
t-1[b]	1.07	.718	1.03	1.19	.917	.807	1.05
t-2	-.322			-.359			
t-3	.278						
t-4	.312				-.440	-.321	
t-5	-.500		-.133		.377	.208	-.110
t-8	.239						
t-9	-.194						
t-12		.407					
t-13		-.371					
R^2	.968	.677	.938	.808	.918	.967	.990
DW	1.67	1.76	1.68	1.96	1.96	2.02	2.03

[a]Variable identification: SLTRT = commercial cattle and calf slaughter, millions lbs. liveweight; PCM = corn meal price, $/100 lbs; PSYML = 44% soymeal price, $/100 lbs; FCRB = broiler feed conversion ratio; FCRT = turkey feed conversion ratio; PDI = per capita disposable personal income, $ annual rates. All prices and income are deflated by the CPI (1967=100).

[b]Omitted lags had no significant (5%) parameters for any variable.

Table 2. Functions for Rational Expectations of Livestock Prices.

Coefficient[a] (Std. Error)	Beef Cattle	Hogs	Broilers	Turkeys
	$/100 lbs.	$/100 lbs.	cents/lb	cents/lb.
Constant	-35.88 (14.45)	-57.03 (16.54)	-17.44 (10.01)	-45.56 (15.57)
$PLCMNTS_{t-2}$	-.00029 (.0003)	-.00093 (.00036)	-.00013 (.00022)	-.00059 (.0003)
$CAFCRP_{y-1}$	.00017 (.00014)	.00054 (.00036)	-.00017 (.001)	-.00021 (.0002)
$FWRNGS_{t-2}$	.00006 (.00007)	-.00024 (.00009)	-.00015 (.00005)	-.00001 (.00008)
$POULTS_{t-2}$	-.054 (.020)	-.045 (.023)	-.023 (.014)	.0013 (.022)
$CAFSLTR^{**t}$	-.0040 (.0011)	.0027 (.0012)	.0019 (.0007)	.00021 (.0012)
$CATWT^{**t}$	-.012 (.013	-.0034 (.014)	-.0032 (.0087)	.0052 (.014)
PCM^{**t}	-1.60 (.66)	-1.40 (.76)	.35 (.46)	-.184 (.72)
$PSYML^{**t}$	-.15 (.25)	.44 (.29)	.52 (.17)	.69 (.27)
$FCRB^{**t}$	6.50 (4.69)	6.05 (5.37)	7.24 (3.25)	2.43 (5.06)
$FCRT^{**t}$	5.60 (2.75)	2.93 (3.15)	2.66 (1.91)	10.79 (2.97)
$MM_{1,t-1}$	86.92 (11.07)	11.33 (12.7)	-.24 (7.67)	7.28 (11.93)
$MM_{2,t-1}$	12.86 (7.44)	75.94 (8.52)	7.17 (5.15)	18.50 (8.02)
$MM_{3,t-1}$	12.23 (8.85)	4.01 (10.1)	16.24 (6.13)	15.38 (9.54)
$MM_{4,t-1}$	-.88 (4.94)	-9.46 (5.65)	-4.43 (3.42)	5.54 (5.32)
PDI^{**t}	.0031 (.0019)	.0067 (.0022)	.0034 (.0013)	.0051 (.0020)
R^2	.872	.878	.852	.856

Table 3. Meat Demand Function Parameter Estimates.[a]

Right-Side Variables	Dependent Variables: Beef Price	Pork Price	Chicken Price	Turkey Price
Constant	2.085	-6.458	7.399	24.263
Own-Quantity	-.8300 (.364) [-.235]	-1.604 (.311) [-.388]	-.7680 (.349) [-.289]	.2960 (.187) [.017]
Beef Price		.0721 (.077) [.086]	.0611 (.077) [.150]	.2913 (.088) [.521]
Pork Price	-.1054 (.102) [-.089]		.1577 (.064) [.325]	.1486 (.093) [.224]
Chicken Price	.5602 (.189) [.228]	.4910 (.213) [.238]		.3069 (.179) [.224]
Turkey Price	.6868 (.136) [.280]	.7299 (.149) [.485]	.3203 (.133) [.439]	
Personal Income	.01542 (.0022) [.683]	.01297 (.0022) [.683]	.001181 (.0032) [.128]	-.00725 (.0020) [-.575]
First-Order Autocorrelation	.677	.473	.417	.697

[a]Coefficients in parentheses are standard errors. Coefficients in brackets are price flexibilities measured at sample means.

Table 4. Prediction Diagnostics for Rationally Expected Livestock Prices, in 1988 Dollars.

	Beef Cattle	Hogs	Broilers	Turkeys
	---- $/100 lbs.----		---- cents/ lb. ----	
In-sample Forecasts (1964-87)				
RMSE	5.27	6.11	3.87	5.68
Actual Mean	78.34	69.22	44.6	64.6
Predicted Mean	78.34	69.22	44.6	64.6
MAPE	5.6%	6.7%	7.0%	7.4%
Out-of-sample Forecasts (1988-89)				
RMSE	5.66	2.40	2.83	12.53
Actual Mean	66.78	41.65	34.8	37.6
Predicted Mean	69.40	41.28	34.4	48.9
MAPE	6.9%	4.9%	7.3%	31.6%

Table 5. Retail Price Prediction Diagnostics, in 1988 Dollars.

	Beef	Pork	Chicken	Turkey
	---------- cents/ lb. -------------			
In-sample Forecasts (1964-87)				
RMSE	17.0	20.4	10.6	12.1
Actual Mean	261	219	106	145
Predicted Mean	254	210	103	143
MAPE	5.4%	7.1%	7.3%	6.4%
Out-of-sample Forecasts (1988-89)				
RMSE	8.4	9.1	9.3	4.9
Actual Mean	228	179	89	105
Predicted Mean	236	188	81	108
MAPE	3.5%	4.8%	8.7%	4.1%

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