Equilibrium Versus Disequilibrium in the Market for Non-Fed Cattle

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Beef-cow inventory demand is considered in a disequilibrium model of the U.S. live non-fed cattle market. Statistical results indicated the possible presence of disequilibrium prices. However, post-model evaluation indicated that the market for non-fed cattle has not been characterized by significant disequilibrium price behavior.

Beef supply is characterized by different components primarily consisting of steers, cows, and heifers. The cow and heifer components of beef supply are unique in that they can be slaughtered for current consumption or retained and bred to build up the total beef herd inventory. Slaughter cattle primarily come from feedlots (fed beef) and cull cows and bulls from cow-calf operations (non-fed beef). Consequently, it may be important to account for changes in beef-cow inventory, usually defined as cows and heifers that have calved, in an empirical model of non-fed beef supply and demand.

In this paper we consider the possibility of beef-cow inventory demand in a disequilibrium model of the U.S. live non-fed cattle market. In the carcass beef market there is recent evidence of the existence of disequilibrium prices. As concluded by the General Accounting Office (1978) and evidenced by Ward (1980), U.S. carcass beef prices do not reflect all available information entering the market since the preceding period.

In live cattle markets, about 80 percent of all fed cattle and 40 percent of all cow and bull sales to packers are the result of direct puchases from producers and these sales are not public information as are terminal and auction market sales [Ward, 1979]. Direct purchase prices for cattle are often the result of "formula pricing" which is based only on a very limited amount of total market transactions.[1] Consequently, the conclusion of some studies is that market information and market prices for cattle, particularly at the local level, may be subject to manipulation [General Accounting Office].

The plan of this paper is as follows. In the next section, a general theoretical disequilibrium market model for non-fed cattle is discussed. Next exogenous factors in an empirical specification of the demand and supply of non-fed cattle are described. Results are then presented along with an analysis of equilibrim speed of adjustment. Post-model evaluation is then addressed. Finally, conclusions and recommendations are given.

Theoretical Model

Consider the following demand and supply equations:

$$D_t = X_t\alpha + P_t\alpha^* + u_t \tag{1}$$

$$S_t = Z_t\beta + P_t\beta^* + v_t \tag{2}$$

where $t = 1 \ldots T$, D_t and S_t represent non-fed cattle demand and available cattle supply

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[1]Formula pricing involves a price settlement between the producer and meatpacker based predominantly on published carcass beef prices from the National Provisioner's "Daily Market and News Service" commonly known as the Yellow Sheet [General Accounting Office, 1978].

during period t, P_t denotes price, X_t and Z_t are vectors of exogenous variable values, and u_t and v_t are uncorrelated, serially independent, normally distributed random errors with zero means and finite variances σ_u^2 and σ_v^2. As in most disequilibrium models [Fair and Jaffee], it is assumed D_t and S_t are not directly observed and that the quantity marketed (i.e. the actual quantity of non-fed cattle slaughtered) is associated with the short side of the market, that is the minimum of demand and supply. On the supply side, this quantity can be viewed as the difference between total available supply and beef-cow inventory demand [Reutlinger]. Subsequently, actual observed quantity marketed, Q_t, can be expressed as follows:

$$(3) \qquad Q_t = \min[D_t, (S_t - \Delta I_t)]$$

where I_t represents the level of beef-cow inventory in time period t. Following Reutlinger, beef-cow inventory demand is defined as:

$$\Delta I_t = I_{t+1} - I_t .$$

Finally, price adjustment in the market is described by the equations:

$$(4) \qquad \begin{aligned} \Delta P_t &= \lambda_1[D_t - (S_t - \Delta I_t)], \\ &\qquad \text{if } [D_t - (S_t - \Delta I_t)] > 0 \\ &= \lambda_2[D_t - (S_t - \Delta I_t)], \\ &\qquad \text{if } [D_t - (S_t - \Delta I_t)] < 0 \end{aligned}$$

where $\Delta P_t = P_{t+1} - P_t$, $0 \leq \lambda_i \leq \infty$, and different upward ($\lambda_1$) and downward ($\lambda_2$) speeds of adjustment are allowed as suggested by Laffont and Garcia.

Since S_t and D_t are not directly observed, it is useful to eliminate them from equations (1) through (4) using Q_t which is observed. If $\Delta P_t > 0$, it follows from equations (1) through (4) that:

$$(5) \qquad \begin{aligned} Q_t &= S_t - \Delta I_t = D_t - \lambda_1^* \Delta P_t \\ &= X_t\alpha + P_t\alpha^* - \lambda_1^* \Delta P_t + u_t \end{aligned}$$

and if $\Delta P_t < 0$,

$$(6) \qquad \begin{aligned} Q_t &= D_t = S_t - \Delta I_t + \lambda_2^* \Delta P_t \\ &= Z_t\beta + P_t\beta^* + \lambda_2^* \Delta P_t \\ &\quad - \Delta I_t + v_t \end{aligned}$$

where $\lambda_i^* = 1/\lambda_i$, i = 1, 2. Using indicator variables, equations (5) and (6) can be written:

$$(7) \qquad Q_t = X_t\alpha + P_t\alpha^* - \lambda_1^* d_t \Delta P_t + u_t$$

$$(8) \qquad Q_t^* = Z_t\beta + P_t\beta^* + \lambda_2^* s_t \Delta P_t + v_t$$

where $Q_t^* = Q_t + \Delta I_t$ and,

$$d_t = \begin{cases} 1, & \text{if } \Delta P_t > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$s_t = \begin{cases} 1, & \text{if } \Delta P_t < 0 \\ 0, & \text{otherwise} \end{cases}$$

so that all variables are observed for $t = 1, \ldots T$.

Equations (7) and (8) can be consistently estimated by the usual two-stage least squares estimator. However, as noted by Amemiya, two-stage least squares is not asymptotically efficient in this case since $d_t\Delta P_t$ and $s_t\Delta P_t$ are not linear functions of the exogenous variables. Amemiya presents the likelihood function for the model and suggests an iterative procedure for deriving maximum likelihood parameter estimates given that $\lambda_1 = \lambda_2$ and $\Delta I_t = 0$ for all t. For the general case that λ_1 and λ_2 are not necessarily equal, Laffont and Garcia present the correct likelihood function given $\Delta I_t = 0$ for all t. The appropriate likelihood function allowing for changes in beef-cow inventory (i.e. $\Delta I_t \neq 0$ for all t) is presented in the Appendix.

Empirical Model

Recent studies have found evidence of disequilibrium behavior in U.S. cattle markets [Multop and Helmuth, and General Accounting Office, 1977] while some agricultural economists have stressed the importance of accounting for disequilibrium in agricultural sector models [Heien]. In this section we construct a simple quarterly disequilibrium model of the market for U.S. non-fed cattle consisting of the four equations described in the previous section: 1) demand, 2) supply, 3) observed quantity transacted, and 4) price adjustment in the market.

The demand for non-fed cattle is considered a function of own price, substitute prices, and income. Supply of non-fed cattle (following Arzac and Wilkinson) is considered a function of own price, prior placements of cattle on feed, and the price of feeder cattle. The general demand equation (1) can be written for empirical purposes as:

$$(9) \qquad D_t = \alpha_o + \alpha_1 FP_t + \alpha_2 HP_t + \alpha_3 M_t + \alpha^* P_t$$

where $t = 1 \ldots T$, D_t is the quantity demanded of non-fed cattle (1000 hd.), FP_t is the price of fed beef (Omaha, 900-1100 lb. choice, \$/cwt), HP_t is the price of hogs (barrows and gilts, 7 mkts., \$/cwt), M_t is per capita income (\$1000), P_t is the price of non-fed beef (Omaha, utility cows, \$/cwt), and the α's represent parameters to be estimated. Since FP_t and HP_t represent substitute prices, α_1 and α_2 are expected to be positive while $\alpha^* < 0$ is expected since P_t is own price. The sign expected for α_3 is less clear. Arzac and Wilkinson found the income elasticity for non-fed beef to be positive while other studies have concluded that non-fed beef is an inferior good [Langemeir and Thompson; Freebairn and Rausser].

The theoretical supply equation (2) is specified for empirical purposes as follows:

$$(10) \quad S_t = \beta_0 + \beta_1 PC_t^* + \beta_2 FSP_t + \beta^* P_t$$

where S_t is the available supply of non-fed cattle (1000 hd.), $PC_t^* = \sum_{i=0}^{3} PC_{t-i}/4$ is the average number of cattle previously placed on feed (1000 hd.), FSP_t is the price of feeder steers (Kansas City, 600-700 lb. choice, \$/cwt), and the β's are parameters. Following Arzac and Wilkinson, PC_t^* enters the supply equation to help explain losses in potential non-fed beef supplies; if more cattle are placed on feed, less are available for current and eventual non-fed beef slaughter. Therefore, β_1 is expected to be negative. Similarly, if FSP_t rises, more cattle will be placed on feedlots lessening current and potential non-fed beef supplies. Consequently, it is expected that $\beta_2 < 0$.

It is arguable in certain price expectations models involving cattle on feed that supply is negatively related to slaughter price, at least in the short-run [Nelson and Spreen]. This argument rests on the assumption that inventory demand ΔI_t is positively related to current slaughter price. Since observed cattle marketings, Q_t, are inversely related to inventory demand, the available supply of non-fed slaughter cattle, S_t, should be inversely related to price if the equilibrium assumption $Q_t = D_t = S_t - \Delta I_t$ is imposed [Reutlinger]. Such price behavior is reasonable if 1) P_t reflects or is based on the price of fed slaughter cattle and 2) market equilibrium is assumed. However, in the disequilibrium model described above, P_t is the price of non-fed beef and $Q_t = \min[D_t, (S_t - \Delta I_t)]$, so that observed marketings, Q_t, are not necessarily equal to available supply less the change in inventory demand. Therefore, there is no reason to expect that, ceteris paribus, $\partial S_t/\partial P_t = \beta^* > 0$ should not occur. Furthermore, since $\Delta I_t = I_{t+1} - I_t$, it is certainly possible that $\partial \Delta I_t/\partial P_t > 0$ and $\partial I_t/\partial P_t < 0$ implying $\partial S_t/\partial P_t > 0$.[2]

The last two equations in the empirical model are given by (3) and (4) so that observed quantity of non-fed cattle marketed, Q_t (1000 hd.) is associated with the short side of the market,[3] and different speeds of price

[2]Notice that by substituting equations (1) and (2) into (4): $\partial \Delta I_t/\partial P_t = [\lambda_i \ (\beta^* - \alpha^*) - 1] \ \lambda_i^*$ and $\partial I_t/\partial P_t = [\lambda_i \ (\alpha^* - \beta^*) + 1] \ \lambda_i^* = -\partial \Delta I_t/P_t$, and since λ_i is non-negative by assumption the signs of these derivatives are not restricted and depend only upon the values of α^*, β^* and λ_i.

[3]In a disequilibrium model, it is important to remember that only Q_t, and not D_t or S_t, is directly observed.

adjustment are allowed in periods of excess supply and excess demand (see equation 4). Lastly, I_t is empirically defined as the beef-cow inventory level (1000 hd., cows and heifers that have calved). Estimation of the empirical disequilibrium model consisting of equations (9), (10), (3), and (4) is discussed next.

Estimation and Results

Numerical results for the model outlined above are presented in Table 1; asymptotic standard errors appear in parentheses. Quarterly data were for the period 1965-1979.[4] Maximum likelihood results appear under the headings ML1 and ML2. For the ML1 model, the restriction $\lambda_1 = \lambda_2$ was imposed implying the speed of price adjustment is the same in either periods of excess demand or excess supply. For the ML2 model, λ_1 and λ_2 are not restricted to be equal. Also presented are results for the model estimated under equilibrium in which the condition $Q_t = D_t = S_t - \Delta I_t$ is assumed to hold in all time periods. The equilibrium model was esimated using two stage least squares (TSLS). For the disequilibrium models ML1 and ML2, maximum likelihood parameter estimates were obtained by iteratively-solving the first order equations of the log-likelihood function (see Appendix) as suggested by Amemiya. Of the total 60 quarterly observations, 26 were demand side ($\Delta P_t > 0$) and 34 were supply side ($\Delta P_t < 0$) for the disequilibrium models.

Referring to Table 2, all estimated parameter values agree with theoretical expectations. Note that the sign of the coefficient on income, M_t, could not be unambiguously determined and none of the estimated income coefficients are significantly different from zero at usual significance levels. Based on the parameter estimates: $\partial \Delta I_t / \partial P_t > 0$, $\partial I_t / \partial P_t < 0$, and $\partial S_t / \partial P_t > 0$, results which are reasonable given the earlier theoretical discussion.[5]

Excluding intercepts and income, all parameter estimates were significantly different from zero in the two disequilibrium models (ML1 and ML2) and in the demand equation for the equilibrium model (TSLS). In comparison, the disequilibrium specifications indicated a less elastic supply curve than did the equilibrium model. Furthermore, the disequilibrium models implied virtually identical demand elasticities, slightly greater than the demand elasticity in the equilibrium specification.[6] Given these results an important question involves the choice between the alternative model specifications.

Fair and Jaffee (1972) suggest that a test of the hypothesis of perfect or continuous equilibrium can be based on the null hypothesis H_o: $\lambda^* = 1/\lambda = 0$. Referring to Table 1, the estimates of λ_1^* and λ_2^* are significantly different from zero in both the restricted and unrestricted models implying that the null hypothesis of continuous equilibrium can be rejected. Based on this test then, the disequilibrium models are preferred to the equilibrium model. However, it has been shown that the Fair and Jaffee test should be regarded with some degree of caution.[7]

In chosing between ML1 and ML2, a simple likelihood ratio test can be used. To test the restriction that $\lambda_1 = \lambda_2$, the usual likelihood ratio statistic:

$$(11) \quad \omega = -2[\log L(\tilde{\Theta}) - \log L(\hat{\Theta})],$$

[4]Data for the analysis were from: USDA *Agricultural Prices, Cattle, Livestock and Meat Situation, Livestock and Meat Statistics*, U.S. Dept. of Commerce *Handbook of Cyclical Indicators*, FRS *Federal Reserve Bulletin*, and USDA worksheets.

[5]For ML1, $\partial \Delta I_t / \partial P_t = 112.75$ and $\partial S_t / \partial P_t = 144.15$ (see footnote 2). Similar results hold for ML2.

[6]Given mean values, estimated price elasticities of demand are as follows: TSLS: -1.57; ML1: -1.66; ML2: -1.66.

[7]In a Monte Carlo study, Quandt concluded that the Fair and Jaffee test leads to a high probability for Type I error but gives satisfactory inferences when the null hypothesis of eqiulibrium is false. Other tests of equilibrium verses disequilibrium have been suggested (see Bowden), but there is no generally accepted approach to the problem.

TABLE 1. Empirical Results for Equilibrium and Disequilibrium Models.

Equation	Parameter Estimates TLSL	ML1	ML2
Demand			
α_o	1025.1000	−57.9857	−167.1640
	(733.1307)	(962.0990)	(1004.6500)
FP_t	89.7774	88.5234	87.6073
	(19.7656)[a]	(23.6119)[a]	(24.6386)[a]
HP_t	52.0473	58.2458	59.1372
	(9.1102)[a]	(11.6519)[a]	(12.1618)[a]
M_t	−7.3920	31.7830	35.7684
	(26.667)	(35.0421)	(36.5919)
P_t	−141.7380	−150.3970	−150.3880
	(21.0798)[a]	(25.1603)[a]	(26.2519)[a]
Supply			
β_o	2058.1300	3155.8100	3325.7000
	(2281.7406)	(586.7360)[a]	(632.9680)[a]
PC_t	−.4380	−.2738	−.3327
	(.4871)	(.1218)[a]	(.1324)[a]
FSP_t	−921.4360	−65.3869	−102.7870
	(564.9169)	(36.2953)[b]	(40.9288)[a]
P_t	1586.2800	144.1460	214.4270
	(959.1148)	(61.7917)[a]	(70.3769)[a]
Price Adjustment			
λ_1^*	-	181.7917	201.6849
		(35.6224)[a]	(37.8846)[a]
λ_2^*	-	181.7917	279.9748
		(35.6224)[a]	(50.2780)[a]

[a]Significantly different from zero, $\alpha = .05$.
[b]Significantly different from zero, $\alpha = .10$.

TABLE 2. Estimated Equilibrium Speed of Adjustment.[a]

Number of Periods	ML1	ML2 (Excess Demand)	ML2 (Excess Supply)
t=1	37.98	19.12	69.70
t=2	61.54	34.58	90.82
t=3	76.14	47.09	97.22
t=4	85.20	57.21	99.16

[a]Defined as the percentage of price adjustment back to equilibrium after a disequilibrium disturbance.

where $\tilde{\Theta}$ is the restricted and $\hat{\Theta}$ the unrestricted maximum likelihood estimator of the true parameter vector $\Theta = [\alpha, \alpha^*, \beta, \beta^*, \lambda_1, \lambda_2, \sigma_u^2, \sigma_v^2]$, has a chi-square distribution if the null hypothesis H_o: $\lambda_1 = \lambda_2$ is true. For ML1 and ML2, $\omega = 2.16$. Given a $\chi^2_{(1,\alpha=.05)} = 3.84$ critical value, this result implies that the restriction $\lambda_1 = \lambda_2$ cannot be rejected given the sample data. Subsequently, ML2 is not statistically preferred to ML1.

An important difference between the equilibrium and disequilibrium models is the speed of adjustment implied by the price adjustment parameters λ_1 and λ_2 in the disequilibrium model. Since the validity of statistical tests for disequilibrium (such as the Fair and Jaffee test) may be questionable, determining the speed of price adjustment implied by the disequilibrium models may allow a choice between the equilibrium and disequilibrium specifications. For example, relatively fast price adjustment would indicate an essentially equilibrium market and lend support to the validity of the equilibrium specification. Alternatively, sluggish adjustment would imply that imposing the restriction of continuous equilibrium may yield unreliable parameter estimates due to specification error. In the next section, speed of price adjustment is considered.

Price Adjustment

An important characteristic of interest in a disequilibrium model is the speed of adjustment with which the system moves back toward equilibrium after it is disturbed. To determine the speed of adjustment toward equilibrium over time, substitute equations (1) and (2) into equation (4), yielding:

$$\text{(12)} \qquad \Delta P_t = \lambda_i(D_t^* + P_t\alpha^* - S_t^* + \Delta I_t - P_t\beta^*),\ i=1,\ 2$$

where $D_t^* = X_t\alpha + u_t$ and $S_t^* = Z_t\beta + v_t$. For purposes of illustration, assume that: 1) $u_t = v_t = 0$ for all t, 2) $D_t^* = \bar{D}$, and $S_t^* = \bar{S}$ where $\bar{D}$ and $\bar{S}$ are constants implying there are no changes in the exogenous factors X_t and Z_t over time, and 3) $\Delta I_t = \bar{I}$ so that there is no change in inventory demand. Then (12) can be written in the general form of a nonhomogeneous first-order difference equation:

$$\text{(13)} \qquad P_{t+1} + aP_t = K$$

where,

$$a = \lambda_i\ (\beta^* - \alpha^*) - 1$$

and,

$$K = \lambda_i\ (\bar{D} - \bar{S} + \bar{I}),$$

where i = 1 if $\Delta P_t > 0$ and i = 2 if $\Delta P_t < 0$. The solution to the difference equation (13) is

$$\text{(14)} \qquad P_t = (-a)^t\left(P_o - \frac{K_o}{1+a}\right) + \frac{K}{1+a},\quad a \neq -1$$

where P_o and K_o represent initial conditions when t = 0 (for example, see Chiang, pp. 508-22). Equation (14) may also be written:

$$\text{(15)} \qquad P_t = (-a)^t(P_o - \bar{P}) + \bar{P}$$

where $\bar{P} = K/(1+a) = (\bar{D} - \bar{S} + \bar{I})/(\beta^* - \alpha^*)$ is the long-run equilibrium or market-clearing price.

From equation (15), the dynamic short-run stability of the disequilibrium system described in equations (1) through (4) can be determined by the parameters α^*, β^*, λ_1, and λ_2 which determine the value of the term $(-a)$. If $|-a| > 1$, the system will explode given a discrepancy between P_o and $\bar{P}$. If $|-a| < 1$, the system will converge toward long-run equilibrium $\bar{P}$ where convergence will be more rapid given smaller values of $|-a|$. If $(-a) < 0$, price adjustment will follow a cobweb path, alternately rising above and falling below the equilibrium price from period to period. Finally, if $(-a) > 0$ and $|-a| < 1$, then observed price will monotonically approach the long-run equilibrium price where the speed of adjustment will be more rapid given smaller values of $|-a|$.

Given the parameter estimates for α^*, β^*, λ_1, and λ_2 presented in Table 1, a = .6202 for ML1. Alternatively, for ML2, a = .8088 if $\Delta P_t > 0$ and a = .3030 if $\Delta P_t < 0$. In Table 2, estimated absolute percent of equilibrium price adjustment is presented. The ML1 model, which restricts both upward and downward adjustment speeds to be the same, implies a one period short-run adjustment of about 40 percent and an adjustment process that is nearly complete after four quarters given an initial disturbance from long-run equilibrium (i.e. $P_o \neq \bar{P}$). Alternatively, the unrestricted ML2 model indicates somewhat slower price adjustment during periods of excess demand but quite rapid adjustment in periods of excess supply. Given initial excess supply, adjustment of P_t back to long-run equilibrium $\bar{P}$ is nearly complete after two or three quarters — about 91 pecent of any shock from equilibrium is absorbed within two periods and the market essentially returns to equilibrium within three to four periods. Except for the excess demand case for the ML2 specification, these results indicate fairly rapid price adjustment given a disturbance from equilibrium and so lend support to the validity of the equilibrium specification.

Post-Model Evaluation

The empirical consequences of specifying a disequilibrium model as an equilibrium model relate largely to forecasting performance. Even if a market is truly characterized by disequilibrium behavior, if an equilibrium model predicts dependent variable values as well as a disequilibrium specification then there would exist little incentive to assume the additional computational burden required by even the most simple disequilibrium models.

The forecasting performance of the estimated models was compared in terms of predicting market price. For the disequilibrium models, predicted price was estimated by substituting equations (1) and (2) into (4) given the parameter estimates presented in Table 1:

$$(16)\quad \hat{P}_t = P_{t-1} + \hat{\lambda}_i(X_{t-1}\hat{\alpha} + P_{t-1}\hat{\alpha}^* - Z_{t-1}\hat{\beta} - P_{t-1}\hat{\beta}^* + \Delta I_{t-1})$$

where $\hat{P}_t$ is the predicted value of P_t and "^" signifies estimated values. In comparing the estimated models, two well established forecasting performance criteria were used. The first was root-mean-square-error (RMSE) in predicting the actual current price P_t. As a second criterion, auxiliary regressions were run for estimated and actual prices of the form:

$$(17)\qquad \hat{P}_t = \gamma_1 + \gamma_2 P_t + e_t$$

where γ_1 and γ_2 are parameters and e_t is a normally distributed random error with zero mean and finite variance. In such a goodness-of-fit model, a perfect fit would result in $\gamma_1 = 0$, $\gamma_2 = 1$, and $R^2 = 1$ (see Mincer and Zarnowitz).

In Table 3, results for RMSE and the auxiliary price equation (17) are presented for the equilibrium (TSLS) and the disequilibrium models (ML1 and ML2). In terms of RMSE, the equilibrium model peformed best and the disequilibrium model ML1 performed worst. The equilibrium model also had the highest R^2 for the auxiliary price equation parameter estimates. None of the estimated values of γ_1 were significantly dif-

TABLE 3. Estimated RMSE and Auxiliary Price Equation Results, 1965-1979.

		Auxiliary Price Equation		
Model	RMSE	γ_1	γ_2	R^2
TSLS	1.3066	.38 (.75)[a]	.98 (−1.05)[b]	.98
ML1	4.4992	2.04 (1.18)	.92 (−1.25)	.78
ML2	3.7653	1.84 (1.28)	.92 (−1.57)	.83

[a]t-statistic for Ho: $\gamma_1 = 0$
[b]t-statistic for Ho: $\gamma_2 = 1$

ferent from zero while none of the estimated values of γ_2 were significantly different from one. However, since the equilibrium model yielded both a higher R^2 the the lowest RMSE, it appears preferred in terms of forecasting market price.

Summary and Conclusions

In this paper we have presented a simple disequilibrium model of the U.S. non-fed cattle market which accounts for beef-cow inventory demand. Statistical results indicated the possible presence of disequilibrium price behavior. However, estimated equilibrium price adjustment was found to be fairly rapid. Furthermore, post-model evaluation involving price forecasting accuracy indicated that the disequilibrium specifications considered did not predict as well as a simple equilibrium model. Overall, these results suggest that the market for non-fed cattle has not been characterized by significant disequilibrium price behavior.[8]

A shortcoming of the analysis is that beef-cow inventory demand was considered to be exogenous in the model. A possibly more interesting model would have resulted if factors explaining beef-cow inventory levels were included endogenously. However, disequilibrium econometric methods are currently limited to simple two-equation market systems. A general topic for further research involves specification and estimation of more sophisticated disequilibrium models which allow for a greater number of endogenous relationships. A further weakness in our analysis involves the sample data. All data were available on a quarterly basis except for beef-cow inventories which were only annually recorded until 1973 and semi-annually recorded thereafter. Consequently, quarterly values were constructed by simple linear interpolation. Further accuracy may have been obtained by seasonally adjusting these data, however, any such approach could be argued to be no less arbitrary. In short, the availability of more reliable estimates of quarterly beef-cow inventories would result in more valid model parameter estimates and perhaps alter overall conclusions regarding the existence of disequilibrium prices.

Econometric disequilibrium models are a relatively recent phenomenon and further applications are needed to determine their general usefulness. Since the models considered in this study are relatively simple and data limitations were encountered, reported results should be considered exploratory in nature. A more sophisticated disequilibrium model and reliable quarterly beef-cow inventory data would no doubt lend added confidence in parameter estimates and behavioral conclusions. However, little incentive for such additional research in the non-fed cattle market is suggested by the results of this study. Alternatively, more fruitful applications of disequilibrium methodology, such as that developed here, may exist in other agricultural markets.

[8]In contrast, stronger evidence has been found for disequilibrium price behavior in the market for fed beef [Ziemer and White].

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Appendix

Likelihood Function for ML1 and ML2

For ML1 and ML2, $\Delta P_t = P_{t+1} - P_t$ so that P_t is exogenous. If $S_t > D_t$ then $(\Delta P_t | Q_t) \sim N[\lambda_2(Q_t + \Delta I_t - Z_t\beta - P_t\beta^*), \lambda_2^2\sigma_v^2]$ and $Q_t \sim N[(X_t\alpha + P_t\alpha^*), \sigma_u^2]$, while if $D_t > S_t$ then $(\Delta P_t | Q_t) \sim N[\lambda_1(-Q_t + X_t\alpha + P_t\alpha^*), \lambda_1^2\sigma_u^2]$ and $Q_t \sim N[(-\Delta I_t + Z_t\beta + P_t\beta^*), \sigma_v^2]$. Let,

$$A_1 = (Q_t - X_t\alpha - P_t\alpha^*)$$

$$A_2 = (Q_t + \Delta I_t - Z_t\beta - P_t\beta^*)$$

$$A_3 = [\Delta P_t - \lambda_2(Q_t + \Delta I_t - Z_t\beta - P_t\beta^*)]$$

$$A_4 = [\Delta P_t + \lambda_1(Q_t - X_t\alpha - P_t\alpha^*)]$$

so that the appropriate log-likelihood function can be written:

$$\begin{aligned} L = & -T_1 \log \lambda_2 - T_2 \log \lambda_1 - T\log \sigma_u \\ & -T\log \sigma_v \\ & - \frac{1}{2\sigma_u^2} \sum_1 A_1^2 - \frac{1}{2\sigma_v^2} \sum_2 A_2^2 \\ & - \frac{1}{2\lambda_2^2\sigma_v^2} \sum_1 A_3^2 \\ & - \frac{1}{2\lambda_1^2\sigma_u^2} \sum_2 A_4^2 \end{aligned}$$

where $\sum_{1}$ applies to the T_1 observations such that $\triangle P_t<0$ and $\sum_{2}$ applies to the T_2 observations such that $\triangle P_t>0$. Following a modified Amemiya algorithm, maximum likelihood parameter estimates were obtained by iteratively solving the first order equations:

$$\tilde{\alpha}=(\Sigma\tilde{X}_t\tilde{X}_t')^{-1}(\Sigma\tilde{X}_t'Q_t+\lambda_1^{*}\sum_{2}\tilde{X}_t'\triangle P_t)$$

$$\tilde{\beta}=(\Sigma\tilde{Z}_t\tilde{Z}_t')^{-1}(\Sigma\tilde{Z}_t'Q_t+\Sigma\tilde{Z}_t'\triangle I_t-\lambda_2^{*}\sum_{1}\tilde{Z}_t'\triangle P_t)$$

$$\sigma_u^2=[\sum_{1}(Q_t-\tilde{X}_t\tilde{\alpha})^2+\sum_{2}(Q_t+\lambda_1\triangle P_t-\tilde{X}_t\tilde{\alpha})^2]/T$$

$$\sigma_v^2=[\sum_{2}(Q_t+\triangle I_t-\tilde{Z}_t\tilde{\beta})^2+\sum_{1}(Q_t+\triangle I_t-\lambda_2 P_t-\tilde{Z}_t\tilde{\beta})^2]/T$$

$$0=T_1\sigma_u^2\lambda_1^2-\lambda_1\sum_{2}\triangle P_t(Q_t-\tilde{X}_t\tilde{\alpha})-\sum_{2}(\triangle P_t)^2$$

$$0=T_2\sigma_v^2\lambda_2^2+\lambda_2\sum_{1}\triangle P_t(Q_t+\triangle I_t-\tilde{Z}_t\tilde{\beta})-\sum_{1}(\triangle P_t)^2$$

where $\tilde{X}_t=[X_t, P_t]$, $\tilde{Z}_t=[Z_t, P_t]$, $\tilde{\alpha}=[\alpha, \alpha^{*}]'$, and $\tilde{\beta}=[\beta, \beta^{*}]'$. Estimated standard errors were based on the analytical Hessian matrix of L. Initial parameter estimates were obtained by applying two-stage least squares to equations (7) and (8).