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SIMULTANEITY, RATIONALITY AND PRICE DETERMINATION IN US LIVE CATTLE

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Abstract

This paper develops a simultaneous rational expectations model of the US live cattle spot and futures markets. The issues addressed are first, the scarcity of such models of futures markets for non-storables, and second the semi-strong efficient markets hypothesis (EMH), on which recent research for this market has been inconclusive. The model contains functional relationships for short and long hedgers, net short speculators in futures and consumers.

The results suggest first, that there is support for Working's hypotheses of selective and operational hedging, for short and long hedgers respectively, second that speculators may be noise traders or risk-loving, and third that beef is a normal good while corn is a complementary input. Time-varying volatility is represented as an EGARCH (*p,q*) process. Post-sample, this model does not *significantly* outperform the futures price in spot price forecasting, implying non-rejection of the EMH.

Key words: futures market; live cattle; rational expectations; market efficiency

JEL Codes: G13, Q13, G14

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I Introduction

The US Live Cattle Futures contract, which began trading on the Chicago Mercantile Exchange in 1964, has attracted considerable attention from researchers in recent years. Issues discussed in this research include the informational efficiency of the live cattle futures market, the relative performance of various forecasts of live cattle prices and returns to traders in live cattle futures. Leuthold (1972) tested the random walk hypothesis with US live cattle data, and was reluctant to reject this hypothesis. Leuthold (1974) tested the unbiasedness hypothesis with live cattle futures price data, and did not reject that hypothesis with lags up to three months from maturity, but did reject with longer lags.

Leuthold and Hartmann (1979) tested the semi-strong form of the efficient markets hypothesis (EMH) by comparing the post-sample forecasting performance of an econometric model of the market with that of a lagged futures price. They found that, for some sub-periods in their sample, spot price forecasts by the model were superior to those implicit in the lagged futures price, although they did not reject the EMH. Leuthold and Garcia (1992) applied this methodology to the live cattle market, and did not reject the EMH. Just and Rausser (1981) compared the forecasting performance of various commercial agencies with that of a lagged futures price, and found that only one of five commercial forecasts outperformed the futures price with lags up to three months. Garcia *et al* (1988) compared the post-sample forecasts of the spot price by a lagged futures price with those of a range of alternative forecasts, and found that, for all time horizons, at least one of the alternatives outperformed the futures price. These authors did not, however, reject the EMH, because mean profits, generated by trading routines based on the best available forecast, were small relative to their variances.

Hartzmark (1987), using Commodity Futures Trading Commission (CFTC) data, found that large speculators (non-commercials) made profits and large hedgers (commercials) incurred losses in live cattle futures, an outcome contrary to that for the other eight markets he studied. Finally, Sanders *et al* (2000) did not reject orthogonality between current and lagged returns to traders for livestock (including live cattle), which was one of five groups, covering 28 markets, studied by these authors.

While several of these papers test the EMH, which is a joint hypothesis embodying both rational expectations and risk neutrality, none of these papers incorporates an explicit representation of rationally expected prices. Indeed, empirical simultaneous rational expectations models of spot and futures markets for non-storables are rare in the literature, although Goss and Avsar (1999) estimated such a model with Australian live cattle data. Moreover, the papers referred to above do not appear to result in any clear conclusion on the question of market efficiency. The purpose of the present paper, therefore, first is to contribute to a reduction in this obvious scarcity in the literature on non-storables, and in doing so to test the rational expectations hypothesis directly, with US live cattle data, in the context of a simultaneous model. Secondly, the purpose of this paper is to provide a more powerful test of the EMH, through the use of a wider information set. Herein lies the motivation for the present paper.

Peston and Yamey (1960) and Stein (1961). Dewbre (1981) and Kawai (1983) developed theoretical models of the simultaneous determination of spot and futures prices, the last of these being a model for non-storables with rational expectations. Giles *et al* (1985) and Goss *et al* (1992) developed empirical models of simultaneous determination of spot and futures prices with rational expectations, for storable commodities. This paper extends the work of Leuthold and Hartmann (1979) and Leuthold and Garcia (1992) to models with rational expectations, and extends the work of Giles *et al* (1985) and Goss *et al* (1992) to non-storables. The remainder of this paper is organised as follows: model specification is discussed in Section II, while data, tests for stationarity and estimation methods are discussed in Section III. Intra-sample results are presented in Section IV, and results for the post-sample period are presented in Section V, while Section VI offers some conclusions.

II MODEL SPECIFICATION

This model contains functional relationships for short hedgers, long hedgers, net short speculators in futures and consumers; it is completed with a spot price equation and a futures market clearing identity. While this model has its foundations in the models of Peston and Yamey (1960), Giles *et al* (1985) and Goss *et al* (1992), the framework common to those models has been adapted to the case of non-storables.

The concepts of discretionary hedging of Working (1953a, 1953b, 1962) were developed for storable commodities, such as grains; nevertheless these concepts also can be adapted to non-storable commodities. Short hedgers in the live cattle market, who are essentially producers, could be assumed to employ either a fixed or a variable hedge ratio. If the former assumption were chosen, and if this ratio was taken to be one to one, the market commitments of short hedgers could be specified in terms of current and expected forward premium (futures price minus spot price). In this case, however, the latter assumption has been made, because of its greater flexibility, and so the market commitments of short hedgers are specified as a direct function of the current futures price, and are assumed to vary negatively with the expected futures price. This specification, which is close to Working's (1962) concept of selective hedging, is therefore

$$H_t = \phi_1 + \phi_2 P_t + \phi_3 P^*_{t+1} + e_{1t} \qquad (1)$$

where H_t = futures market commitments of short hedgers; P_t = current futures price; P^*_{t+1} = rational expectation of the futures price in period $(t + 1)$, formed in period t; e = error term; t = time in months; and ϕ_1 = constant; $\phi_2 > 0$; $\phi_3 < 0$.

The activities of long hedgers, such as beef exporters and/or meat processors, were analysed by Working (1953b, 1962) using his concept of operational hedging. The objective of hedging for these agents is to facilitate forward contract pricing, while the forward premium can act as a guide to the timing of input purchases. The market commitments of long hedgers, therefore, can be expected to vary negatively with the current forward premium and directly with the expected forward premium. The futures commitments of long hedgers can be expected to vary directly also with measures of their spot market commitments, such as anticipated consumption of beef, or anticipated exports of beef. The specification of this relationship is therefore:

$$L_t = \phi_4 + \phi_5 (P_t - A_t) + \phi_6 \left(P^*_{t+1} - A^*_{t+1}\right) + \phi_7\, C^*_{t+1} + \phi_8\, X^*_{t+1} + e_{2t} \qquad (2)$$

where L_t = futures market commitments of long hedgers; A_t = current spot price of live cattle; A^*_{t+1} = rational expectation of the spot price in period $(t + 1)$, formed in period t; C^*_{t+1} = rational expectation of consumption of beef in period $(t + 1)$, formed in period t; X^*_{t+1} = rational expectation of exports of beef in period $(t + 1)$, formed in period t; and $\phi_5 < 0; \phi_6, \phi_7, \phi_8 > 0$.

Short speculators in futures expect the futures price to fall, and their supply of futures contracts would be expected to vary directly with the current futures price and negatively with the expected futures price. Short speculators' supply of futures also would be expected to vary negatively with the marginal risk premium, according to the classic papers of Kaldor (1960), Brennan (1958), although Stein (1986, pp. 48-52) has argued, in his hedging pressure theory, that the effect of an increase in the risk premium on the forward price, and hence on the market positions of agents, may be positive or negative. Long speculators in futures, on the other hand, expect the futures price to fall, and their demand for futures would be expected to vary negatively with the current futures price, positively with the expected futures price, and again the influence of a change in the risk premium may be ambiguous. In this paper the activities of speculators are represented by the commitments of net short speculators, whose supply of futures is taken to be a direct function of the expected change in the futures price $\left(P_t - P_{t+1}^*\right)$, while it is accepted that the sign of the risk premium may be positive or negative. Hence this relationship can be written as

$$NSS_t = \phi_9 + \phi_{10}\left(P_t - P_{t+1}^*\right) + \phi_{11} r_t + e_{3t} \tag{3}$$

where NSS = market commitments of short speculators less market commitments of long speculators; r = marginal risk premium; and

$\phi_{10} > 0, \phi_{11} \gtrless 0$.

Consumption demand for live cattle, being demand for an input, can be represented as a function of the spot price of live cattle, and as a function of the parameters of demand for the end product, and parameters of the supply of other inputs. In this paper the consumption of live cattle is taken to vary negatively with the spot price of live cattle, directly with anticipated real income and with the price of hogs as proxies for parameters of demand for the end product, where hogs are assumed to be a substitute for beef in final consumption. It is assumed that corn and live cattle are complementary inputs in the creation of the final product, and consumption demand for live cattle is represented also as a negative function of the price of corn, which is employed here as a proxy for the supply of other inputs. To take account of the evidently longer time taken by firms to respond to changes in grain input prices, following the recent tendency to concentration of beef production in large-scale units, the price of corn has been lagged by 12 months.[1] The consumption relationship, therefore, is:

$$C_t = \phi_{12} + \phi_{13}A_t + \phi_{14}Y^*_{t+1} + \phi_{15}A^P_t + \phi_{16}A^G_{t-12} + e_{4t} \qquad (4)$$

where C_t = consumption demand for live cattle; Y^*_{t+1} = rational expectation of real income in period $(t + 1)$, formed in period t; A^P_t = spot price of hogs; A^G = spot price of corn; and $\phi_{13}, \phi_{16} < 0$; $\phi_{14}, \phi_{15} > 0$.

The model is completed with a spot price equation and a market clearing identity. The spot price of live cattle is related directly to the futures price, and negatively to the number of cattle marketed; the specification of this equation is augmented with seasonal dummy variables:

$$A_t = \phi_{17} + \phi_{18}P_t + \phi_{19}N_t + \sum_{i=1}^{11}\theta_i D_{it} + e_{5t} \qquad (5)$$

where N_t = cattle marketings in selected states; D_{it} are seasonal dummy variables;

and $\phi_{18} > 0$; $\phi_{19} < 0$.

The futures market clearing identity can be written:

$$L_t - H_t \equiv NSS_t \qquad (6)$$

This identity states that net long hedging equals net short speculation.

Expectations in this model are represented according to the rational expectations hypothesis (REH). Much has been written on the assumptions, implications and formation of rational expectations, and it is not intended to summarise this literature here; helpful surveys will be found in the work of Sheffrin (1983), Minford and Peel (1983), Pesaran (1989), and others. The opportunity will be taken here, however, to emphasise three points. First, any test of the REH is a joint test of the expectations hypothesis and the appropriateness of the model in which the expectations are embedded

(Maddock and Carter, 1982). Second, experimental evidence on the convergence of prices to a rational expectations equilibrium in asset markets has been discussed in the work of Plott and Sunder (1982), Friedman *et al* (1983), Forsythe *et al* (1984) and Harrison (1992). Experiments reported in the last three papers suggest *inter alia* that convergence to a full information equilibrium is more rapid with futures markets operating. Third, in a recent study of noise trader sentiment in 28 futures markets, Sanders *et al* (2000) found that noise traders (i.e. agents who trade on non-information) had little impact on prices. Indeed, their livestock group, which included live cattle, was the only group of markets for which the hypothesis of full orthogonality between sentiment and returns was not rejected.

Conventional identification conditions are not applicable to simultaneous, linear rational expectations models, with forward expectations (Pesaran, 1989, p. 119). As Pesaran (1989, pp. 120, 157-60) demonstrates, in these models the reduced form parameters are highly non-linear functions of the structural parameters, and rank conditions for global identification cannot be derived. Nevertheless, local identification is possible, and Pesaran (1989, p. 160) derives a practical order condition.[2] That condition is fulfilled in this model, and estimation, with the program employed (see below), would not proceed if this condition were not fulfilled.

III. Data, Tests for Stationarity and Cointegration, and Estimation

This section discusses the data, tests for unit roots and cointegration, and methods of estimation. The intra-sample period for this paper is 1986(01) to 1992(12) (84 observations), while the post-sample forecast period is 1993(02) to 1995(01) (24 observations).

Data

Data are discussed in this section under the headings 'Endogenous Variables' and 'Exogenous Variables'.

Endogenous Variables

The futures price (*P*) is the price in cents per lb for standard grade live cattle on the last trading day of the month (last trade), for a futures contract nearest delivery,[3] as quoted by the Chicago Mercantile Exchange, and purchased on disc from the Futures Industry Institute, Washington, D.C. Spot price data (*A*) are daily quotations, at Omaha, for choice steers, in cents per lb, published by the United States Department of Agriculture, and purchased on disc from the Futures Industry Institute, Washington, D.C.

Data on short hedging, long hedging (commercial), short speculation and long speculation (non-commercial) are open positions in number of contracts as reported by the Commodity Futures Trading Commission *Commitments of Traders* at end of month for large (reporting) traders (after September 28, 1993 these data were obtained from the website <www.cftc.gov>). Open positions for non-reporting traders are not classified as between hedging and speculation, and it has been suggested that for some commodities for some time periods these positions should be treated as all speculative (Peck, 1982). In the absence of such information about live cattle, however, open positions of non-reporting traders in this paper have been divided between hedging and speculation in the same ratio as those of reporting traders.

Consumption data are monthly observations on federally inspected slaughter of cattle in the United States in thousand head, obtained from the Kight-Ridder *CRB Commodity Yearbook* 1990, 1992, 1996. The marginal risk premium is represented as an M-GARCH variable, following Engle, Lilien and Robins (1987), and is measured by the conditional standard deviation (see below: Estimation) in number of contracts. It is, therefore, an endogenous variable. This treatment is consistent with the view of Stein (1991, p. 39) that the risk premium should be related to objectively measured economic variables, and contrasts with Giles *et al* (1985, pp. 752-54) where the risk premium is treated as exogenous.

Exogenous Variables

Income data are monthly observations on US Disposable Income in billion dollars, from the *Survey of Current Business*, divided by monthly observations on the Consumer Price Index, also from the *Survey of Current Business*. Data on exports are quarterly observations on US exports of beef in million pounds from Knight-Ridder *CRB Commodity Yearbook* 1990, 1992, 1996, interpolated to monthly data with the program TRANSF (Wymer, 1977). Spot price of hogs data are monthly average wholesale prices at Sioux City in dollars per hundred pounds, also from *CRB Commodity Yearbook* 1990, 1992, 1996. Corn prices are monthly average spot prices for No. 2 Yellow in Central Illinois in dollars per bushel, from the same source as hogs price data. Cattle marketings data are monthly observations, in thousand head, on US Cattle Marketings in Seven States, from the same source as export data.

Tests for Stationarity and Cointegration

In the interest of obtaining stationary residuals of the structural equations, unit root tests were conducted for all variables in the model. The residuals of the structural equations will be stationary if all variables are I(0), or alternatively, if some of these variables are non-stationary, this condition will be fulfilled only if the non-stationary variables are integrated of the same order, and are cointegrated. Both Augmented Dickey-Fuller (ADF) and Phillips-Perron tests were conducted for variables in this model. Both tests address the null of non-stationarity. In this paper a 10 per cent level of significance has been employed, because of the acknowledged low power of these tests (see Evans and Savin, 1981).

Calculated Phillips-Perron test statistics for all variables in the model, together with 10 per cent critical values are reported in Table 1, while corresponding statistics for Augmented Dickey-Fuller[4] tests are provided in Table 2. It will be seen that the variables A, Y, A^G are I(1), that the outcome for P is ambiguous, and that all other variables are stationary, according to these tests. In the case of the futures price (P), it may be tempting to prefer the Phillips-Perron (PP) test because of the generally greater power of the PP tests compared with the ADF tests (Banerjee *et al*, 1993, p. 113). In this case, however, it is arguable that the futures price should be treated as I(1), first because the spot price is unambiguously I(1) and the spot and futures prices are cointegrated,[5] and second, because $(P - A)$ is clearly I(0). The outcome of the PP test in this case could reflect a size distortion to which the PP test can be unduly prone under certain conditions (Banerjee *et al* 1993, pp. 108-109, 113, 129). The question is then whether the I(1) variables in the respective equations are cointegrated. Equation (1) contains two I(1) variables, P_t and P^*_{t+1}; cointegration in this case, however, can be presumed, because the instrument for P^*_{t+1} is a fitted value for P_{t+1} on a set of public information (see below: Estimation). In equations (2) and (3) all variables are stationary, while in equation (4) there are three I(1) variables, A, Y, A^G. It has been demonstrated above that the I(1) variables in equation (5), namely P and A, are cointegrated (see note 5). The question to be investigated, therefore, is whether the spot price of live cattle, income and the price of corn are cointegrated in equation (4): again 10 per cent significance level will be employed. Table 3A reports the results of an Augmented Engle-Granger test, which addresses the null of no cointegration, for these variables. This test suggests that this hypothesis is rejected at significance levels above

7.3%. The Engle-Granger procedure, however, suffers from the disabilities that it is capable of identifying one cointegrating relationship only, and the distribution of the test statistics may not be independent of the nuisance parameters. (This second difficulty does not apply in this case because both Y and A^G are exogenous.) To overcome these difficulties the Johansen maximum eigenvalue test is reported in Table 3B. This procedure tests the hypothesis that the number of cointegrating relationships m is at most equal to q ($q < n$, the number of I(1) variables in the equation), against the specific alternative that $m \leq q + 1$. This test suggests that there is one cointegrating relationship between these three variables at the 5% significance level. This outcome, while consistent with the result reported in Table 3A, may give rise to concerns that one of these variables may not be cointegrated with the other two. Nevertheless, the estimation of equation (4) can proceed on the anticipation that the residuals will be stationary, and the critical evaluation of this issue will be provided by the diagnostic tests on residuals (see later).

Estimation

Full information procedures for the estimation of linear rational expectations models, while potentially more efficient than limited information methods, require a full characterisation of the stochastic processes generating the exogenous variables, are less robust to specification errors, and are computationally more demanding (Pesaran, 1989, pp. 162-3, 189, 195-96). For these reasons, the model developed in this paper is estimated by limited information methods.

The first task is to obtain an instrument for the rational expectation of endogenous variables, such as P^*_{t+1} in (1). Following McCallum (1979), this is obtained as a fitted value, by ordinary least squares (OLS), for P_{t+1}, on the information set ϕ_t, defined here as all pre-determined variables in the model. That is $P^*_{t+1} = E(P_{t+1}/\phi_t)$ and $P_{t+1} = E(P_{t+1}/\phi_t) + \eta_t$ where $E(\eta_t) = 0$, and η_t is uncorrelated with the elements of ϕ_t under rational expectations (rational expectations of exogenous variables, such as X^*_{t+1} in (2), are treated in the same way). Estimation by limited information methods, implies that each equation is estimated separately. Different estimators, therefore, may be required for different equations, depending on the behaviour of the respective error terms. For example, if the error term of a structural equation is serially uncorrelated, consistent estimates of the coefficients, in the presence of forward rational expectations, can be obtained by instrumental variable (IV) estimation (McCallum, 1979, p. 67). This method was employed for equation (4), which has an expectation of an exogenous variable (Y^*_{t+1}). In addition, IV estimation was employed for equation (5), which has an endogenous regressor, a correction for first order serial correlation, but no expectational variables.[6]

In equations (1), (2) and (3), however, a Lagrange multiplier test revealed the presence of ARCH (Autoregressive Conditional Heteroscedasticity) effects, and the Akaike Information Criterion suggested that these effects should be represented by an EGARCH process to capture the evidently asymmetric relationship between innovations and volatility (see Nelson, 1991). The lag lengths employed were determined by general to specific modelling (see Maddala and Kim, 1998, pp. 78, 191). Consequently, the conditional variance of the error terms in equations (1) and (2) was represented as an EGARCH (2, 2) process, while that for equation (3) was represented as an EGARCH (1, 2). Conditional heteroscedasticity and volatility clustering evidently influence the market positions of agents, because the GARCH in mean or M-GARCH variables are significant (Engle, Lilien and Robins, 1987; see below Section IV: Results). Equations (1), (2), (3) were re-specified to incorporate these effects, and the conditional variances of the error terms of these equations were represented as described above. For example, equation (1) was estimated in the following form:

$$H_t = \phi_1 + \phi_2 P_t + \phi_3 P^*_{t+1} + \psi_1 \sqrt{h_{1t}} + e_{1t} \quad \text{(1A)}$$

where $\psi_1 \gtrless 0$, and h_{1t}, the conditional variance of e_{1t} is represented by

$$\ln(h_{1t}) = \alpha_0 + \alpha_1 \left| \frac{e_{1t-1}}{\sqrt{h_{1t-1}}} \right| + \alpha_2 \left| \frac{e_{1t-2}}{\sqrt{h_{1t-2}}} \right| + \beta_1 \ln h_{1t-1} + \beta_2 \ln h_{1t-2} + \gamma_1 \frac{e_{1t-1}}{\sqrt{h_{1t-1}}} + \gamma_2 \frac{e_{1t-2}}{\sqrt{h_{1t-2}}} \quad \text{(1B)}$$

Equations (1A) and (1B) were estimated by maximum likelihood. Corresponding adjustments were made to the specification of equations (2) and (3) which become

$$L_t = \phi_4 + \phi_5 (P_t - A_t) + \phi_6 \left(P^*_{t+1} - A^*_{t+1}\right) + \phi_7 C^*_{t+1} + \phi_8 X^*_{t+1} + \psi_2 \sqrt{h_{2t}} + e_{2t} \quad \text{(2A)}$$

$$NSS_t = \phi_9 + \phi_{10} \left(P_t - P^*_{t+1}\right) + \phi_{11} r_t + e_{3t} \quad \text{(3A)}$$

where r_t is measured by $\sqrt{h_{3t}}$.

The variance equation for (2A) is

$$\ln(h_{2t}) = \alpha_3 + \alpha_4 \left| \frac{e_{2t-1}}{\sqrt{h_{2t-1}}} \right| + \alpha_5 \left| \frac{e_{2t-2}}{\sqrt{h_{2t-2}}} \right| + \beta_3 \ln h_{2t-1} + \beta_4 \ln h_{2t-2} + \gamma_3 \frac{e_{2t-1}}{\sqrt{h_{2t-1}}} + \gamma_4 \frac{e_{2t-2}}{\sqrt{h_{2t-2}}} \quad \text{(2B)}$$

while the variance equation for (3A) is

$$\ln(h_{3t}) = \alpha_6 + \alpha_7 \left| \frac{e_{3t-1}}{\sqrt{h_{3t-1}}} \right| + \beta_5 \ln h_{3t-1} + \beta_6 \ln h_{3t-2} + \gamma_5 \frac{e_{3t-1}}{\sqrt{h_{3t-1}}} \quad \text{(3B)}$$

Equations (1A), (1B), ..., (3B) were estimated by maximum likelihood (ML), which will produce asymptotically efficient estimates. Estimations referred to in this section were executed with *Eviews* 2.0, Lilien *et al* (1995).

IV RESULTS: INTRA-SAMPLE PERIOD

Results are presented and discussed in this section under the headings parameter estimates, intra-sample simulation and diagnostic tests.

Parameter Estimates

Estimates of the coefficients of equations (1A), (1B), ..., (5), together with asymptotic t values and adjusted values of coefficient of determination, are presented in Table 4. It will be helpful to discuss the results for each equation in turn. In the short hedging equation (1A) estimates of the coefficients of the price and expected price variables suggest that there is support for the REH in the context of the selective hedging hypothesis, although this test evidently does not have the power to discriminate between Muth Rational Expectations and a situation where agents are still learning the true model driving the economy (see Goss and Avsar, 2000). The positive estimate of the coefficient of the conditional standard deviation $(\hat{\psi}_1)$ implies that short hedgers increase their hedge in response to an increase in uncertainty (as measured by the conditional variance; see Enders, 1995, pp. 158-59).

The results for the long hedging equation (1B) indicate that there is support for the REH in the context of the hypothesis of operational hedging, although again this interpretation is subject to the same qualification as in the case of the short hedging equation. Moreover, rational expectations of consumption and exports of beef evidently are satisfactory proxies for the spot market commitments of long hedgers. The negative estimate of the coefficient of the conditional standard deviation is interpreted to mean that an increase in uncertainty leads agents to reduce spot market commitments (correlation between $\sqrt{h_{2t}}$ and C^{*}_{t+1} and between $\sqrt{h_{2t}}$ and X^{*}_{t+1} is negative), and futures market positions are reduced in response to the reduction in spot commitments. The results for the net short speculation equation (3A) are not consistent with the REH embedded in a risk-averse model of speculation, although because of the joint nature of the hypothesis, as emphasised above, it is not clear from these results which branch of the hypothesis has been contravened. The negative estimate of the coefficient of $\left(P_t - P^*_{t+1}\right)$ is consistent with rival hypotheses such as risk-loving behaviour or noise trading. This outcome is somewhat surprising because Sanders *et al* (2000) did not find evidence of noise trader impact on prices for their livestock group (which included live cattle), and indeed livestock was the only group for which full orthogonality between noise trader sentiment and returns was not rejected (Sanders *et al*, 2000, p. 109). In light of the evidence presented by Sanders *et al* (2000) for live cattle, the preferred interpretation in this case is that these results are consistent with risk-loving behaviour (increasing marginal utility of money). Moreover, the positive estimate of the coefficient of the risk premium in equation (3A) is consistent with this interpretation. Such an interpretation is not inconsistent with the formation of rational expectations, but it clearly is inconsistent with the incorporation of the REH in a risk-averse model of speculation. To validate this interpretation, further research is required on the attitude to risk of non-commercials in this market.

The results for the consumption equation (4) are consistent with the hypothetized form of that relationship. The consumption demand for live cattle, as an intermediate good, varies negatively with the spot price of cattle, and directly with expected real income, suggesting that beef is a normal good as expected. Consumption demand for beef also varies directly with the spot price of hogs, which are assumed to be a substitute for cattle in consumption, while the significant negative estimate of ϕ_{16} is consistent with the hypothesized complementarity of corn and live cattle in production.

The results for the spot price equation (5) are as anticipated, confirming the positive relationship between spot and futures prices, and the negative impact of cattle marketings upon the spot price. The presence of a seasonal pattern in (5) was confirmed, although only five of the dummy variables were significant, and the others were omitted.

In the variance equations, 12 of the 16 EGARCH coefficients are significant, and the significance of the estimates of γ_1, γ_2, γ_3, γ_5 confirms the asymmetry between innovations and volatility in (1A), (2A), (3A). In (1A), (3A) the current value of the conditional standard deviation responds directly to prior innovations, while in (2A) this relationship is negative.

Intra-Sample Simulation

Results of intra-sample simulation are evaluated in Table 5 according to the criteria of correlation coefficient, Theil's inequality coefficient and per cent root mean square error. Concentrating on the per cent RMSE criterion, it will be seen that of the two prices, the better simulation is that of the futures price, and the only other variable simulated with comparable accuracy is consumption. It is noteworthy that although the per cent RMSE for *NSS* is affected by outliers, most of the turning points have been captured. Notwithstanding the anomalous result in the estimation of the coefficient of expected price change, the results for equation (3A) may not be misleading.

Diagnostic Tests

For valid statistical inference it is necessary that the residuals of the structural equations are non-autocorrelated, stationary and normally distributed. Table 6 reports the results of four diagnostic tests on the residuals of equations (1A), ..., (5). The Ljung-Box Q statistic, which tests the null hypothesis that all autocorrelation coefficients, up to lag 24, are zero, does not indicate the presence of autocorrelation in equations (1A), (2A), (3A), (4), (5) at the five per cent level. The Augmented Dickey-Fuller and Phillips-Perron tests address the null of a single unit root, and the results confirm the stationarity of the residuals of all equations at five per cent. The

Jarque-Bera statistics test the null of normality, which is not rejected for any equation at the five per cent level.

V POST-SAMPLE RESULTS

Table 7A summarises the results of post-sample simulation of spot and futures prices, two months ahead. It can be seen, according to the per cent RMSE criterion, that first simulation of both prices has improved compared with intra-sample tracking, and second that simulation of the futures price is again the more accurate. Table 7B compares the results of post-sample forecasts of the spot price by the model (AS) with alternative spot price forecasts. ANAIVE is a random walk forecast two months ahead, while P_{t-2} is the futures price lagged two periods, and it is clear that the model outperforms both alternative forecasts in per cent RMSE terms. The comparison between the post-sample forecasts of the spot price provided by the model and the lagged futures price affords a test of the semi-strong efficient markets hypothesis (EMH).[7] If the model outperforms the lagged futures price in this comparison, the model evidently contains information not reflected in the futures price, and this would constitute evidence against the EMH.[8] Conversely, if the lagged futures price outperforms the model, this is no proof of market efficiency, but may reflect an inadequate model.

In this case, while the model forecast of the spot price has a lower per cent RMSE than that of P_{t-2}, this difference in per cent RMSE's is not statistically significant.[9] The implication of this outcome is that the EMH should not be rejected, for this model evidently does not contain any information which is not reflected in the futures price. This result is consistent with the rational expectations hypothesis, which assumes that agents make full use of publicly available information, and that agents know the model driving returns in practice. This outcome is consistent with the results obtained by Leuthold and Garcia (1992), although it is not consistent with the formal result obtained by Garcia *et al* (1988), in which some rival forecasts were found to be superior to the forecast provided by the futures price. The result obtained here, however, is consistent with the conclusion reached by Garcia *et al* (1988, pp. 168-69) where employment of the best rival forecast for trading purposes generated small profits with high variances, so that the authors argued that inefficiency could not be demonstrated.

Finally, the question is whether the result obtained here, that is non-rejection of the EMH, can be reconciled with the presence of a significant M-GARCH term, which has been interpreted as a risk premium, in the equation for net short speculation (3A). Normally, the presence of such a risk premium could be expected to lead to rejection of the EMH. It is suggested that reconciliation can be found in the view that the post-sample test of the EMH is more powerful than an intra-sample hypothesis test on the coefficient of a single variable. A similar conflict was encountered in Goss and Avsar (2000, pp. 74, 79) where significant estimates were obtained of all coefficients of rational expectations of prices, yet the model significantly outperformed the futures price in post-sample forecasting. It is suggested as a future research topic, that an empirical investigation of the relative power of these two classes of test would be instructive.

VI CONCLUSIONS

This paper develops a simultaneous model of the US live cattle spot and futures markets, with expectations explicitly represented according to the rational expectations hypothesis. This last attribute appears to be lacking in the literature on the US live cattle market. The model contains functional relationships for short hedgers, long hedgers, net short speculators in futures, consumers and a spot price equation. A further objective of the paper is to employ post-sample forecasts of the spot price, by the model, to test the efficient markets hypothesis, because previous research on this issue is inconclusive.

The conclusions are as follows:

1. The results support the view that the behaviour of short hedgers is consistent with the selective hedging hypothesis in the classic papers of Working, although with expectations represented according to the rational expectations hypothesis (REH). Similarly, the behaviour of long hedgers is evidently consistent with Working's concept of operational hedging, although again with expectations specified according to the REH.
2. The results for net short speculators are anomalous, in that their market commitments appear to vary negatively with an expected fall in the futures price. This behaviour would be consistent with noise trading or risk-loving speculation.
3. The conditional variance in the hedging and speculation equations has been represented as an EGARCH (*p*, *q*) process, to capture the evidently asymmetric relationship between innovations (news) and volatility. The significant M-GARCH terms in these equations indicate that hedgers may increase or decrease their market commitments in response to an increase in volatility; (this will depend, in part, on changes in their spot market commitments). The results indicate that net short speculators increase their market commitments with volatility, an outcome which is consistent with the interpretation of risk-loving speculation.
4. The results for the consumption equation are conventional. They indicate that beef is a normal good, for which pork is a key substitute in consumption. Moreover, the results are consistent with the view that corn is a complementary input with live cattle in beef production.

The diagnostic tests on the residuals of these equations suggest that the residuals are stationary, normally distributed and are not autocorrelated.

5. Post-sample forecasts of the spot price by the model are numerically, but not significantly, superior to those implicit in a futures price lagged two periods from maturity. This outcome implies that this study produces no significant evidence against the efficient markets hypothesis, and is consistent with employment of the REH in model specification. This last result is consistent with the results in Leuthold and Garcia (1992) and with the conclusions in Garcia *et al* (1988).

NOTES

1 The authors are indebted to Ray Leuthold for this suggestion. A lag of 12 months was chosen because this lag length removes the persistent autocorrelation previously encountered in this equation.

2 This condition is that the total number of predetermined variables in the model should be at least as large as the total number of endogenous variables, predetermined variables and expectational variables in the equation minus one (Pesaran, 1989, p. 160).

3 The futures price quotation was selected according to the following rule: when the month is January, the future is February; when the month is February, March, the future is April; when the month is April, May, the future is June; when the month is June, July, the future is August; when the month is August, September, the future is October; when the month is October, November, the future is December; when the month is December, the future is February.

4 For the execution of the ADF tests the following general model was employed:

$$\Delta Z_t = \mu + \beta t + \gamma Z_{t-1} + \sum_{j=1}^{k} \phi_j \Delta Z_{t-j} + e_t \tag{E1}$$

where Z is an economic variable, μ is constant, β, γ, ϕ_j are coefficients to be estimated, $j = 1, 2, \ldots, k$, and e_t is NID $(0, \sigma^2)$. The hypothesis of a single unit root in Z_t is addressed by testing the hypothesis $H(\gamma = 0)$ in (E1). Inclusion of time trend and lagged values of ΔZ_t in the model for a specific test were determined according to whether serial correlation was present in e_t, and by general to specific modeling (see Maddala and Kim, 1998, pp. 78, 191).

5 The hypothesis of no cointegration between A and P is rejected at one per cent with an Augmented Engle-Granger test, where the calculated test statistic is –4.9096; the p-value is 0.0002. With a Johansen maximum eigenvalue test, the hypothesis of no cointegrating relationships, against the alternative of one, is rejected at one per cent with a likelihood ratio of 26.5522 and a one per cent critical value of 20.04.

6 The instruments employed in the estimation of equation (4) are:

$$N_t, A_{t-1}, Y^*_{t+1}, A^P_t, A^G_{t-12}, P_{t-1}, X_t, NSS_{t-1}, NLH_{t-1} \text{ (where } NLH \equiv L-H\text{)}, C_{t-2}.$$

Instruments employed in the estimation of equation (5) are:

$$A_{t-2}, P_{t-2}, C_{t-2}, X_t, A^G_t, A^P_t, N_t, Y^*_{t-1}, D_{3t}, D_{4t}, D_{5t}, D_{6t}, D_{11t}.$$

7 In producing post-sample forecasts of the spot price, the parameters were re-estimated so that the model always produced a two-month-ahead forecast. This updating procedure ensures that the model and the lagged futures price were placed on the same informational footing.

8 Finding a model which significantly outperforms the futures price as a forecast of the spot price is a necessary condition in the demonstration of market inefficiency. A sufficient condition is the employment of such a model in trading routines which produce significant risk-adjusted profits (see Rausser and Carter, 1983; Garcia *et al*, 1988; Leuthold and Garcia, 1992).

9 According to the test proposed in Granger and Newbold (1986, pp. 278-79), the calculated test statistic is 0.98, which is not significant.

Table 1 Unit Root Tests: Phillips-Perron

Variable	Calculated Test Statistic	10% Critical Value	Order of Integration
P	− 3.3544	− 3.1581	I(0)
A	− 2.8169	− 3.1581	I(1)
(P-A)	− 4.8569	− 2.5851	I(0)
H	− 3.7114	− 2.5851	I(0)
L	− 4.8889	− 2.5851	I(0)
NSS	− 4.0944	− 2.5851	I(0)
C	− 6.8878	− 2.5851	I(0)
X	− 3.1993	− 3.1581	I(0)
Y	− 2.7388	− 3.1581	I(1)
A^P	− 2.7769	− 2.5851	I(0)
A^G	− 1.9396	− 2.5851	I(1)
N	− 6.5429	− 2.5851	I(0)

Table 2 Unit Root Tests: Augmented Dickey-Fuller

Variable	Calculated Test Statistic	10% Critical Value	Order of Integration
P	− 2.9644	− 3.1585	I(1)
A	− 2.9112	− 3.1585	I(1)
(P-A)	− 5.5751	− 2.5855	I(0)
H	− 3.7235	− 2.5858	I(0)
L	− 3.9326	− 2.5853	I(0)
NSS	− 4.2315	− 2.5855	I(0)
C	− 3.1376	− 2.5858	I(0)
X	− 3.9285	− 3.1597	I(0)
Y	− 2.1977	− 3.1585	I(1)
A^P	− 3.0038	− 2.5853	I(0)
A^G	− 1.9059	− 2.5855	I(1)
N	− 4.4587	− 2.5853	I(0)

Table 3A Engle-Granger Cointegration Test

Equation	Variables	Calculated Test Statistic	p-value	Null Hypothesis
(4)	A, Y, A^G	− 3.5881	0.0731	no cointegration

Table 3B Johansen Cointegration (maximum eigenvalue) Test

Equation	Variables	Calculated Test Statistic	5% Critical Value	No. of Cointegrating Vectors: m
(4)	A, Y, A^G	38.5853	34.91	$m \leq 0$
		15.3623	19.96	$m \leq 1$

Table 4 Parameter Estimates*

Equation	Coefficient	Variable	Estimate	Asymptotic t Value
(1A)	ϕ_1	Constant	70220	6.771
	ϕ_2	P_t	2229.41	14.210
	ϕ_3	P^*_{t+1}	− 2883.55	11.756
	ψ_1	$\sqrt{h_{1t}}$	4.196	15.182
$\bar{R}^2 = 0.6154$	DW = 1.692			
(1B)	α_0	Constant	10.408	64.976
	α_1	$\left\lvert \frac{e_{1t-1}}{\sqrt{h_{1t-1}}} \right\rvert$	0.235	6.500
	α_2	$\left\lvert \frac{e_{1t-2}}{\sqrt{h_{1t-2}}} \right\rvert$	-0.119	1.588
	β_1	$\ln h_{1t-1}$	0.220	5.272
	β_2	$\ln h_{1t-2}$	0.184	4.275

Equation	Coefficient	Variable	Estimate	Asymptotic *t* Value
	γ_1	$\frac{e_{1t-1}}{\sqrt{h_{1t-1}}}$	0.320	44.785
	γ_2	$\frac{e_{1t-2}}{\sqrt{h_{1t-2}}}$	0.383	14.188
(2A)	ϕ_4	Constant	33404	13.523
	ϕ_5	$(P_t - A_t)$	– 743.331	– 5.860
	ϕ_6	$(P^*_{t+1} - A^*_{t+1})$	241.122	2.761
	ϕ_7	C^*_{t+1}	9.180	13.634
	ϕ_8	X^*_{t+1}	76.691	3.545
	ψ_2	$\sqrt{h_{2t}}$	– 6.739	– 11.405
$\bar{R}^2 = 0.4571$	DW = 2.008			
(2B)	α_3	Constant	4.961	86.109
	α_4	$\left\lvert\frac{e_{2t-1}}{\sqrt{h_{2t-1}}}\right\rvert$	– 0.161	– 3.907
	α_5	$\left\lvert\frac{e_{2t-2}}{\sqrt{h_{2t-2}}}\right\rvert$	0.260	9.475
	β_3	$\ln h_{2t-1}$	0.685	41.087
	β_4	$\ln h_{2t-2}$	0.012	0.756
	γ_3	$\frac{e_{2t-1}}{\sqrt{h_{2t-1}}}$	– 0.184	– 7.091
	γ_4	$\frac{e_{2t-2}}{\sqrt{h_{2t-2}}}$	0.015	0.419
(3A)	ϕ_9	Constant	– 56548	– 3.600
	ϕ_{10}	$(P_t - P^*_{t+1})$	– 3166.338	– 8.602
	ϕ_{11}	r_t	5.542	3.131
$\bar{R}^2 = 0.620$	DW = 1.812			

Equation	Coefficient	Variable	Estimate	Asymptotic *t* Value
(3B)	α_6	Constant	5.277	26.868
	α_7	$\left\lvert \frac{e_{3t-1}}{\sqrt{h_{3t-1}}} \right\rvert$	0.033	0.649
	β_5	$\ln h_{3t-1}$	1.232	256.087
	β_6	$\ln h_{3t-2}$	– 0.532	– 93.620
	γ_5	$\frac{e_{3t-1}}{\sqrt{h_{3t-1}}}$	0.174	3.106
(4)	ϕ_{12}	Constant	2597.633	3.159
	ϕ_{13}	A_t	– 25.219	– 4.064
	ϕ_{14}	Y^*_{t+1}	54.032	1.835
	ϕ_{15}	A^P_t	14.054	3.991
	ϕ_{16}	A^G_{t-12}	– 145.893	– 1.969
$\overline{R}^2 = 0.251$	DW = 2.073			
(5)	ϕ_{17}	Constant	15.312	1.730
	ϕ_{18}	P_t	0.891	8.826
	ϕ_{19}	N_t	– 0.0055	– 2.174
	θ_3	D_{3t}	4.516	5.631
	θ_4	D_{4t}	4.167	4.440
	θ_5	D_{5t}	7.216	6.707
	θ_6	D_{6t}	4.420	4.662
	θ_{11}	D_{11t}	1.838	2.564
	ρ_5		0.633	7.400
$\overline{R}^2 = 0.9124$	DW = 2.0272			

Notes: Equations (1B), (2B), (3B) are variance equations.
Estimation is by maximum likelihood for (1A), (1B), (2A), (2B), (3A), (3B) and by instrumental variables for (4), (5).
DW is the Durbin-Watson statistic.
ρ_5 is a first order autocorrelation coefficient.

Table 5 Intra-Sample Simulation*

Variable	Correlation Coefficient	Theil's IC	%RMSE
A	0.8988	0.0260	5.5320
P	0.9389	0.0200	4.2509
H	0.8434	0.0584	12.7958
L	0.7785	0.0551	11.2663
NSS	0.8118	0.1702	29.2649**
C	0.6306	0.0298	5.8798

Notes: *Theil's inequality coefficient and per cent RMSE are defined in Pindyck and Rubinfeld (1981, pp. 362, 364).
**Four outliers clipped.

Table 6 Diagnostic Tests on Residuals

Test \ Equation	1A	2A	3A	4	5
Ljung-Box Q					
Calculated χ^2_{24}	14.194	30.543	18.456	16.252	24.864
Critical $\chi^2_{24}(0.05)$	36.415	36.415	36.415	36.415	36.415
ADF					
Calculated test statistic	– 4.7131	– 5.5253	– 4.8417	– 2.9813	– 5.1629
5% Critical value	– 2.8972	– 2.8972	– 2.8972	– 2.9042	– 2.8981
PP					
Calculated test statistic	– 8.7961	– 9.2853	– 8.1972	– 9.2656	– 9.6332
5% Critical value	– 2.8963	– 2.8963	– 2.8963	– 2.9029	– 2.8972
Jarque-Bera					
Calculated test statistic	1.6660	0.5387	1.6895	1.2430	0.5076
p-value	0.4347	0.7639	0.4297	0.5371	0.7759

Table 7A Post-Sample Simulation: Spot and Futures Prices

Variable	Correlation Coefficient	Theil's IC	%RMSE
A	0.9267	0.0238	5.3445
P	0.9427	0.0098	2.0876

Table 7B Post-Sample Spot Price Forecasts

Forecast Model	Correlation Coefficient	Theil's IC	%RMSE
AS	0.9267	0.0238	5.3445
ANAIVE	0.7265	0.0318	7.0386
P_{t-2}	0.7146	0.0324	7.2097

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