An Annual Model of Purebred Breeding Bull Price

R. Clyde Greer and J. J. Urick

A geometric distributed lag model was hypothesized as the structural relationship between purebred breeding bull price and economic variables determining the bull's value as a productive asset. Parameter estimates for the nonstochastic difference equation were obtained from a data sample including nineteen years of average price paid for yearling purebred Hereford bulls. Statistical results supported the hypotheses; expected bull price was responsive to calf price and cowherd inventory. An oscillating geometric adjustment pattern was found which reflected periodicity in bull replacement decisions. The general conclusion was that relevant information is rapidly incorporated into purebred bull market behavior and price adjusts quickly.

Key words: breeding bull price, distributed lags, livestock prices.

Cattle price analyses have focused almost solely on the behavior of participants and price outcomes in the markets for the primary output of the beef enterprise. A broad literature considers, individually and the linkages among, the market for calves and the subsequent market stages as the output moves from calves to fed cattle to meat products. These studies provide estimates of short- and long-run elasticities and an understanding of the adjustment processes. Noticeably missing from this literature, other than some work on breeding cattle inventories (Rucker, Burt, and LaFrance), are price analyses of the markets for breeding cattle. We suspect this void is not an implied unimportance or lack of interest, but rather it reflects differences in market organization and data availability. Time-series data relevant to modeling meat animal markets are readily and consistently available through the efforts of public information agencies. Such is not the case for breeding animal markets, specifically breeding animal prices.

The purpose of this research was to estimate the structural coefficients of the relationship between economic variables and purebred breeding bull price. The economic variables reflect the value of a breeding bull as a productive asset and, therefore, a producer's willingness to pay for bulls. The estimated coefficients are useful in calculating price flexibilities which provide some insight into market behavior and information to decision makers.

The following section presents the economic model, a discussion of the data sample, and the statistical model to be estimated. Results and implications are then discussed, followed by a concluding section.

Theoretical Considerations, Data, and Model Specification

Purebred beef bulls are purchased for their value as a capital asset which, along with the existing or planned female breeding herd, will produce a saleable product—calves. Thus, a producer's willingness to purchase bulls is in part derived from calf price and in part derived from the planned female inventory. Added to these variables are characteristics specific to the line of purebred Herefords from which the data sample was available. The model hypothesized was

$$(1) \qquad BP = f(CP, CI, HI, D78, D79),$$

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where *BP* is average Miles City Line 1 yearling bull price, year *t*; *CP*, medium frame, number 1 steer feeder calf price; *CI*, January 1 inventory, beef cows and heifers that have calved; *HI*, January 1 inventory, heifers 500 pounds and over, replacements for beef cows; *D*78 = 1 when year was 1978, = 0 otherwise; and *D*79 = 1 when year was 1979, = 0 otherwise.

The primary data available to this research were the average prices paid for yearling Miles City Line 1 bulls (*BP*) from 1966 through 1984 at the Fort Keogh Livestock and Range Research Station (LARRS) surplus research animal sale. LARRS is a cooperative U.S. Department of Agriculture (USDA)–Montana Agricultural Experiment Station conducting beef cattle and range research. Surplus cattle suitable for breeding are sold the first week of May (except 1981) through an annual auction in Miles City. The sale is similar in character to a private purebred breeder's annual production sale. The reputation of the LARRS Line 1 stock is such that, in addition to Montana producers, buyers from many of the western and Great Plains states are present or represented with occasional participation by breeders from Corn Belt states. Commercial cow-calf operators as well as purebred breeders are active participants at the auction. Thus, there is a broad geographic as well as industry representation to the prices paid at the LARRS sale.

Delineating Line 1 yearling bulls from all of the bulls sold provides a homogenous data sample and an opportunity to gain some insight into market behavior and outcomes with respect to producer acquisition of a durable asset. One might speculate that the same variables and mechanisms extend to the broader bull market, but generalization to even other lines within the Hereford breed is left to the reader.

Calf price (*CP*) is a measure of the value of the output resulting from holding the asset. Thus, its inclusion as an explanatory variable follows directly from economic theory. There was a question, however, regarding which calf price best represented the information used by bull market participants; the annual average or the fourth quarter (October, November, December) average price. The fourth quarter price may correspond more closely to the character of the cow-calf range cattle sector where calves are predominately spring born then weaned and sold in the fall. Consequently, for a majority of the cow-calf producers the relevant output price may be the fall price. One further consideration was important. While current and past calf prices are known, prices to be received for future calf production are not known with certainty. Thus, the willingness to pay for bulls is based upon some expectation regarding future calf price; an expectation likely formed from a series of past weighted calf prices rather than simply the contemporaneous price.

Since bulls have an expected life greater than one year it seems their expected contribution to net return should also consider maintenance cost; nutrients and perhaps health care expenditures. However, nutrient sources, native vegetation, and feedstuffs, would not differ greatly from those used in the production of slaughter cattle. While the quantities and proportions might differ, the prices and, consequently, bull maintenance cost would be highly correlated with the cost of producing meat animals. Thus, separate variables measuring maintenance cost would not likely add information to that already incorporated through calf price.

Economic logic suggests that investment decisions regarding female breeding stock are related to output price just as is the bull purchase decision. Thus, the effect of female inventory change, just as bull maintenance cost, may well be captured by calf price. However, the total stock may include additional information since usual management is to maintain some female/bull ratio. While adjustments in the ratio are possible in response to calf price, the total inventory may well provide additional information to the decision process: the willingness to purchase bulls as replacements for those that have completed their useful life. Useful life may be defined not only in terms of physical well-being but also in terms of their relation (genetic) to females in or entering the breeding herd. Specifically, the willingness to purchase replacement bulls may well be based upon the expected inventory with a distinction made between females in the breeding herd (*CI*) and replacements (*HI*). The variable *HI* is not measured without error. First, it is unlikely that exactly all heifers held as replacements in fact enter the breeding herd. Second, given spring calving there are two distinct, but not practically separable, subsets within *HI*: (a) calves just weaned, between six and eleven months old and not yet bred, and (b) heifers

one year older than those just weaned and which are bred and nearing their first calving.

Selecting *CI, HI,* and *CP* data series was an initial concern. Average bull price (*BP*) was taken from only one sale (annually) which included only an average of twenty Line 1 yearling bulls. While Line 1 has at least a regional reputation, no a priori argument dictated which data series—a Montana or a national series—best represented the information used by participants. To test their relative contribution, both Montana and U.S. inventories and Montana and Kansas City calf prices were included in the initial data sample. In addition, annual as well as fourth quarter (October, November, December) average calf prices were included. Data for calf prices and herd inventories were taken from relevant issues of *Livestock and Meat Statistics* (USDA, ERS) and *Livestock Detailed Quotations* (USDA, AMS). All prices were deflated by the consumer price index (CPI: 1967 = 100).

The two binary variables, *D*78 and *D*79, were included in the model to test the hypothesis that there was a change in the reputation of the Line 1 stock during the sample period. Reputation or buyer perception of differences between close substitutes is difficult to define and even more difficult to measure. However, particularly strong show ring performances of a few Line 1 animals in 1977 appeared to attract more attention to the line. This attention, it was hypothesized, was translated into price increases at the LARRS sale greater than would be explained by calf price or female inventory change(s). The apparent increase in 1978 and 1979 average price was not solely attributable to the highest price paid but included an increase in the lowest and median prices as well.[1] While a change in reputation might occur abruptly, as suggested by the binary variables, the effect is likely to be distributed over time. The effect would diminish, however, if the "strong performance" were not maintained.

The time-related adjustments in bull price to expected values of future calf prices and inventories and the possible dissipation of the effect of a change in reputation call for a dynamic structure to appropriately model purebred bull price behavior. With no compelling a priori reasoning regarding the exact type of dynamic adjustment in bull price, it was assumed that expected values of the independent variables were generated by geometric weights on past observations. For a simple regression case, the model was developed as

$$(2) \quad Y_t = \alpha + \beta(X_t + \lambda X_{t-1} + \lambda^2 X_{t-2} + \ldots).$$

Then, applying the Koyck transformation and adding a white noise disturbance term yields an equation that can be estimated, i.e.,

$$(3) \quad Y_t = \alpha(1 - \lambda) + \beta X_t + \lambda Y_{t-1} + e_t$$

(see Johnston; Judge et al.; Kmenta). Following the work of Burt, with application by Marsh, the difference equation was expressed as the expectation of the lagged value of the dependent variable, i.e.,

$$(4) \quad Y_t = \alpha(1 - \lambda) + \beta X_t + \lambda E(Y_{t-1}) + u_t,$$

where $u_t = \lambda u_{t-1} + e_t$. The advantage is that the systematic part of the regression is purely exogenous even though the disturbance process is first-order autoregressive.

Applying the above to bull price, the statistical model was a first-order nonstochastic difference equation with an AR(1) disturbance process:

$$(5) \quad BP_t = \alpha(1 - \lambda) + \beta_0 CP_t + \beta_1 CI_t + \beta_2 HI_t + \beta_3 D78 + \beta_4 D79 + \lambda E(BP_{t-1}) + u_t.$$

Because of $E(BP_{t-1})$ and u_t, the parameters are nonlinear and ordinary least squares (OLS) is inappropriate. Consistent least squares estimates were calculated with a modified Marquardt nonlinear least-squares algorithm.

Results and Implications

Parameter estimates and statistics for the dynamic model are presented in table 1. The regression fit was quite good; adjusted R^2 (excluding the error structure) was .989, and the standard error of the estimate, 89.11, was 4.7% of sample mean *BP*. All asymptotic *t*-ratios for the respective independent variables and error term were significant at the 99% probability level.[2] It also should be noted that the param-

[1] While there was certainly a "high-priced" bull each year, in no year was the highest price so much larger than the second highest or succeedingly lower prices that deleting it from the average calculation could be defended.

[2] The error structure of the model was tested by estimating it exclusively as an MA(1) and ARMA(1, 1) process. Throughout estimation, the estimated coefficient on the MA term, whether alone or as part of the ARMA process, was not significantly different from zero, nor was there improvement in other measures of statistical fit.

Table 1. Regression Results, Bull Price Equation

Variables	Estimated Coefficient	Asymptotic t-Ratio
Constant	−7,173.30	−22.21
MCI_t	143.50	13.53
HI_{t-2}	331.90	11.53
KCP_{t-1}	87.499	24.41
$D78$	1,980.80	19.75
$D79$	2,994.40	25.91
$E(BP_{t-1})$	−.27605	−9.29
e_{t-1}	−.64392	−3.47
Statistics		Value
Standard error of the estimate		89.112
Adjusted $\bar{R}^2$		.9921
$\bar{R}^2$ (excluding error structure)		.9885
Durbin-Watson		2.121

eter estimates were robust based upon results from alternative specifications and truncation of the data sample, suggesting considerable credibility in the structure of the behavioral relation.[3] For both the inventory and calf price variables the broader representation, U.S. inventory and Kansas City Price (*KCP*) were selected because there was at least marginal improvement in statistical fit. The structure of the relation and variables included in the final model provide some interesting insight in terms of information used in price discovery in the purebred bull market as represented by this data sample.

Results with respect to the inventory variables were consistently indicative of an age distribution phenomenon and led to the inference that producers distinguish among three subsets of females. In none of the specifications tested was the estimated coefficient on HI_t significantly different from zero. Thus, it was inferred that the current inventory of replacement heifers did not add information to that already expressed in calf price. The conclusion with respect to the existing breeding herd inventory was quite different as MCI_t[4] and HI_{t-2} contributed significant information in addition to that expressed in calf price. At time t, HI_{t-2} is the inventory of young females approaching their second or third calving and in the process of establishing a production record, and MCI_t is the inventory of females that have an established production record and have reached biological maturity.

The respective estimated coefficients of 143.50 and 331.90 for MCI_t and HI_{t-2} suggest a relatively strong positive response in bull price to changes in these variables. Using the model coefficients along with the relative sizes of inventories provided estimates of price responsiveness to percentage changes through time-related flexibilities. The short-run price flexibilities for MCI_t and HI_{t-2} inventories were calculated to be 2.48 and 1.17, respectively. That is, a 10% increase in *MCI* would elicit almost a 25% increase in *BP*, while a 10% increase in HI_{t-2} would result in an 11.7% increase in *BP*. The long-run price flexibilities were also calculated, with the percentage values being 1.94 and .92 for a 1% change in *MCI* and HI_{t-2}, respectively.[5] A plausible explanation for the greater responsiveness to *MCI* change lies in the biological relation between cow age and pounds of calf produced. While genetic improvement might be anticipated, i.e., through selection the HI_{t-2} females would be genetically superior to the *MCI* females, the biology of reproduction and current practices are such that *MCI* females—mature females with an established record—are the ones most likely to be bred to reputation bulls. Consequently, the expected marginal impact of *MCI* on bull price would be greater.

The statistical results supported the hypothesis that fourth quarter calf price was the relevant output price in the bull purchase decision. The specific notation KCP_{t-1} is actually a result of the calendar and does not represent a lagged effect. Since the LARRS sale was held in May (except 1981) the most recent or contemporaneous (in terms of time only) price information known was the preceding fourth

[3] The model was also tested by including a supply variable, number of bulls offered for sale, as a separate regressor. With the variable included, parameter estimates on the other variables were not different than those presented in table 1 in at least the first two digits, nor were the measures of fit improved. The result may well support LARRS management's statement that offering animals for sale is dictated by research program focus and resource constraints rather than revenue generation.

[4] MCI_t is defined as $CI_t - HI_{t-2}$. At first glance it might seem that HI_{t-1} should also be subtracted from CI_t to estimate the inventory of mature cows. However, such a subtraction would, first, doubly subtract the younger subset of females in HI_{t-2} and, second, subtract from *CI* heifers that have not yet been counted in *CI*, those approaching their first calving.

[5] Long-run price flexibilities for this first-order, nonstochastic difference equation with no higher-order lagged values of the explanatory variables were calculated by $(\hat{\beta}_i/1 - \hat{\lambda})\ (\bar{X}_i/\overline{BP})$, where $\bar{X}_i$ and $\overline{BP}$ were respective sample means.

quarter.[6] Additional lags on *KCP* were tested but did not improve the statistical results, suggesting that producers buying bulls regard the most recent calf price as having the most weight in reflecting market information about the future.

The short-run price flexibility with respect to *KCP* (calculated at the sample means) was 1.286. Thus, the immediate response of a producer to a change in calf price is a somewhat greater-than-proportionate change in willingness to pay for reputation bulls, bulls expected to have a higher genetic potential for gain. It may well be that when calf price increases, bulls are relatively more valuable because genetic improvement will be immediately distributed over the herd; whereas the corresponding response in cowherd size or genetic potential is subject to some fixity. Over the longer run an equilibrium based on movement toward a proportionate response would be expected. Indeed, the calculated long-run bull price flexibility with respect to calf price from this data sample was 1.008.

In the geometric function, calf price is implicitly dynamic by entering through the difference equation and undoubtedly indirectly affects the cowherd inventory variables. These two effects could not be separately measured. If the cowherd effect was strictly static, then producers, knowing the number of cows, would instantaneously adjust their bull purchases and MCI_t and HI_{t-2} should be excluded from the difference equation. Such an exclusion would be tantamount to restricting the dynamic effects to calf price expectations. When such a change was specified, a reduction in statistical precision resulted; and so it was concluded that (based on this data sample) the initial specification was superior.

Estimated coefficients on the two binary variables were positive and relatively large. The two-year increases in bull price, with the increase in the second year being somewhat larger, attributed to these two variables are unexplained except for the subjective term reputation. It should be noted that, while the increase occurred rapidly, the effect did not decrease as abruptly as might be inferred from a cursory view of the binary variables. Both variables were included in the difference equation because, again, the statistical results were superior to results with them excluded. Thus, a continuing effect of the increase in reputation persisted or was distributed over time.

The estimated coefficient on the difference equation term, −.276, implied a very rapid dampening of distributed lag effects from the independent variables. Thus, a general conclusion was that relevant information was rapidly incorporated into purebred bull market behavior and price adjusts quickly. In fact, 95% of the adjustment toward long-run equilibrium would be realized within 2.3 years (Nerlove and Addison, p. 874). The pattern of adjustment, however, was oscillating rather than a continuous decline. While the result may be somewhat surprising, the sign and absolute order of magnitude were consistent throughout estimation. The inference was some rigidity or periodicity to the adjustment process. A plausible explanation lies with the biology of the beef breeding herd and transactions costs incurred in replacing an owned asset with, perhaps, an improved but essentially a like asset. Common practice is to select female replacements from within the herd and to breed them so that they calve at two years of age. Thus, once a bull is introduced into a herd, there is a period of two years, and perhaps three with careful management, before inbreeding becomes a concern. Additionally, yearling bulls particularly are purchased under considerable risk or uncertainty. While they have been tested for breeding soundness, their breeding performance and the performance of their offspring is subject to considerable variation. Breeding performance can be assessed initially after the first year or less by pregnancy testing, but assessing offspring performance beyond weaning requires at least 18–24 months. While there may be market-induced motivation to replace a currently held bull with a bull offering a different genetic contribution, the risk (uncertainty) involved with assessment reduces the problem to one of essentially replacing an asset with a like asset. Thus, the inbreeding dimen-

[6] In 1981 the sale was held the first week of November. Thus, buyers had available quite different information than they did for the usual spring sale; within rather narrow limits, fourth quarter 1981 calf price was known; and they had at least begun to formulate, if not achieve, January 1982 inventory levels. Consequently, KCP_{81}, MCI_{82}, and HI_{80} were input as the 1981 observations. As part of model testing, the chronological data sample was input and a dummy variable specified to denote the 1981 fall sale. The results were judged inferior to those reported in table 1; parameter estimates were very similar to those reported in table 1, $\hat{\rho}$ was almost 20% larger, and the measures of statistical fit were marginally poorer. This comparison was viewed as further support for the hypothesis that information is incorporated and utilized rapidly in the bull market.

sion of the problem dominates and implies a two- to three-year replacement period.

Conclusions

Little research exists regarding price behavior in the purebred breeding bull market. Statistical results from a distributed lag model support a rapid incorporation of information into bull purchase decisions. The dynamic time path of bull price (generated by model parameter estimates) provides useful information in understanding a specialized segment of the cattle market. One conclusion is that bull price is relatively efficient since value adjustments occur quite rapidly. The model itself is a geometric, first-order nonstochastic difference equation with only contemporaneous values of the explanatory variables entering directly. The variables are measures of (a) the value of output, Kansas City fourth quarter average feeder calf price; (b) the age distribution of the stock of the complementary input held, mature U.S. beef cow and young beef cow inventories; and (c) a change in the reputation of the specific Hereford line from which the sample was drawn.

The results were not sufficient to delineate calf price uncertainty from asset fixity, i.e., discerning adaptive expectations from partial adjustment components. The geometrically declining effect of shifts in calf price and cowherd inventories was oscillating. The oscillating pattern was consistent with periodicity in bull replacement as a result of genetic relationships within the herd and uncertainty in assessing breeding performance of potential replacements. Given time for the adjustments to be completed and long-run equilibrium achieved, the estimated responsiveness of bull price to changes in the explanatory variables was consistent with theoretical expectations; long-run bull price change was positive and proportional to a calf price change and greater than proportional with respect to a change in the mature cowherd inventory. The latter, increasing (decreasing) relative worth of reputation bulls as the mature cowherd inventory increases (decreases) raises interesting, but not currently testable, hypotheses regarding the substitution of reputation bulls for nonreputation bulls and/or adjustment of the cow/bull ratio.

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