The Beef Cow Replacement Decision

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This analysis examines effects of several common assumptions on net present values (NPVs) of beef cows. While effects on NPVs vary over a price cycle or successive price cycles, several generalities manifest themselves. A cow is not likely to recover the lost revenue from not having just one calf. Incorporating genetic improvement into the herd increases the probability of an older cow being culled. Variable net replacement/culling rates make sense in the context of cattle inventory and price cycles because of the effects cyclical series of prices have on NPV.

Key Words: asset replacement, cattle cycle, cull, net present value

Simplifying assumptions are often necessary in order to proceed with conceptual and empirical work. In studies of livestock inventories and dynamics, these assumptions include constant genetics (no genetic improvement) in replacement females, constant culling and replacement rates over the cattle cycle, the formation of producers'/ decision-makers' expectations and other factors that motivate decisions affecting inventory changes, and sources of replacement females. Each of these assumptions distorts model outcomes in specific ways. These assumptions have implications for total cow and heifer inventories, especially when viewed as a series of decisions over inventory and price cycles.

This study extends earlier work on the beef cow replacement decision (Jarvis, 1974; Yager, Greer, and Burt, 1980; Melton, 1980; Blake and Gray, 1981; Bentley and Shumway, 1981; Ritchie, 1995; Rucker, Burt, and LaFrance, 1984; Trapp, 1986; Bourdon and Brinks, 1987; Spire and Hotz, 1995; Foster and Burt, 1992; Frasier and Pfeiffer, 1994; Tronstad and Gum, 1994; Marsh, 1999; and others) by examining the effects of selected assumptions on empirical net present value (NPV) models of the beef cow replacement decision. The contextual thrust of this analysis is on the cattle cycle, especially the effects of decision making at various points during the cattle cycle.

Effects of the interaction between NPV and inventory and price cycles are specifi- cally examined under assumptions of genetic improvement, varying portions of heifer

calf crop retention, the distribution of expected productive potential, and failure to produce just one calf over a cow's productive life. This study does not examine the full optimal replacement problem, but rather focuses on NPVs of cows and heifers as potentially productive assets. Although the value of a heifer sold at or near weaning is compared to her potential productive value as a cow, we do not examine the problem of optimal cow replacement by comparing NPV to the opportunity costs of cow slaughter in the current period.

The article begins with a review of the literature pertaining to the cow replacement decision. A simple conceptual framework is then presented. The empirical work that follows focuses on the NPV elements of the conceptual framework. In the empirical sections, data and data issues are described, construction of a series of data matrices is documented, and finally the implications of the results from examining our constructed NPV data for understanding replacement dynamics through the cattle cycle are discussed.

Literature Review

The principal criteria for general asset replacement of current value versus expected future productive value have been examined in both deterministic (Perrin, 1972) and stochastic applications (Burt, 1965; Collins and Hanf, 1998; Cooper, Haltiwanger, and Power, 1999). Specifically looking at cows as assets, several studies have addressed various aspects of optimal cow replacement (Yager, Greer, and Burt, 1980; Melton, 1980; Bentley and Shumway, 1981; Ritchie, 1995; Trapp, 1986; Bourdon and Brinks, 1987; Spire and Hotz, 1995; Foster and Burt, 1992; Frasier and Pfeiffer, 1994; Tronstad and Gum, 1994; Marsh, 1999).

Jarvis (1974) used a portfolio approach to determine optimal slaughter age. Building on Jarvis' study, Rucker, Burt, and LaFrance (1984) developed a model of cattle inventories that dealt with problems using annual data, first differences in dynamic modeling, and stochastic elements of right-hand-side (RHS) variables (prices, weather, and hay production). Stochastic elements can affect error terms of models, and consequently the precision of resulting parameters. The algorithm used by Rucker, Burt, and LaFrance allowed them to partition RHS variables into stochastic and nonstochastic variables, then treat the model as a nonstochastic difference equation with autoregressive moving average (ARMA) disturbances. Trapp (1986) allowed retention and culling rates to vary over the cattle cycle, but not stochastically.

Various stochastic elements have been addressed in different studies. Frasier and Pfeiffer (1994) incorporated biological uncertainty in their model of optimal cow replacement. Tronstad and Gum (1994) incorporated stochastic prices in their model of the cow-culling decision, and, in earlier investigations, Bentley, Waters, and Shumway (1976); and Yager, Greer, and Burt (1980) included both stochastic production and stochastic prices. Collins and Hanf (1998) criticized the use of and demonstrated bias in results from using mean values in NPV calculations when variables are stochastic, thus pointing out the need to think of replacement in terms of distributions rather than point estimates.

Others have examined cattle cycles by abstracting from the detail encountered in the NPV/microeconomic framework (Mundlak and Huang, 1996; Rosen, Murphy, and Scheinkman, 1994; Rosen, 1987). Nerlove and Fornari (1998) expressed criticism of the Rosen, Murphy, and Scheinkman (1994) paper for its abstracted simplicity (for example, its treatment of prices), for its use of a long inconsistent data series, and for not accounting for the significant structural change the industry has undergone in the 100+ years of the study period.

Several papers have concentrated on selection or culling criteria (Bourdon and Brinks, 1987; Spire and Hotz, 1995; Ritchie, 1995). In addition, Melton (1980) has addressed the issue of culling and replacement decisions under genetic progress, and increasing productivity has been examined at both the herd level (Ringwall, Berg, and Boggs, 1992) and in the aggregate for U.S. cattle inventories over the cattle cycle (Marsh, 1999). Ringwall, Berg, and Boggs, however, focused almost entirely on physical aspects of maximum production, not optimal production, and mention economic factors only in passing.

Genetic improvement generally means moving the herd average for a set of traits toward some more or less specific goal defined by the decision maker. Many studies, both older and more recent, have either alluded to (Kaps, Herring, and Lamberson, 1999; Grosz and MacNeil, 2001; Bennett and Gregory, 2001; Ferriera, MacNeil, and Van Vleck, 1999; Hayes, Newman, and Shepherd, 2000; Sullivan et al., 1999; MacNeil, Short, and Urick, 1999; Thallman et al., 1999) or discussed directly [U.S. Department of Agriculture/Animal and Plant Health Inspection Service (USDA/APHIS), 1994a; Ritchie, 1995; Spire and Hotz, 1995; Ringwall, Berg, and Boggs, 1992; Bullock et al., 2000; MacNeil, Urick, and Decoudu, 2000; Marsh, 1999] the use of weaning weight as a selection criterion for improving various aspects of herd genetics.

The reason for using weaning weight as the measure of genetic progress in this study is two-fold. First, its use here emphasizes the economic importance of weight to the cattle producer's revenues and the relationships between weaning weight and several economically important traits such as milk production, growth rates, and yearling weights (Ensminger, 1987; Warwick and Legates, 1979; O'Mary and Dyer, 1972; MacNeil and Mott, 2000). Second, our use of weaning weight reflects the paucity of data at the national level for specific traits, including weaning-weight data. There are additional traits for which measures other than weaning weight are employed as selection criteria and which define genetic improvement in their particular contexts, but data are not available at the national level.

The notion that "bigger is better" has undergone several rounds of qualifications historically, as negative traits have been encountered in the pursuit of growth (Sullivan et al., 1999; MacNeil, Short, and Urick, 1999; MacNeil and Mott, 2000; MacNeil, Urick, and Decoudu, 2000). Heavier birth weights, heavier mature weights, and longer feeding times to grade are negative traits which have followed selection for heavier weaning and yearling weights. More recently, the goal is to produce the heaviest calves possible that will reach desirable yield grade scores without excessive feeding and without encountering the negative economic effects of feeding

larger, less efficient cows or suffering dystochia problems from larger birth weights (Kaps, Herring, and Lamberson, 1999; Grosz and MacNeil, 2001; Bennett and Gregory, 2001).

A Conceptual Model of Replacement

Several factors can modify the NPV of an asset in the replacement decision. Asset productivity is distributed according to some (unknown?) probability distribution for each asset cohort. For livestock, this means some assets (animals) from each age cohort are more productive than others the same age. This range of productivity and its implications for the genetic pool of the cow herd are not captured in the usual point-estimate dependent framework (Collins and Hanf, 1998). When these highly productive assets can be identified, it is advantageous to keep them in production in any given year. In addition, expected NPVs may fluctuate with the patterns of asset and product price trends or cycles expected over successive periods. Optimal replacement behavior could vary systematically with, for example, cyclical prices. Finally, expected NPV is seriously affected if an asset does not produce, for what-ever reason, during even one period of its productive life. Thus, the probability of a given asset remaining in production is a function of individual and collective asset productivity, age, and other variables.

The beef cow is an asset in which the issues of age distribution, cyclical prices and inventories, and skips in production affect replacement decisions (USDA/APHIS, 1994b, 1997). Expansions of cattle inventories are often rationalized in the literature as the result of higher cattle and calf prices motivating heifer retention for herd building (e.g., Arzac and Wilkinson, 1979; Nelson, 1984). Others suggest cow herds increase during periods of adverse economic conditions—low prices or low to negative net returns—to be in position to capture higher returns over cycles (Rucker, Burt, and LaFrance, 1984; Trapp, 1986). One possible explanation for this dichotomy may lie in how producers view price expectations for the future, the effects of cyclical prices on cow and heifer NPVs, and where during the cattle cycle a replacement decision is made (Rucker, Burt, and LaFrance; Trapp).

Suppose a livestock producer is considering what to do with a new crop of calves, especially the female calves (heifers), and replacement of some portion of the livestock breeding herd. The producer's objective, W_m, is to maximize the expected utility of wealth:

$$(1) \qquad W_m = \max E[U_m(NPV_{1,J}, ..., NPV_{k,J}; NPV_{k+1,J}^p, ..., NPV_{N,J}^p)],$$

where U_m is a utility function for the utility of wealth for the mth producer and wealth is solely embodied in the cow herd. $NPV_{n,J}$ is the NPV of female n ($n = 1, ..., k$) raised on the operation or breeding females already in the herd, and $NPV_{n,J}^p$ denotes females purchased either as replacements or as breeding-aged females ($n = k + 1, ..., N$) to be added to the herd, with $1 < k < N$. Once added to the herd, each element (breeding female) of $NPV_{n,J}^p$ reverts to an element of $NPV_{n,J}$ for future comparisons. Each

female is expected to have a productive life of J production periods, which is peculiar to each cow, and should be designated as J_n. The necessary sub-subscripting to denote each cow's age has been left out in the interest of reducing notational clutter. It is the behavior of these NPVs under various assumptions with which this paper is concerned.

Replacing cows with heifers presents the rancher an interesting set of dilemmas. First, the decision of whether to keep or sell some of the heaviest, and often oldest, heifers from each calf crop for replacements directly affects current-year income. Larger heifers are often worth more in total receipts per head, so selling them increases current-year revenue, while keeping them reduces current-year revenue but may increase revenues over the next several years. Second, most calves are born during March through May, and sold when weaned—often at seasonally low fall prices. And finally, ranchers must decide whether or not to replace a cow that is not pregnant or that fails to wean a calf. In general, the choice of which cows to replace is a nontrivial, capital-asset replacement problem.

Holt and Moschini (1992) and Antonovitz and Green (1990) recognized risk can affect inventory behavior. Risks associated with each cohort of females affects the expected income streams generated by each cohort. Risk elements embodied in the selection of breeding females include, but are not limited to, risks that the replacement female may not breed the first time, may suffer from accident, illness, calf loss, or death, or offspring may not exhibit the expected genetic potential, and heifers can be culled for a variety of reasons before they enter the breeding herd (Spire and Hotz, 1995). Females already in the herd may also suffer illness, injury, bad teeth, eye, udder, foot, or other physical problems, calf loss, or death. Prices may not move according to the expected patterns.

These chronic problems adversely affect expected NPV and make cows less desirable when compared with the prospect of a replacement heifer's longer potential productive life. The adverse effects on NPV may come from increases both in annual costs of and lowered calf weaning weights from keeping a physically impaired or inferior cow. In the empirical model below, risk elements are indirectly incorporated in the data generation process through the use of distributions rather than incorporating a direct risk measure. That is, instead of incorporating a direct measure of risk, like variance, each segment of the distribution of weaning weights is examined. The graph in figure 1 shows the distribution of weaning weights by cow age group (old cows, young cows).

More specific to this study, a cow/calf operator makes keep-or-sell decisions about some or all individual calves in each calf crop when the calves are weaned, when they are put on pasture, or when they are put into the feedlot. The rancher often knows which group of heifers will definitely be kept for replacements and which group of heifers will definitely not be kept for replacements (Spire and Hotz, 1995). It is the heifers near the boundary of this keep-or-sell continuum, the "marginal" heifers, that are affected by situation-dependent optimal criteria at the decision juncture. Factors determining these optimal criteria include the distribution of weaning weights, age, productivity, prices, costs, and when during the cattle cycle
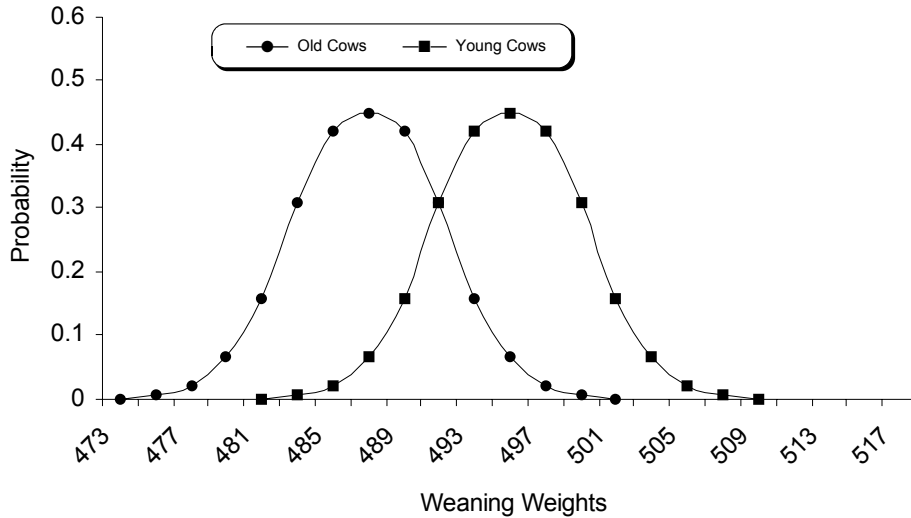
Figure 1. Distribution of weaning weights by cow age group

the decision is made. Our model allows us to examine each of these factors in the following sections.

Let the producer consider the NPV of the nth breeding female at time t, represented by

$$(2) \qquad NPV_{n,J,t} = \sum_{j=1}^{J} \frac{(R_{n,t+j} - C_{n,t+j})}{\displaystyle\prod_{h=0}^{J-1}(1 + r_{t+h})} + \frac{S_{n,t+J}}{\displaystyle\prod_{j=0}^{J-1}(1 + r_{t+j})} - S_{n,t-1}.$$

$NPV_{n,J,t}$ is the NPV of the nth breeding female at time t, where the nth female $\in$ {cow herd} and is expected to produce for J periods into the future. The first term on the right-hand side (RHS) of equation (2) is the discounted net revenue from all the offspring breeding female n will have during her remaining time (j production periods) in the herd, with $R_{n,t+j} = P_{t+j}X_{n,t+j}$, where P_{t+j} is price of $X_{n,t+j}$, the units of output (i.e., pounds, cwt, etc.) at time $t + j$ for offspring in each production period ($j = 1, 2, ..., J$) a breeding female has in the future; $C_{n,t+j}$ represents the costs of producing offspring at time $t + j$; and r_{t+h} is the discount rate applicable at time $t + j$ when $j >= h$. The second RHS term is the discounted salvage value of the nth breeding female that remains in the herd J periods. The third RHS term is the "cost" of the nth female up through the period just before she enters the herd and could represent the costs of raising or purchasing a replacement heifer or purchasing a replacement cow. $NPV_{n,t}$ increases as costs or discount rates decrease and as P_{t+j} increases. The change in $NPV_{n,t}$ as J increases is ambiguous, depending on whether successive annual net returns are positive, negative, increasing, or decreasing.

Net Present Value Data

In this section, we develop several matrices of NPVs of future production for heifer calves and cows of various ages remaining in the herd from 1 to 14 calving years, a period extending beyond one cattle cycle. One set of matrices is based on steer, heifer, and cow prices for 1973–97, and automatically incorporates the innate dynamic, stochastic price relationships through one recent cattle cycle. Prices for the 1973–97 period are required to allow full information on future NPVs for the 1973 through 1984 years. The other set of matrices is based on inflation-adjusted prices for a simulated 12-year cycle (Trapp, 1986), which we repeat over several cycles for a total of 45 years.

Dimensions of each matrix are the number of years for which prices extend 14 years into the future (either 12 years or 45 years for repeated cycles) by the number of production periods (14 potential production periods); that is, matrix dimensions are either 12×14 or 45×14. Each element of each matrix is calculated by directly applying equation (2): the sum over j_n periods of [(calf price in $t + j_n$ times calf weight) discounted for $t + j_n - 1$ periods]. The expected number of production periods for each matrix ranged from 1 to 14. Both sets of matrices were calculated for increasing percentages (10%, 20%, ..., 50%) of heifer calves kept for replacements. The result was a set of matrices for each price regime. These matrices are summarized using regression techniques.

The underlying distribution of heifer calf weaning weights is crucial to the development of the NPV matrices used in this analysis. Information on the distribution of weaning weights is not readily available on a regular basis for the national cow herd, although it is sometimes available for a specific firm or subset of firms, so some facsimile must be constructed from known data.

There is a positive relationship between a heifer's weaning weight relative to the weaning weights of other heifers in her cohort and her genetic potential, including future productivity and relative weaning weights of calves she produces (Ensminger, 1987; Warwick and Legates, 1979; O'Mary and Dyer, 1972; MacNeil, Urick, and Decoudu, 2000; Ferriera, MacNeil, and Van Vleck, 1999; Bennett and Gregory, 2001; Kaps, Herring, and Lamberson, 1999; MacNeil and Mott, 2000). Therefore, those heifers in the heaviest end of their cohort will, on an age-of-calf, age-of-dam adjusted basis, produce calves falling in the heaviest end of the weaning weight distribution of their respective cohorts. For this reason, heifer weaning weight is often used as one of several selection criteria (USDA/APHIS, 1994a; Spire and Hotz, 1995).

The relationship between a heifer's relative weaning weight and the relative weaning weights of her calves to other calves in the herd is not perfect. Selection of a single individual may not achieve the desired result. However, by expanding the selection process to the whole herd or calf crop, there is an increased likelihood of capturing superior genetics for the selected trait, generally resulting in some measure of genetic progress (Kaps, Herring, and Lamberson, 1999; Sullivan et al., 1999). In our study, this relationship between heifer weaning weight and measures of potential

productivity (weaning weight, yearling weight, and rates of gain) is exploited by using relative weaning weights as a proxy for relative genetic potential.

Genetic improvement has an influence on the rate of change, direction of change, and the age structure of the cow herd, all of which have effects on expected NPVs. Bulls also have some effect on genetic progress in a herd (Ensminger, 1987; Warwick and Legates, 1979; O'Mary and Dyer, 1972; Thallman et al., 1999; MacNeil, Short, and Urick, 1999; Sullivan et al., 1999; Bullock et al., 2000; Ferriera, MacNeil, and Van Vleck, 1999), but, in this investigation, their influence is subsumed in their effects on replacement females. We incorporate a simple constant rate of genetic improvement in heifers and cows through increases in calf weaning weights each year, differences in productive capacity of different aged females, and the effects of selecting various portions of the heifer calf crop on weaning weights. These results are also summarized in the regression analyses presented below.

Distribution of Heifer Calf Crop Weaning Weights

One of the risks we can incorporate is production risk in the form of distributional effects of heifer weaning weights in the context of retention rates and genetic improvement (figure 1). By assuming weaning weights are distributed according to some probability distribution, an average weaning weight for all heifer calves can be calculated. The normal distribution, with its symmetry and its other well-known properties, is a convenient distribution to use, and Blake and Gray (1981) verified yields for cow/calf and yearling operations in New Mexico were normally distributed. Based on the limited distributional data available through USDA/APHIS (1997), the average weaning weight of all calves was 515 pounds in 1996; bulls and steers averaged 529 pounds, nonreplacement heifer calves averaged 494 pounds, and replacement heifers averaged 513 pounds.

In addition, the USDA/APHIS (1997) 513-pound average is assumed to be based on an estimate of 32% of heifers kept for replacements in 1996. The 32% retention rate is based on USDA's reported 17% of calves saved for replacements during the last half of 1993 (USDA/APHIS, 1994b). It is assumed 1% of calves are replacement bull calves, and the remaining 16% are heifers. If half of the calves in a calf crop are heifers, then 16% of all calves translates into 32% of heifer calves. From the preceding information and assumptions, a distribution of weaning weights for heifers was constructed with a mean for 1996 of 501 pounds and a standard deviation of 10 pounds.

It was useful to separate the heifers into weight subgroups of 10% of the estimated distribution of weaning weights. The 10-percentile subgroups (deciles) were arbitrarily chosen. To estimate average weaning weights for each subgroup (decile), the minimum and maximum weights for each subgroup (the weight at the breaks between the deciles) were averaged. Then to estimate the average weaning weight for the top $x\%$ (i.e., 10%, 20%, ..., 50%) of heifers kept for replacements, a weighted average for the $x\%$ retention group was calculated. That is, the total number of heifers in each decile subgroup was multiplied by the average weight for the same subgroup,

and then total weights for each decile in *x* were added and divided by the total number of heifers kept.

This tedious procedure was necessary because the shape of the normal distribution does not yield the same slope from minimum to maximum for each decile. Even breaking the averaging process into deciles resulted in estimates which are only approximate. In addition, the average weaning weight for the top decile of the heifer calf crop is potentially underestimated because we used an arbitrary and conservative estimate of the upper bound for the heaviest heifer in the calf crop; the average weight for the second decile is overestimated because at that point in a normal distribution, the probability density function is convex to its base; and the estimated average weight for the fifth decile is underestimated because of concavity to its base.

Net Present Values

To construct the NPV data matrices, the weight distribution of calves was modified to account for genetic improvement by means of a spread-preserving shift of the distribution to heavier mean weights as one moves through successive years. That is, calves with heavier average weaning weights were born to successive cohorts of cows with more genetic potential. The genetic production potential of each sequentially older cohort is increased by 0.5% per year. Since data on weight distribution are for 1996, weaning weights were adjusted by a 0.5% decline for each year before 1996, no adjustment for 1996, and by a 0.5% increase in 1997. There was no accounting for stochastic variability in average weaning weights from one year to the next due to weather, disease, and all the other factors affecting weaning weight variation.

It was assumed that a heifer or cow would have both steers and heifer calves during her productive life, and that a proportion of her calves could be kept for replacements. The value of each heifer calf in the cohort, valued as if they had been sold the fall before as just-weaned calves, was also calculated for use in comparing NPVs of heifers. Additionally, the NPV of cows potentially with a range of years left in the herd but not weaning the current year's calf was calculated for comparison. A constant discount rate of 6% was assumed throughout.

Prices for the fall quarter, when the calves most likely would have been sold as weaned calves, were used in the expected NPV calculations, with price data taken from USDA/Economic Research Service publications (*Livestock, Dairy, and Poultry Situation and Outlook*, 1973–98, and *Red Meats Yearbook*, 1995). Cow prices were Sioux Falls, boning utility prices; calf prices were Oklahoma City medium no. 1 feeder steer (500–550 pound) and feeder heifer (450–500 pound) prices.

It was suspected that these fall prices follow a different pattern from average annual prices often used in these beef cow asset replacement studies. To test this working hypothesis, average fall steer and heifer prices were regressed on annual average prices per cwt. R^2s for both steer and heifer regression models were the same, 0.88. In addition, the fall prices are generally more volatile than annual averages, which would also cause fall price-based estimates of net annual incomes to be more volatile.

Matrices of NPVs were constructed for two sets of prices over cattle cycles. For repeated cycles, simulated inflation-adjusted steer prices (Trapp, 1986) were used over a 45-year period, and for the actual cattle cycle of the 1970s, actual prices for 1973–97 were used over a 12-year cycle. Both sets of prices were used over increasing percentages of heifer calves kept for replacements (*PCTHFRS*) and for cows with 1 to 14 years of production left (*YRSLEFT*).

The 1973–97 price series provided data for NPVs for only 1973–84, because calculating NPVs for the 1984 heifers with 14 years of production left required prices from 1984 through 1997. A variable for each year of each 12-year cycle in the simulated steer-price data was created by giving each year a value from 1 to 12. NPVs for repeated cycles for cows not producing the next calf of their expected productive lives were also simulated using 30% of heifer calves as replacements and actual prices for 1973–97. This procedure generated a matrix of NPVs that was not easy to interpret. To facilitate interpretation of these estimates, these matrices were summarized by regressing NPVs for cows (*COWNPV*) on *PCTHFRS*, *YRSLEFT*, and either *CYCLE* for simulated prices or *YEAR* for actual prices for point during the cattle cycle. The results are reported below.

Results and Discussion

NPV simulations demonstrate that NPVs depend on price patterns and cyclical variations. Regressing the NPVs of cows on year of the cycle, percentage of heifers kept for replacement, and years of production remaining in the cow's life, yielded the following estimates with simulated steer prices (*t*-statistics are in parentheses):

$$(3) \quad COWNPV = 103.7761 + 27.3066 * PCTHFRS - 0.4763 * PCTHFRS^2$$
$$\qquad\qquad (2.90) \qquad (17.42) \qquad\qquad (-19.66)$$

$$- 4.6920 * YRSLEFT + 0.6992 * YRSLEFT^2 + 12.8077 * CYCLE$$
$$\quad (-0.91) \qquad\qquad (2.45) \qquad\qquad (2.20)$$

$$- 0.5865 * CYCLE^2 - 0.3331 * PCTHFRS * YRSLEFT$$
$$\quad (-1.72) \qquad\qquad (-4.43)$$

$$- 0.27558 * PCTHFRS * CYCLE - 0.0627 * YRSLEFT * CYCLE$$
$$\quad (-3.26) \qquad\qquad\qquad (-0.22)$$

$$R^2 = 0.2326, \quad F\text{-statistic} = 55.29 \text{ (significant at } < 0.001 \text{ level).}$$

This regression may be considered a second-degree, Taylor-series approximation to a more representative but unknown functional form. The mean for *COWNPV* for this regression is $356.81. Taking derivatives with respect to each variable, we observe that *COWNPV* increases at a decreasing rate as *PCTHFRS* declines, peaking at 24.164% of heifers kept for replacements. *COWNPV* decreases from our arbitrary 14 years of remaining productive life (*YRSLEFT*), reaches a minimum at 10.79 years of production left, then increases. Cows with seven or fewer years of production left

have higher NPVs than older cows. *COWNPV* increases to a maximum at 3.47 years from the start (trough) of the cattle cycle (*CYCLE*), then decreases.

Similar results, in terms of NPVs though not parameter estimates, were obtained using actual prices for 1973–97. The second estimated equation was specified as

$$(4) \quad COWNPV = -13{,}150{,}729 + 798.6892 * PCTHFRS + 0.01451 * PCTHFRS^2$$
$$\qquad\qquad\quad (-10.03) \qquad\;\; (5.58) \qquad\qquad\qquad (0.69)$$

$$+\, 2{,}050.262 * YRSLEFT - 0.17525 * YRSLEFT^2 + 13{,}280.97 * YEAR$$
$$\quad (4.09) \qquad\qquad\qquad (-0.72) \qquad\qquad\qquad\; (10.02)$$

$$+\, 3.3503 * YEAR^2 - 1.13849 * PCTHFRS * YRSLEFT$$
$$(-10.01) \qquad\qquad (-18.39)$$

$$-\, 0.404132 * PCTHFRS * YEAR - 1.02478 * YRSLEFT * YEAR$$
$$(-5.59) \qquad\qquad\qquad\qquad (-4.04)$$

$$R^2 = 0.70, \quad F\text{-statistic} = 218.22 \text{ (significant at} < 0.001 \text{ level).}$$

The maximum NPV calculated from the derivative with respect to *YEAR* occurred in year 1977.49, the year of lowest real prices (1982–84 dollars), two years after the peak in cattle and calf inventories (1975), and one year after peak commercial beef production (1976). The mean for *COWNPV* for this regression is $221.45. For the regression with actual prices over what is basically one cattle cycle, the derivatives are not as useful as in the former regression. For the data range underlying this regression, the quadratic functional form serves only to capture some of the curvature in the otherwise linear relationships for *PCTHFRS* and *YRSLEFT*. The maximum NPV with respect to *PCTHFRS* occurred at the lowest (10%) value for heifers kept as replacements. Similarly, NPVs for cows with the shorter times left in production (*YRSLEFT*) were highest.

On the surface, results from the two regressions appear quite different. Parameter estimates are different because the time variables for year in the models differ by a scale factor of 100; that is, two digits represent years 1 through 45 in the simulated model, equation (3), versus the four digits that represent 1973 through 1984 in the second model, equation (4). This scale difference resulted in much higher values for the cycle variable in equation (4) than in equation (3). The difference in R^2 values occurs because the first model contains a larger number of observations, and therefore more variability. This variability exists because the underlying price data contain a stochastic element, despite the fact that the data were "manufactured" in a systematic manner.

Results are, however, consistent in several ways. First, keeping replacement heifers appears to have the highest advantage over keeping cows when prices have reached a cyclical low point and will be increasing, like 1975–77. Second, heifers in the smallest percentage of heifer crop retained for replacements had higher NPVs than most cows already in the herd. Given weaning weight as a selection criteria, these heifers in the smallest percentage of heifer crop retained for replacements would be

the ones with the highest weaning weights, which translates into the heifers with the highest expected genetic potential.

Generally, when comparing expected NPVs of replacement heifers and potential cull cows, results here suggest it is not advantageous to keep heifers and sell cows every year. NPVs for the oldest cows were higher than some younger cohorts because of relatively less discounting of impending salvage values for the older cows and because of where the salvage point was in the cattle cycle. These findings are consistent with Trapp's (1986) optimal solution and with Rucker, Burt, and La-France's (1984) forward-looking expectations.

These results can also be examined from the perspective of decreasing marginal genetic contribution to expected NPV from each additional increment in the proportion of the heifer calf crop kept for replacements. *COWNPV* is negatively affected (negative signs on parameter estimates) as *PCTHFRS* increases and interacts with *YRSLEFT* and *CYCLE*. In 1993 and 1996, only a small percentage of breeding aged females (5.2% and 5.7% of cows sold, respectively) were culled for producing poor calves (USDA/APHIS, 1994b, 1997). This small portion of cows culled is reason to suspect that most genetic progress occurs through introducing improved genetics both from selecting superior replacement females, raised or purchased, and through using better bulls, rather than from culling low producing cows.

The Effect of Missing a Calf on Net Present Value

In most instances, it appears to be more important to keep cows that wean any calf than it is to cull cows that produce lightweight calves. Interpreting higher values for *PCTHFRS* as a move toward lower herd average weaning weight, and correspondingly lower *COWNPV*, any calf is worth more than no calf. About 7% to 7.5% of cows do not have calves in a given year (USDA/APHIS, 1997). Between 19% (USDA/APHIS, 1994a) and 25% (USDA/APHIS, 1997) of cows sold were sold because of pregnancy status, meaning they most likely were not pregnant.

Examining *COWNPV* in the context of the same variables as the two regressions above, but looking at only the 30% level of *PCTHFRS* and introducing a situation where a cow fails to have its next calf, *COWNPV* drops significantly. A cow is not likely to recover the lost revenue if she fails to have just one calf. Under this scenario, most NPVs are negative for the study period (table 1). Spire and Hotz (1995) argue retaining middle-aged cows that are not bred and that perhaps have been nutritionally mismanaged might be appropriate when calf prices and replacement costs are high. Nevertheless, our results indicate there are few instances in which a cow of any age not weaning the next of her remaining calves will likely have a high enough NPV to justify keeping her instead of replacing her.

In general, the only positive NPVs are for 10-year-old to 5-year-old cows during 1973, with the highest NPVs for cows with seven years of expected production left. Over the period 1973–80, positive NPVs shift to cows with fewer years of production left.

Table 1. Net Present Values for Cows Not Weaning Their Next Calf, 1973–83

Years of Expected Production	Net Present Values, by Year										
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
14	-110.30	-33.61	-17.79	6.40	12.23	-92.41	-184.33	-226.79	-238.20	-272.75	-319.24
13	-102.41	-71.53	-25.55	23.27	20.85	-43.57	-159.07	-209.00	-170.82	-173.34	-229.47
12	-61.79	-67.60	-71.81	8.79	31.41	-47.17	-122.41	-195.76	-163.35	-113.29	-135.71
11	-38.63	-28.95	-73.66	-46.44	8.82	-48.58	-141.16	-170.29	-160.59	-116.63	-83.56
10	1.93	-3.91	-32.02	-47.71	-48.92	-71.13	-141.00	-188.69	-132.34	-112.46	-85.83
9	45.91	39.57	-4.82	-2.89	-49.47	-130.95	-163.26	-187.04	-150.61	-81.28	-80.15
8	131.06	86.67	41.93	26.62	-1.17	-130.15	-225.04	-209.17	-147.63	-99.41	-45.84
7	140.22	177.41	92.51	76.85	30.90	-77.58	-222.57	-273.20	-169.86	-95.03	-63.80
6	72.49	187.59	189.34	131.13	84.93	-42.22	-165.22	-269.12	-236.50	-117.37	-57.91
5	-102.82	120.99	207.23	241.08	151.01	29.92	-110.10	-192.53	-218.88	-174.72	-68.01
4	-100.30	-64.39	137.24	260.67	268.30	101.26	-32.10	-132.73	-136.54	-154.89	-127.63
3	-57.58	-61.28	-58.65	187.11	289.80	226.86	45.03	-48.70	-72.01	-66.47	-105.45
2	-38.45	-15.55	-54.74	-19.91	212.56	250.93	179.67	34.41	18.20	3.06	-10.56
1	161.73	5.17	-5.67	-15.15	-6.16	170.31	206.68	178.48	107.43	99.82	64.30

Selling versus Retaining Heifers

Another dynamic which turns the cow replacement problem into more of a portfolio management problem is the alternative of selling the heifers at weaning or at some other time before they are added to the breeding herd. Looking at this alternative, adding heifers to the breeding herd makes the most dollar sense in years of low prices with expectations of higher prices. Specifically, in years of low prices with expectations of higher prices in the future, the NPV of a heifer added to the breeding herd is higher than the immediate net revenue generated by selling her at weaning. At other times, keeping a heifer as a replacement heifer comes at the loss of considerable short-term revenue.

As shown in table 2, for the 1973–84 period, the NPV of the top 20% of heifers if retained for breeding was higher than their value at weaning had they been sold on a per pound basis. At the 30% level, heifer NPV was higher for the years 1974–79, and lower for 1973 and 1980–84. The number of years for which NPVs are higher than value if sold at weaning declines as the percentage kept for replacements increases. At 50%, heifers were worth more at weaning on a per pound basis than they were as replacements for every year.

Culling and Retention Rates for Various
Classes of Breeding Females

Closely related to the previous section on selling versus retaining heifers is culling rates and heifer retention rates. Culling rates and heifer retention rates are important because rates of change in the herd genetic pool depend on selection pressure. As cull and retention rates vary, rates of change in the herd genetic pool also vary. Chavas and Klemme (1986, p. 61) note that "under genetic progress, one would expect a high proportion of heifers in the dairy herd to give added incentives to cull older, less productive, cows."

The cattle producer's objective function is a balance between the elements of incorporating genetic (and therefore economic) improvements into the herd and maximizing revenues by selling heifers whose expected NPV is maximum as weaned or feeder calves, before they are allowed to produce calves when the expectation of the value of their calves is low. The majority of replacement heifers are raised on the ranch where they were born. According to USDA/APHIS (1994a), in 1992, 88.4% of replacement females were raised, while 11.6% were purchased. USDA/APHIS also reported that of the beef calves weaned from July 1, 1993 to December 31, 1993, 17% were kept for replacements. Presumably this 17% is almost entirely made up of heifer calves, as most bulls used for breeding are purchased. Spire and Hotz (1995) estimate "at least 16% of a cow herd is replaced annually."

Trapp's (1986) results for a simulated 12-year cattle cycle, and Chavas and Klemme's (1986) results for dairy replacements also support variable replacement and culling percentages. Trapp, studying investment and disinvestment in beef cow breeding herds, permitted cow herd size to vary over his cycle by allowing culling

Table 2. Selling Heifers at Weaning versus Keeping Them as Replacements, 1973–84

| | Percent of Heifer Calf Crop Kept for Replacements for 14 Years of Production | | | | | | | | | |
| | 10% | | 20% | | 30% | | 40% | | 50% | |
Year	Average Value at Weaning	NPV	Average Value at Weaning	NPV	Average Value at Weaning	NPV	Average Value at Weaning	NPV	Average Value at Weaning	NPV
1973	108.52	333.64	107.47	212.52	105.67	97.42	104.27	-14.84	103.02	-123.66
1974	-29.23	339.43	-29.74	212.90	-30.62	92.66	-31.29	-24.63	-31.90	-138.34
1975	-20.55	439.77	-21.15	300.89	-22.19	168.87	-22.99	40.10	-23.71	-84.74
1976	-16.20	498.66	-16.87	348.53	-18.03	205.76	-18.92	66.48	-19.72	-68.56
1977	21.69	577.27	20.89	415.19	19.52	261.02	18.47	110.60	17.52	-35.26
1978	150.98	581.15	149.52	408.83	147.02	244.88	145.09	84.89	143.36	-70.26
1979	166.06	508.44	164.36	332.49	161.44	165.08	159.18	1.72	157.16	-156.70
1980	94.31	431.88	92.83	254.26	90.28	85.27	88.31	-79.65	86.55	-239.58
1981	16.48	358.95	15.25	178.26	13.13	6.31	11.49	-161.50	10.02	-324.23
1982	4.55	314.97	3.34	130.76	1.24	-44.56	-0.37	-215.66	-1.82	-381.59
1983	-0.75	287.59	-1.99	99.38	-4.11	-79.74	-5.74	-254.57	-7.21	-424.12
1984	-5.63	406.70	-6.90	211.87	-9.08	26.44	-10.77	-154.56	-12.28	-330.09

and retention rates to vary. In his simulation, cows culled exceeded heifers retained for replacements in years 4 through 9. However, the USDA's Agricultural Resource Management Study (ARMS)[1] data for 1996 yielded an estimated 17.4% replacement rate. The consistency between the ARMS estimate and the 17% replacement rate reported by USDA/APHIS (1994b) for 1993 does not support variable replacement rates over time, and 1996 was a peak year and turning point for cattle numbers for the cycle of the 1990s when one could expect a lower replacement rate.

Several hypotheses about the effects of breeding female inventories and calf crop sizes on the cattle cycle were examined. At least three possibilities emerge related to the different paths of cattle inventories observed for the simulated and actual inventories. First, both retention rates and culling rates may vary over the cattle cycle, yielding the observed pattern. Second, heifer retention rates could vary over the cattle cycle, while cow culling rates remain constant. Third, cow culling rates might vary over the cattle cycle, while heifer retention rates remain constant.

A simulated beef cow inventory, based on constant replacement, culling, and death rates, is compared with actual beef cow inventories over the same time period, July 1990 through January 1998 (figure 2). The simulated inventory of beef cows from 2 to 13 years old was constructed assuming (*a*) a constant 17% of each calf crop was saved as replacement heifers, (*b*) a constant 10% of cows were culled each year, and (*c*) there was an additional constant death loss of 0.5% each year.

As seen from figure 2, the base simulation of constant replacement, culling, and death rates does not follow actual breeding aged beef cow inventories very closely. Comparing actual cattle inventories with the simulated path of beef cow inventories based on fixed retention and cull rates indicates, counter to earlier reported survey results, that net replacement rates do vary over the cattle cycle. This result further suggests the net change between culling rates and replacement rates varies and is a function of the phase of the cattle cycle in which the replacement decision is made. The simulation results identify several potential departures from a routine breeding female replacement program. The data series for replacement heifer inventories and cow slaughter shows the net change in the two series is not a constant portion of the total beef cow inventories, nor do the portions necessarily equal one another in a given year.

The third hypothesis, that cow culling rates might vary over the cattle cycle while heifer retention rates remain constant, is supported by other USDA findings for 1993 (USDA/APHIS,1994b) and 1996 (USDA/APHIS, 1997). In 1993, the leading category for culling breeding aged females (36.4% of females sold) was for being open, having aborted a calf, or for other reproductive reasons. This category of reproductive reasons for culling was followed by age or bad teeth (21.4% of breeding aged females sold). In 1996, these two categories reversed their positions, so that age and bad teeth led as the primary reason for culling (39.8% of breeding aged females
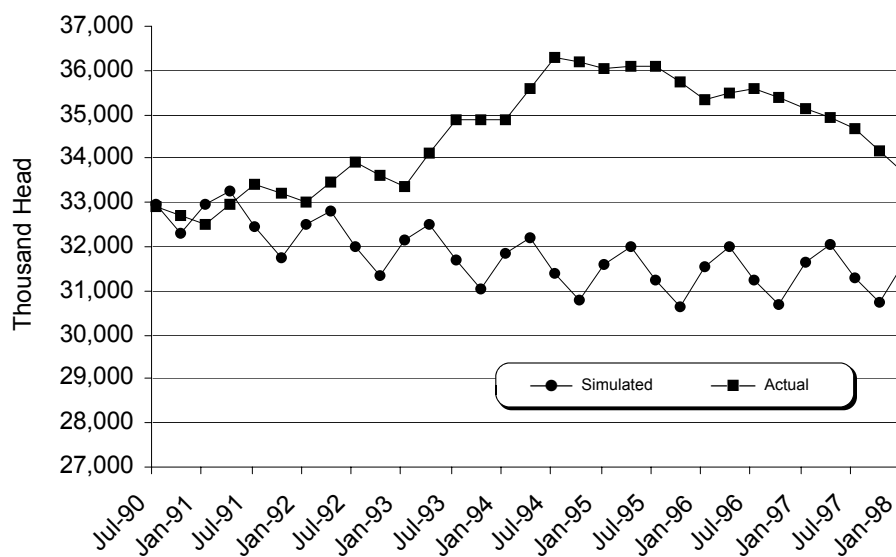

**Figure 2. Actual and simulated quarterly breeding female
inventories, July 1990 – January 1998**

sold), followed by reproductive problems (27.2%). Interestingly, "economics," including drought, herd reduction, and market conditions, was in third place during both years (15.2% in 1993 and 18.5% in 1996) as a reason for selling breeding aged females. However, it is possible that aged cows, cows with reproductive problems, and cows culled for other listed reasons were actually the same cows or were cows with some other combination of reasons which were compounded or confounded by low productivity.

Implications

Many studies begin by describing a biological life cycle for beef cow herd expansion that typically runs through two breeding cycles and takes about four years. Describing the biological life cycle in this static manner is a useful way to present basic cow life-cycle dynamics in complex econometric models. However, this description leaves out a great deal of information which becomes relevant at the firm level. For example, not every cow has a calf, not every heifer is kept for breeding, and half of every calf crop consists of male calves who don't have calves later (even though a small portion will sire future calves). Finally, not every culled cow goes to slaughter. Some "culled" cows go into other herds rather than slaughter, affecting the replacement heifer/cow slaughter dynamic, and confounding attempts to look at aggregate culling and retention rates. The objective of this study was to examine factors affecting cow and heifer NPVs over the cattle cycle and the effects of these factors on the replacement decision.

Retaining heifers can introduce improved genetics into the herd. Incorporating genetic improvement increases the probability of an older cow being culled (decreases the probability of an older, genetically inferior cow remaining in the herd from one period to the next). A replacement heifer calf weighing 578 pounds when sold would have to be sold at a price 1.8 times higher per pound as a cull cow weighing 1,040 pounds to be equal in per head value, not accounting for discounted future returns. Heifer prices have been 1.8 times cow prices per pound for the last 33 quarters, and only one previous quarter in our data series. This price relationship indicates cow prices have fallen recently relative to heifers. An additional factor in this relationship is the fact that both average heifer weights and average cow weights have increased over time.

Some measure of mutual validation is evidenced by the consistency of several results of this NPV analysis with known culling practices. For instance, culling of cows that don't wean calves makes sense because a given cow is not likely to recover the decrease in NPV from failing to wean just one calf. Culling older cows makes sense in the presence of genetic progress because younger, higher-producing heifers generally have a higher expected NPV than do older cows due to their likelihood of carrying with them some genetic improvement. However, old cows can still be found in most herds; old cows that were at the upper end of the distribution for their cohort for a trait when they were selected may still rank higher than some younger members of the cow herd in terms of the genetic potential of their calves (overlapping distributions). Variable net replacement-culling rates make sense in the context of cattle inventory and price cycles because of the effects on NPV of cyclical series of prices.

The general principles and results of this study apply to inventory dynamics of virtually any asset, especially any livestock species. Some variant of each of these factors can affect the value of any asset in terms of useful life and replacement age. However, differences in production technologies, marketing methods, biology, and other factors for other livestock species would alter the beef cattle-specific details of the models discussed and explored in this study.

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