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SELECTION AND DEVELOPMENT OF THE REPLACEMENT ASSET: THE CASE OF THE REPLACEMENT BEEF HEIFER

Paul H. Gutierrez, Norman L. Dalsted, and Yvonne C. Jonk

Beef Cattle Management is a series of decisions designed to accomplish clearly defined goals. Several major management decisions are made annually that impact the biological and economic efficiency of commercial cow-calf operations. The selection and development of replacement heifers is one of these major management decisions which significantly affects the productivity and profitability of the cattle operation. When replacement heifers are selected, producers are anticipating and predicting the future biological and economic performance of their herd. One of the questions most commonly asked by cow-calf producers is "How do I go about selecting and developing my replacement heifers?" And like most other commonly asked questions, this question has no particularly satisfying answer. The most truthful answer would probably be "it depends". "It depends" on the individual producer's management philosophy, the level of performance of the producer's herd for a number of traits (genotypic), the environment (phenotypic), availability of individual cost and performance data, breeding system, current and future market prices and financial position--to name a few. It is postulated that the theory of replacement in the biological process has not been adequately developed to answer some of these questions.

The limiting assumption of replacement theory research efforts, from the individual producer's perspective, is inadequate qualification and quantification of the selection and development process of the replacement animal. The research reported in this paper will indicate a procedure to be used to determine replacement heifer selection and development values for use in asset replacement theory. Sensitivity analysis will be presented to quantify the economic importance of accurately assessing the selection and development cost of the replacement female.

Previous Research

The problem of determining optimal policies for the replacement of assets has been addressed extensively in the agricultural economics literature. Replacement optimization is particularly important in agriculture because of change over time in pregnancy rates, weaning rates, growth rates, feed consumption and conversion rates, annual yields, etc., that are often associated with biological production processes.

Chisholm's and Perrin's work set the precedence for most present day work in this area. The result of Chisholm's effort was the establishment of a correctly specific theory of asset replacement based upon the principal of maximizing net present value (NPV). Perrin expanded upon Chisholm's work in 1972. He developed an alternative and equivalent replacement criterion based upon equating marginal revenue and marginal opportunity cost.

Numerous articles have appeared in the literature since Chisholm's and Perrin's work (Kay and Rister; Boehlje and White; Gunter and Bender; Bradford and Reid). Asset replacement research specific to the area of livestock breeding animal replacement decisions has also progressed. In 1976, Bentley et al. combined Perrin's marginal criteria for replacement with Burt's methodology for considering stochastic conditions. Through this effort they determined the optimal replacement age for beef cows in the presence of stochastic calving

Colorado State University

rates and cow life. The work of Bentley et al. however, assumed constant levels of reproductive efficiency of replacement heifers, input and output prices and herd-size.

Several research efforts have attempted to address the problem of optimal replacement with cyclical prices (King; Plain and Williams; Bentley and Shumway). The most notable work of asset replacement of beef livestock breeding animal replacement decisions was done by Trapp. Trapp expanded previous research efforts to consider the case of cyclical prices and varying firm size and theoretical conditions for an optimum culling and replacement for a beef breeding herd. Trapp's expanded theory allowed for separate asset acquisition and salvaging as opposed to the classical self-replacement theory. The salvage and acquisition decisions in Trapp's expanded theory were determined by the comparison of the internal net present value of animals as breeding stock, versus their external opportunity value as a slaughter animal. The results of this research provided a general observation that a flexible culling and replacement strategy is optimal for coping with cyclical cattle prices. However, the modeling process and solutions procedures neglected to consider the internal production risk associated with the selection and development of the replacement female.

Methodology: The Replacement Heifer Analysis

There are many variables that affect how the replacement heifer enterprise is analyzed including the interrelationships between cost-of-production, fertility, growth, replacement rates, the farm or ranch operating environment, the producer managerial skills, market prices and other measures of biological efficiency for beef cows.

To effectively evaluate the biological and economic relationships in the selection and development of replacement heifers, the analysis is divided into three production phases: 1) production, 2) growing, 3) breeding. Each phase is evaluated as an intermediate enterprise in the selection and development of the replacement heifer. As intermediate enterprises, the production and cost-of-production relationship quantified in each phase is transferred to succeeding phases in the analysis.

Replacement Heifer Selection and Development (RHSD) values are calculated to reflect measures of biological efficiencies (production data), marketing assumptions and cost-of-production for each phase of the replacement heifer enterprise.

Phase 1: Production Phase. The production phase is characterized as the period from weaning to weaning, the cow/calf production phase. During this phase, the producer largely depends on the dam to nurture and care for the replacement heifer until weaning.

The RHSD values in this section reflect the value of the weaned heifer calf selected for retention, taking into consideration the cost-of-production, the heifer calf retention rate, weaned calf crop, cow death loss, marketing assumptions and percent male and female calves. The basic equation for calculating the RHSD value for this production phase is as follows:

$$(1) \quad RHSD(1,y) = [HATC(1,y)/ HPROD(1,y)] * HEIFWT(1,y)$$

where RHSD(1,a) is the replacement heifer selection and development value per head at the end of phase 1, the production phase, for a heifer that is a daughter of a cow calving y-years of age; HATC(1,y) is the average total heifer development cost for phase 1 for a heifer that is a daughter of a cow calving y-years of age; HEIFWT(1,y) is the average heifer weaning weight in phase 1 for a heifer that is a daughter of a cow calving y-years of age.

The RHSD expressed in equation (1) appears deceptively simple until the simultaneity between economic and biological measures of efficiency are considered. Current weaning rates, weaning weights, death loss and heifer calf retention rates affect current RHSD values as well as future RHSD values. The following system of equations describe the proper injection of these production and cost-of-production parameters into equation (1). The cost component HATC(1,y) of RHSD(1,y) becomes:

$$(2) \quad HATC(1,y) = CATC(1) * [[[HEIFWT(1,y) * RATIO(1,y) * [1-HEIFRT(1,y)] * WR(1,y)] * HEIF\$(1,y)]/ ETR(1,y)]$$

where CATC(1) is the average total annual cost of maintaining a cow/calf pair in phase 1; RATIO(1,y) is the ratio of heifer calves to steer calves in phase 1 for a cow calving y-years of age; HEIFRT(1,y) is the rate at which heifer calves are retained as potential replacements (as a percent of a cow y-years of age) from a cow calving y-years of age; WR(1,y) is the successful weaning rate of a cow calving y-years of age; HEIF$(1,y) is the feeder heifer price in phase 1, for a heifer that is a daughter of a cow y-years of age; ETR(1,y) is the expected total revenue flow in phase 1 from a cow calving y-years of age.

The two terms in equation (2) which additively determine expected total revenue flow in phase 1 from a cow calving y-years of age, ETR(1,y), are respectively: expected revenue from calf sales; and expected revenue from cull cow sales. Expected revenue from calf sales is the product of the probability that a cow y-years of age will wean a calf and the average value received for steer and heifer calves after heifer calves retained for potential replacements have been selected. Cows not weaning a calf are culled from the herd. The expected revenue value of ETR(1,y) becomes:

$$(3) \quad ETR(1,y) = [WR(1,y)*[[STEERWT(1,y) * STEER\$(1,y)] + [HEIFWT(1,y) * HEIF\$(1,y) * [1-HEIFRT(1,y)]]] * RATIO(1,y)] + COW\$(1,y) *[1-WR(1,y) - DR(1,y)] * COWWT(1,y)$$

where STEERWT(1,y) is the average steer weight at weaning in phase 1 for a steer who is a son of a cow calving y-years of age; STEER$(1,y) is the feeder steer price in phase 1; COW$(1,y) is the cull cow price for a cow y-years of age; COWWT(1,y) is the weight in phase 1 of a cow y-years of age; DR(1,y) is the death rate of cows y-years of age. All cows which die are assumed to have failed to produce a weaned calf.

The final component of RHSD value in equation (1) is production or yield, i.e., HPROD(1,y).

$$(4) \quad HPROD(1,a) = [HEIFWT(1,y) * RATIO(1,y) * [1-HEIFRT(1,y)]] * WR(1,y)$$

This term reflects the level of feeder calf (market) production per cow taking into consideration the heifer to steer calf ratio, the heifer retention rate

and weaning rate of a cow calving y-years of age.

Phase 2: Growing Phase. The growing phase covers the time from when the heifer calf is weaned until she reaches a breeding age of approximately twelve to thirteen months and a weight of 650-750 pounds. Replacement heifers need to weigh about 65-70 percent of their mature weight in order to consistently breed as yearlings.

The equation for calculating RHSD values for this phase is:

$$(5) \quad RHSD(2,y) = RHSD(1,y) + [HATC(2,y)/ [1-HDR(2)*.5]]$$

Where HDR(2) is the heifer death rate in phase 2. The RHSD value in this phase reflects the value of the year old replacement heifer, taking into consideration the cost and reproductive efficiency of the cow calving y-years of age from which she was selected from (if not a purchased heifer analysis) and the production assumptions and cost of development of the growing phase.

Phase 3: Breeding Phase. The breeding phase would include that phase of time when the heifers are turned out with the bulls and/or artificially inseminated until pregnancy check. At the end of this phase, the cow-calf producer would select replacements configuring to his/her management objectives. The replacement heifer is approximately 19 months of age and weighs 850-950 pounds.

The RHSD value (per head) reported in this production phase reflects the value of the bred (or open) heifer taking into consideration the cost and reproductive efficiency of the cow calving y-years of age from which she was selected from (if not a purchased replacement heifer analysis), the production assumptions and cost of development of the growing phase and the reproductive efficiency, net sales of cull replacements and cost of production in the breeding phase. The equation for calculating the RHSD value for this phase is:

$$(6) \quad RHSD(3,y) = [[RHSD(2,y) + HATC(3,y)/[HDR(3)*.5]] / [[HEIFPR(3,y)] * HEIF\$(3,y)] - sum(1\text{-}3)HATC(y)] * [HEIMKTD(3,y)/ HEIFRT(3,y)$$

where HEIFPR(3,y) is the replacement heifer pregnancy rate in phase 3 for a heifer who was the daughter of a cow y-years of age; HEIFMKTD (3,y) is the number of heifers marketed in phase 3 from a cow calving y-years of age. The RHSD reported in equation (6) reflects the biological and economic efficiency of selecting and developing the replacement asset, in this case the bred heifer. The RHSD values are important in replacement theory if one considers the many combinations and permutations of land, labor, capital and management that replacement heifers are selected and developed under. No two cow-calf operators exhibit the same reproductive efficiency in the selection and development of the replacement female.

Equations (1), (5) and (6) are appropriate for calculating the replacement heifer selection and development value for a heifer who is a daughter of a cow calving any age over a one year period. However, the system of equations is not appropriate for calculating the Expected Replacement Heifer Selection and Development (ERHSD) value over time. Modification of equations (2), (3) and (4) and hence equations (1), (5) and (6) to consider the probability that a cow will remain in the herd and that a replacement heifer selected for replacement will enter the herd and by subscripting all variables for time as described by Trapp, will allow for consideration of non-constant replacement heifer selection

will enter the herd and by subscripting all variables for time as described by Trapp, will allow for consideration of non-constant replacement heifer selection and development, cow herd production and prices into replacement heifer theory. The integration of ERHSD values into replacement heifer theory would enhance the replacement decision problem by more accurately assessing the biological process inherent in the selection and development of the replacement beef heifer.

Sensitivity Analysis

For the individual cow-calf operator, determination of the development "cost" of the replacement heifers is needed to address the such decisions as, "Do I raise the heifers or purchase them? How many heifers do I retain at weaning, cull later as yearlings, or cull after pregnancy checking? Are there market alternatives for open heifers or pregnant heifers that do not fit my breeding program?" For the individual researcher of replacement theory in biological processes, determination of the development "cost" of replacement heifers is needed to address the problem of determining what the optimal investment (replacement) and disinvestment (culling) rules for variable firm size are, given cyclical beef prices, varying levels of management and herd performance for a number of traits, breeding system, etc.

The RHSD values for each production phase reflect the individual cow-calf producer's replacement heifer development cost and the interrelationship of cow herd and heifer reproductive efficiency, market prices and other measures of biological efficiency for beef cows. The following cow herd example and sensitivity analysis tables will illustrate the importance of incorporating biological and economic measure of replacement heifer selection and development into the optimal replacement decision problem. A deterministic simulation model and solution algorithm were developed to determine the RHSD values in each production phase, i.e., equations (1), (5) and (6).

Consider the example of a 200-head cow herd, a 10-percent cow-culling rate and a 2-percent death loss (20 cull cows are sold and four cow deaths) result in a net replacement need of 24-bred heifers to maintain cow numbers ((200 * .10) + (200 * .02) = 24). In this analysis, it was assumed that the producer's production/marketing objective was to maintain cow numbers at 200 head. Thus, 24-bred heifers are needed at the end of the breeding phase. With an 86-percent weaned calf crop and a 50:50 heifer to bull calf ratio, a total of 86-heifer calves would be available to select replacements from (200 * .86 * .50 = 86). Tables 1, 2 and 3 summarize the replacement heifer selection and development values for the production, growing and breeding phases, respectively, for three levels of production cost and three levels of heifer retention rates.

Based on the expected cost-of-production and the production/marketing assumptions specified for the production phase, the RHSD values for heifer calves retained as potential replacements is $376.49, $394.49 and $414.30 per head for the 12-percent, 16-percent and 20-percent heifer retention rates, respectively, (see Table 1). The RHSD values at the end of the growing phase for the 12-percent, 16-percent and 20-percent retention rates are $516.49, $530.49, and $554.30, per head, respectively. Assuming an 85 percent pregnancy rate, the RHSD values at the end of the breeding phase are $713.51, $703.70 and $702.69 per head for the 12-percent, 16-percent and 20-percent heifer retention rates, respectively.

Table 1: Replacement Heifer Selection and Development Values, Phase 1: Production Phase

Total Cost of Production		Heifer Retention Rates: 12.00%	16.00%	20.00%
Low	Cost of production per head	280.50	280.50	280.50
	RHSD value per head	320.02	335.32	352.16
	RHSD price per cwt	64.00	67.06	70.43
Expected	Cost of production per head	330.00	330.00	330.00
	RHSD value per head	376.49	394.49	414.30
	RHSD price per cwt	75.30	78.90	82.86
High	Cost of production per head	379.50	379.50	379.50
	RHSD value per head	432.96	453.67	476.45
	RHSD price per cwt	86.59	90.73	95.29

480 lb. hfr. calf 86.00% Weaned Calf Crop

Table 2: Replacement Heifer Selection and Development Values, Phase 2: Growing Phase

Total Cost of Production		Heifer Retention Rates: 12.00%	16.00%	20.00%
Low	Cost of production per head	420.50	420.50	420.50
	RHSD value per head	460.02	475.32	492.16
	RHSD price per cwt	63.48	65.59	67.91
Expected	Cost of production per head	470.00	470.00	470.00
	RHSD value per head	516.49	534.49	554.30
	RHSD price per cwt	71.27	73.75	76.49
High	Cost of production per head	519.50	519.50	519.50
	RHSD value per head	572.96	593.67	616.45
	RHSD price per cwt	79.06	81.92	85.06

725 lb. hfr. calf

Table 3: Replacement Heifer Selection and Development Values, Phase 3: Breeding Phase

Total Cost of Production		Preg. Rate	Heifer Retention Rates: 12.00%	16.00%	20.00%
Low	Cost of production per head		510.49	510.49	510.49
	RHSD value per head	80.00%	687.52	667.12	657.15
	RHSD value per head	85.00%	647.07	625.55	614.35
	RHSD value per head	90.00%	611.13	588.60	576.30
Expected	Cost of production per head		559.99	559.99	559.99
	RHSD value per head	80.00%	758.11	749.62	750.06
	RHSD value per head	85.00%	713.51	703.70	702.69
	RHSD value per head	90.00%	673.87	662.88	660.58
High	Cost of production per head		609.49	609.49	609.49
	RHSD value per head	80.00%	828.70	832.12	842.98
	RHSD value per head	85.00%	779.95	781.85	791.03
	RHSD value per head	90.00%	736.62	737.17	744.86

As might be expected, the RHSD value is higher for the higher heifer retention rates in the production and growing phases. As more and more potential market heifer calves are retained, fewer market calves are available to cover the cost-of-production incurred in the production phase, thus the RHSD value of each heifer calf retained for the replacement heifer program increases.

The cost-of-production also has a significant effect on the RHSD value. To illustrate this, total direct cost were varied 15 percent above (High) and below (Low) the expected level. Consider the 16-percent heifer retention rate. If production costs are 15-percent lower than expected for the growing phase, $420..50 per heifer, the RHSD value would be $475.32 per head or $59.17 per head less (see Table 2) than the RHSD per head value for the expected cost level.

In addition to varying levels of production cost, the RHSD analysis in Table 3 reports replacement heifer pregnancy rates 5 percent above (90%) and below (80%) the 85 percent pregnancy rate for each cost and retention rate level. The varying levels of pregnancy rates provide a good indication of the value of reproductive management practices or selection criteria(s) that have been documented to improve the reproductive efficiency of the replacement heifer selection and development. For example, consider the 16 percent retention rate for the expected cost-of-production level in phase 3. A 5-percent improvement in replacement heifer pregnancy rate to 90 percent, due to improved nutrition in the growing phase, for example, reduces the RHSD value $40.82 to $662.88 per head, a significant amount. Conversely, a 5-percent decrease in pregnancy rates increases the RHSD value $45.92 to $749.62 per head.

It's also interesting to note the trade off between higher retention rates and replacement heifer pregnancy rates. For example, consider the expected level of cost-of-production and the 16 percent and 20 percent retention rates. The RHSD value for a 16 percent retention rate and 90 percent pregnancy rate is

$662.88 per head compared to $750.06 per head for a 20 percent retention rate and 80 percent pregnancy rate, $87.18 per head difference.

Conclusion

Replacement theory research specific to the area of livestock breeding animal replacement decisions has progressed. However, optimal replacement theory research in the area of breeding livestock can be faulted for not zeroing in on the biological and economic efficiencies of selecting and developing breeding females. "Optimal" culling and replacement decisions can be more accurately researched for individual producers by considering the cost-of-production and reproductive efficiency of the individual cow herd in the selection and development of replacement females. The research presented here indicates a methodology for assessing biological and economic efficiencies in the selection and development of the replacement beef heifer, which could then be incorporated into previous replacement theory efforts.

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