Open Cow Replacement Decisions: an Application of Asset Replacement Theory

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Beef producers have traditionally been faced with the decision to either retain or replace a cow that fails to conceive during the breeding season (termed an open cow[1]). If the producer retains the open cow, then the producers incurs all expenses related to upkeep of the cow for a year without the cow generating income. A small percentage of cows fail to conceive during the breeding season due to a permanent biological alteration in their ability to conceive. Thus, open cows are potentially less likely to conceive in the subsequent breeding season than similarly aged cows. However, a far greater percentage of cows fail to conceive due to improper management (e.g., inadequate nutrition resulting in reduced fertility). These open cows will enter the subsequent breeding season with an excellent opportunity to conceive early. Cows that conceive early are more productive because they wean older, therefore heavier calves. Also, cows that conceive early in one breeding season are more likely to conceive early in subsequent seasons because they will have a longer post-partum recovery period before the next breeding season begins. Therefore, a majority of open cows have the potential to become productive cows.

Producers who replace the open cow with a bred heifer do not invest annual feed and other maintenance costs without a calf being produced. They essentially replace a shorter life asset with a similar, longer life asset. There are more differences between the assets than just life, however. Cows do not reach their maximum productivity until 4 years of age. Therefore, replacement heifers will not wean as heavy a calf as a fully mature cow for three years. More importantly, until they reach maturity, replacement heifers run a considerably higher risk than mature cows of not re-breeding, especially if the heifers are not properly managed. This high probability of either failing to re-breed or conceiving late in the breeding season could dramatically affect the productivity of replacement females and therefore the decision to either retain or replace.

The objective of this study is to determine under what circumstances an open beef cow should be replaced with a bred heifer. Replacement decisions are examined in a net present value framework that compares the costs and returns from keeping the open cow until her normal replacement age against the costs and returns from replacing the cow with a bred heifer. The model employed here helps to alleviate the problem of comparing assets with different lengths of life. The model is applied to a Kentucky cow-calf operation to determine for what age of an open cow is replacement with a bred heifer the optimal decision. Sensitivity analysis is conducted to determine how differences in productivity between heifers and mature cows affect the optimal culling/replacement decision.

Previous Research

Cow-calf producers constantly evaluate how long to keep their animals. Schroeder and Featherstone consider optimal calf retention and marketing strategies for cow-calf producers. Other studies specifically address the replacement of breeding stock. Larson, McLemore, and Stokes analyze whether producers should purchase heifer replacements or raise their own replacements. Whittier considers this same issue. Studies by Tronstad and Gum, Azzam and Azzam, and also Frasier and Pfeiffer analyze when to replace beef cows.

The dairy science literature also includes several studies about cow replacement decisions. These dairy cow replacement decisions must consider milk value in addition to the calf value. Van Arendonk (1986 and 1988), Van Arendonk and Dijkhuizen, and DeLorenzo et al. all evaluate decisions about insemination and replacement of dairy cows.

Many of the studies use dynamic programming to solve for the optimal cow replacement decision. Van Arendonk (1988) uses dynamic programming to calculate management guides that tell a producer what to do with a cow in a given production and price situation. This study uses the same model as Van Arendonk and Dijkhuizen. In this second study, the objective is to maximize the present value of cash flow of present and future replacement cows. Three alternatives are considered in the model for the open cow; insemination, leave open, or replace immediately. Van Arendonk (1986) expands upon the other two models by adding a variable for month of calving to account for seasonal variation in production and prices. DeLorenzo et al. also solves for optimal dairy cow replacement decisions using dynamic programming. Their study maximizes the net present value of a cow and replacements over a 20 year horizon. State variables include class of parity, production level, calving month, lactation month, and days open.

Tronstad and Gum use dynamic programming to determine culling decision rules for open beef cows. They present a biannual calving model (i.e., within the same herd, some cows are bred to calve in the spring, some in the fall) that treats prices as stochastic rather than deterministic, addresses age-dependent fertility, and has different costs for spring versus fall calving. Pregnancy status, cow age, calf price, replacement price, and cull value are all state variables. Frasier and Pfeiffer use a dynamic framework that tries to incorporate the effects of management practices on future productivity. Specifically, the cow's body condition, the winter feed level, and the length of calving season were incorporated into the model.

Results from previous studies show that open cows are most often culled. Frasier and

Pfeiffer developed policies that always culled open cows. Tronstad and Gum showed open cows should be kept 26% of the time. However, their study allowed for biannual calving so that an open cow could be re-bred in six months. Operations that only practiced Spring calving would have to wait a year to re-breed which further discourages keeping open cows. Azzam and Azzam showed that open cows should always be culled even when fall calving was considered.

Using dynamic programming presents some limitations, particularly concerning the usability of the model by a beef producer. Tronstad and Gum only use a 15 year planning horizon that does not incorporate discounting future cash flows. However, the usability is addressed by developing Classification and Regression Trees (CART) which presents a flowchart of how to analyze different values of the decision variables. Frasier and Pfeiffer use an infinite planning horizon with discounted cash flows but the results are limited should prices change. Producers would need to be familiar with dynamic programming to use this model. A more useful approach would be to use net present value analysis to evaluate keeping an open cow versus replacement with a bred heifer.

Perrin developed a framework for these types of problems. Perrin looks at two different types of asset replacement decisions. The first decision considered when as asset should be replaced with a new version of itself. Decisions in this category include when to harvest a forest and when to replace a truck. The other decision considered by Perrin is when to replace an asset with a technologically improved asset. The open cow replacement decision roughly fits into this category. However, there are some differences as the cow's revenue stream changes when she becomes open. Her marginal revenue goes down and then back up, making application of

Perrin's criteria for replacement difficult.

Mathematical Model

The model employed here is an extension of net present value (NPV) analysis of investments with different economic lives that are purchased on a recurring basis. The cow replacement problem fits into this category because an ongoing beef operation will use a whole series of cows over the life of the farm. Thus, comparing the NPV of keeping the open cow versus the NPV of a single replacement heifer is inaccurate. The replacement heifer has a longer life and will generate more years of cash flows when compared to the open cow. If the open cow is kept, she will eventually be replaced at the end of her useful life. As shown in Barry et al., in order to properly evaluate these types of investments, they must be placed on a common time basis. The value of keeping the open cow and the value of a single replacement heifer are defined in equations (1) and (2).

$$(1) \qquad V(c) = \sum_{n=1}^{LC} \frac{P_n(c)}{(1+i)^n} + \frac{S_{LC}(c)}{(1+i)^{LC}}$$

$$(2) \qquad V(h) = \sum_{n=1}^{LH} \frac{P_n(h)}{(1+i)^n} + \frac{S_{LCH}(h)}{(1+i)^{LH}} - H_0(h)$$

In these equations, *V(c)* and *V(h)* are the value of the retained cow and a single replacement heifer, respectively. *LH* represents the expected lifespan of the heifer while *LC* represents the remaining life of the cow. Therefore, *LC* is the difference between *LH* and the age of the open cow. $P_n(c)$ and $P_n(h)$ are the net value of the calf crop produced in each year n, while $S_{LC}(c)$ and $S_{LH}(h)$ are the salvage values if the cow or heifer is kept to the end of her expected useful life. The discount rate is *i* while the cost of a new replacement heifer is $H_0(h)$.

Equations (3) and (4) represent the formulation to use to evaluate the problem when the beef farm is considered as an ongoing operation. Multiple replacements over time will be purchased whether the open cow is kept or replaced immediately. These equations use equations (1) and (2) as the foundation. Equation (3) starts with retaining the open cow [equation (1)] and then adds a series of discounted replacement heifers by using equation (2). Equation (4) sells the open cow and starts with replacement heifers immediately. The value of the heifers from equation (2) is again expressed in the series formulation of equation (4).

(3) $$V_0(\text{Retain Cow}) = V(c) + \sum_{j=0}^{QC} \frac{V(h)}{(1+i)^{(LC+(j \cdot LH))}}$$

(4) $$V_0(\text{Replace Cow}) = S_0(c) + \sum_{j=0}^{QH} \frac{V(h)}{(1+i)^{(j \cdot LH)}}$$

In these two equations, $S_0(c)$ is the salvage value of selling the open cow immediately while *QC* and *QH* represent the number of future replacements to consider in evaluating the retain or replace decision, respectively.

A problem occurs in this formulation because the replacement assets all have the same expected lifespan. The model requires using a series of replacement heifers for both the retain and replace decision. Thus, a common time basis can never be achieved (i.e., a number can never be chosen for *QC* and *QH* such that *(LC+(QC·LH))* is equal to *(QH·LH)*. There will always be a difference between the time lines of either *LC* or *LH-LC*. While this difference in lengths of asset life can be important when the time line is short, extending the time line reduces the importance of the time differential (for any positive *i* discount rate). Therefore, by setting *QH* equal to *QC* and then using enough replacement animals (i.e., using a large value of *QH*), the replace versus retain decision can be fairly evaluated. The last replacement animal has such a small value that the extra time allocated to one of the choices in immaterial.

There is likely to be uncertainty at several points in the model. Specifically, $P_n(c)$, $P_n(h)$, $S_{LC}(c)$, $S_{LH}(h)$, and $H_0(h)$ are expected values. The current salvage values and replacement costs (S and H) in the model are known quantities but become less certain in the future. Without being able to predict cattle prices, current salvage and replacement costs are assumed not to change for future replacements. Most of the uncertainty in the model comes from the yearly revenue numbers, P_n. By assuming risk neutral cattle producers and taking expectations, a single number can be used for the formula. The model still works for risk averse producers by using a certainty equivalent approach to calculate P_n.

Empirical Model

The empirical model includes all variables needed to calculate the elements of (3) and (4). These include annual variable costs per cow and calf value per head (used to calculate $P_n(c)$ and $P_n(h)$), age of the open cow, cost of a bred replacement heifer, current salvage value of the open cow, salvage value of the cow or replacement heifer at the end of its productive life, length of the typical reproductive life of a cow, and discount rate.

The value of the calf at the cow's productive peak is used as the basis of the calf value for reproductive years 4 through 11. Before a cow reaches her fourth reproductive year, she is reproductively less efficient and usually produces a smaller calf. Therefore, the calf crop value is assumed to decline by 5% (of the peak calf value) per year for years three to one. This means the replacement heifer, in her first productive year, will usually produce a calf with a value \$60 less than that of a mature cow's calf. The calf crop in reproductive years 11 onward is 5% less than the calf crop from a peak reproductive cow. The model assumes that the cost to maintain the cow is not affected by age. Revenues and costs from one heifer replacement to the next are assumed to be the same.

A fertility discount is subtracted from the value of the calf crop. There is always a risk that a cow will not re-breed. This risk is higher for the open cow than it is for a cow of the same age with a calf. Data from Tronstad et al. provide probabilities for various outcomes (pregnant, open, culled, or dead) for open cows both with and without calves by age group. These probabilities are used to quantify the risk of failure to re-breed for cows of various ages and pregnancy status. This data is summarized in table 1. One deficiency of this data is that it does not reflect the fact that first-calf heifers may have more trouble re-breeding. Implications of this data limitation will be addressed using sensitivity analysis.

A series of 10 consecutive replacements is used to evaluate the retain versus replace decision. This would give the decision to retain an open cow an advantage of *LC* extra years of cash flow since the retain cow decision keeps the cow until the end of her productive life before adding replacements. However, because these extra years are so far into the future, the NPV of the cash flow from these years is very small (about $1/head). With an average lifespan of 10 years for a replacement heifer, these cash flows are 100 years into the future.

The empirical model was programmed in an Excel spreadsheet. The critical output from the model is a NPV of future cash flows from a bred replacement heifer and from a retained open cow. The appropriate management decision (retain the open cow or replace with a bred heifer) is indicated by the higher of these two NPVs.

Obviously, results obtained from the model will be influenced by values selected for the variables listed earlier. Among the most critical of these variables are age of the open cow, variable costs per cow, and cost of replacement heifers. Sensitivity analysis can be employed to determine what will be the appropriate decision (retain or replace an open cow) under a variety of circumstances. Table 2 presents the results of sensitivity analysis related to these three key variables. Note that in this table, negative values denote situations in which the optimal decision is to retain an open cow. Results indicate that as the cost of replacement heifers increases, retaining cows becomes an increasingly viable option. This is also true as variable maintenance costs decrease. As a general principle, these results certainly have intuitive appeal; however, previous studies did not find the retention of open cows to be the optimal decision unless the cows could be re-bred for a fall calving season. Results in table 2 indicate that with a bred replacement heifer cost of $850 and annual variable maintenance costs of $300/cow, retaining an open cow that is up to 4 years old is an appropriate decision. Thus, it seems that the common length of life approach to the calculation of NPV as developed here can potentially lead to somewhat different conclusions than do the other methods of evaluating replacement decisions represented in the literature.

Consideration of the physiological component of the replacement decision provides at least circumstantial evidence in support of the result noted above. Data presented in table 1 indicate that, as noted, replacement heifers are not as efficient as mature cows (i.e., their calves are lighter at weaning). Therefore, replacing a 3 to 5 year old cow with a heifer entails replacing an animal that is just entering her peak productivity with one that will be going through her least productive phase. There is undoubtedly a trade-off involved in replacing an open cow with a replacement heifer. Specifically, culling an open cow reduces maintenance costs but will also reduce income until the open cow's replacement reaches full maturity. Results in table 2 seem to appropriately reflect this tradeoff (i.e., age of cows which may be retained increases as production costs decrease).

While data used in this study do indicate lighter weaning weights for calves, they do not reflect any differences in fertility between heifers and mature cows. In fact, it is unlikely that first-calf heifers (i.e., heifers that have just had their first calf) will re-breed at as high a rate as mature cows. Heifers take longer to recover from the physical stress of calving (see footnote 2). Without special management, heifers are unlikely to re-breed at the same rate as mature cows. Survey data from the Animal and Plant Health Inspection Service indicates that few producers actually practice the type of management that would keep first-calf heifer breeding percentages on par with those of mature cows (United States Department of Agriculture). For example, only about 13% of operations reported breeding replacement heifers earlier than the rest of the herd. (This results in earlier calving–giving heifers a longer post-partum recovery period prior to start of the next breeding season.) Additionally, less than one-third of operations reported feeding heifers separately from mature cows. (This ensures that the higher nutritional requirements of heifers are met, allowing them to recover from calving, maintain their own growth, and support the growth of their calf.)

Given that relatively few operations are likely to realize the same level of fertility in first-calf heifers as in mature cows, additional sensitivity analysis on this parameter is in order. Tronstad et al. data (table 1) indicate that 14.59% of the cows in a beef herd will fail to re-breed, and this percentage is constant across age groups. To investigate the effect of first-calf heifer fertility on the results of the NPV model developed here, this percentage of open cows was examined at two additional levels (19.59% and 24.59%) for 3-year-old cows. Table 3 presents results from the NPV model for the three different levels of first-calf heifer fertility (14.59% open, 19.59% open and 24.59% open) at bred replacement heifer costs of $750 and $800.

As expected, with higher levels of open first-calf heifers, retaining open cows becomes the preferred option more often (i.e., for older cows and with higher production costs). This follows from the fact that as first-calf heifer fertility decreases, replacing mature cows with bred heifers involves increasing production (and therefore income) risk. This is an important result because it provides managers some basis for considering the replacement decision within the framework of overall herd management. For example, a manager with low costs of production (e.g., a producer in the Southeastern U.S. intensively managing improved forage varieties) who lacks the on-farm infrastructure to separate heifers from mature cows may find it advantageous to keep 4 or possibly even 5-year-old open cows whereas a relatively high-cost producer who can manage heifers and cows separately would possibly never find it advantageous to keep an open cow.

A final sensitivity analysis was conducted to evaluate the impact of open cow fertility on model results. Specifically, changes in the probability that on open cow of any age would remain open through the subsequent breeding season (line 10 in table 1) were examined. In this analysis, values from line 10 in table 1 were adjusted to 90% and 110% of their reported value. Results of this analysis are presented in table 4. Changes of the magnitude investigated here have a relatively minor impact on model results; however, it is clear that as open cow fertility increase (i.e., as the probability that an open cow will fail to rebreed in the following breeding season decreases) the value of the open cow relative to a bred heifer increases. Conversely, as open cow fertility decreases, the value of the open cow relative to a bred heifer decreases.

Summary and Conclusions

NPV analysis forms the basis of a beef cow replacement decision model in which assets with different lengths of life (i.e., mature open cows and bred replacement heifers) can be fairly compared. Results of the model indicate that, while replacement of open cows with bred heifers is generally advantageous, it may not always be so. Specifically, replacing young open cows (< 4 years old) is not necessarily the best decision. The replacement decision is sensitive to production costs and replacement heifer cost. For operations with high production costs, replacement of open cows of any age may, in fact, be the optimal decision unless replacement heifer cost is very high (i.e., > $850). On the other hand, for low cost producers, keeping young open cows may make good economic sense even at moderate replacement heifer prices (i.e., below $800).

Sensitivity analysis was used to demonstrate the impact of first-calf heifer and open cow fertility on the replacement decision. The issue of first calf heifer fertility is particularly important since this variable can be influenced by management practices. Operations that are able to intensively manage first calf heifers to minimize calving and rebreeding problems will more often find it preferable to replace rather than retain young open cows. The key point that this model clearly illustrates is that managers need to be aware of how their production costs and management practices should influence their replacement decisions.

Table 1. Production Data Used to Develop Open Cow Replacement NPV Model

		Calving Rates for Pregnant Cows by Age							
Cow Age	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5
Pregnant to no calf	2.17	2.78	3.23	3.53	3.68	3.68	3.52	3.22	2.76
Pregnant to live calf	97.83	97.22	96.77	96.47	96.32	96.32	96.48	96.78	97.24
		Estimated Fertility of Open Cows with Calf by Age							
Cow age	3	4	5	6	7	8	9	10	11
Calf at side to pregnant	81.95	80.80	79.33	77.52	75.39	72.94	70.15	67.04	63.59
Calf at side to open	14.59	14.59	14.59	14.59	14.59	14.59	14.59	14.59	14.59
Calf at side to cull (unsound)	1.40	1.86	2.65	3.77	5.21	6.98	9.08	11.51	14.26
Calf at side to cow died	2.06	2.75	3.43	4.12	4.81	5.49	6.18	6.87	7.55
		Estimated Fertility of Open Cows with No Calf by Age							
Open to pregnant	70.99	69.26	67.03	64.41	61.52	58.49	55.44	52.49	49.75
Open to open	25.09	24.09	23.08	22.08	21.08	20.08	19.07	18.07	17.07
Open to cull (unsound)	3.32	5.58	8.21	11.09	14.10	17.13	20.04	22.72	25.05
Open to cow died	0.60	1.07	1.68	2.42	3.29	4.30	5.44	6.71	8.12

Note: Table based on Tronstad et al.

Table 2. Difference in NPV from Replacement Heifer and Retained Open Cow (*V*(*h*) - *V*(*c*))

Variable	Age of Open Cow						Heifer
Cost	3	4	5	6	7	8	Cost
$240	$10	$26	$57	$90	$125	$163	$750
$270	$27	$45	$77	$111	$148	$187	
$300	$45	$64	$97	$133	$171	$212	
$330	$63	$83	$117	$154	$194	$237	
$360	$80	$102	$137	$176	$217	$261	
$390	$98	$121	$158	$197	$240	$286	
$240	($12)	$7	$40	$75	$113	$154	$775
$270	$6	$26	$60	$96	$136	$178	
$300	$24	$45	$80	$118	$159	$203	
$330	$41	$64	$100	$140	$182	$227	
$360	$59	$83	$120	$161	$205	$252	
$390	$77	$102	$141	$183	$228	$277	
$240	($33)	($12)	$23	$60	$101	$144	$800
$270	($15)	$7	$43	$82	$124	$169	
$300	$2	$26	$63	$103	$147	$193	
$330	$20	$45	$83	$125	$170	$218	
$360	$59	$83	$120	$161	$205	$252	
$390	$56	$82	$124	$168	$216	$267	
$240	($54)	($31)	$6	$46	$89	$135	$825
$270	($36)	($12)	$26	$67	$112	$160	
$300	($19)	$7	$46	$89	$135	$184	
$330	($1)	$26	$66	$110	$158	$209	
$360	$17	$44	$87	$132	$181	$233	
$390	$34	$63	$107	$154	$204	$258	
$240	($75)	($50)	($11)	$31	$77	$126	$850
$270	($58)	($31)	$9	$53	$100	$150	
$300	($40)	($13)	$29	$74	$123	$175	
$330	($22)	$6	$49	$96	$146	$199	
$360	($5)	$25	$70	$117	$169	$224	
$390	$13	$44	$90	$139	$192	$249	
$240	($97)	($69)	($28)	$17	$65	$116	$875
$270	($79)	($51)	($8)	$38	$88	$141	
$300	($61)	($32)	$12	$60	$111	$165	
$330	($44)	($13)	$33	$81	$134	$190	
$360	($26)	$6	$53	$103	$157	$215	
$390	($8)	$25	$73	$124	$180	$239	

Note: Negative values denote situation in which open cow should be retained. Calf value at weaning is assumed to be $400. Results for 9 and 10 year old cattle are not reported in this table.

Table 3. Effect of First-Calf Heifer Fertility on Difference in NPV from Replacement Heifer and Retained Open Cow

Variable	Age of Open Cow			Age of Open Cow		
Cost	3	4	5	3	4	5
	Replacement Heifer Cost = $750			Replacement Heifer Cost = $800		
P(first-calf heifer open) = 0.1459						
$240	$10	$26	$57	($33)	($12)	$23
$270	$27	$45	$77	($15)	$7	$43
$300	$45	$64	$97	$2	$26	$63
$330	$63	$83	$117	$20	$45	$83
$360	$80	$102	$137	$59	$83	$120
$390	$98	$121	$158	$56	$82	$124
P(first-calf heifer open) = 0.1959						
$240	($5)	$13	$45	($47)	($25)	$11
$270	$13	$32	$65	($30)	($6)	$31
$300	$30	$51	$85	($12)	$13	$52
$330	$48	$70	$106	$6	$31	$72
$360	$66	$89	$126	$23	$50	$92
$390	$83	$108	$146	$41	$69	$112
P(first-calf heifer open) = 0.2459						
$240	($20)	$0	$33	($62)	($38)	$0
$270	($2)	$19	$54	($44)	($19)	$20
$300	$16	$38	$74	($27)	($1)	$40
$330	$33	$57	$94	($9)	$18	$60
$360	$51	$76	$114	$9	$37	$80
$390	$69	$94	$134	$26	$56	$100

Note: Negative values denote situation in which open cow should be retained. Calf value at weaning is assumed to be $400. Optimal decision for all ages above 5 is to cull open cow.

Table 4. Effect of Open Cow Fertility on Difference in NPV from Replacement Heifer and Retained Open Cow

Variable	Age of Open Cow					
Cost	3	4	5	6	7	8
	10% decrease in P(open to open)					
$240	($42)	($21)	$15	$52	$93	$137
$270	($24)	($2)	$35	$74	$116	$162
$300	($6)	$17	$55	$96	$139	$186
$330	$12	$36	$75	$117	$162	$211
$360	$29	$55	$95	$139	$185	$235
$390	$47	$74	$115	$160	$208	$260
	Base P(open to open)					
$240	($33)	($12)	$23	$60	$101	$144
$270	($15)	$7	$43	$82	$124	$169
$300	$2	$26	$63	$103	$147	$193
$330	$20	$45	$83	$125	$170	$218
$360	$59	$83	$120	$161	$205	$252
$390	$56	$82	$124	$168	$216	$267
	10% increase in P(open to open)					
$240	($24)	($3)	$31	$68	$108	$151
$270	($7)	$16	$51	$90	$131	$176
$300	$11	$34	$71	$111	$154	$201
$330	$29	$53	$92	$133	$177	$225
$360	$46	$72	$112	$154	$200	$250
$390	$64	$91	$132	$176	$223	$274

Note: Negative values denote situation in which open cow should be retained. Calf value at weaning is assumed to be $400. Replacement heifer cost is assumed to be $800.

Endnotes

1. An open cow is one that has been found not to be pregnant. In spring-calving beef herds, pregnancy checking is typically done at or shortly after the previous year's calves are weaned (i.e., generally in October or November), by which time bred cows should be in the second trimester of pregnancy.

2. This occurs because young cows have not yet reached their mature body weight. A portion of their energy thus goes to supporting their own growth rather than to fetal development or milk production.

References

Azzam, S. M., and A. M. Azzam. "A Markovian Decision Model for Beef Cattle Replacement That Considers Spring and Fall Calving." *J. Anim. Sci*. 69(1991):2329-2341.

Barry, P. J., P. N. Ellinger, J. A. Hopkin, and C. B. Baker. *Financial Management in Agriculture.* Danville, Illinois: Interstate Publishers, 2000.

DeLorenzo, M. A., T. H. Spreen, G. R. Bryan, D. K. Beede, and J. A. M. Van Arendonk. "Optimizing Model: Insemination, Replacement, Seasonal Production, and Cash Flow." *J. Dairy Sci*. 75(1992):885-896.

Frasier, W. M., and G. H. Pfeiffer. "Optimal Replacement and Management Policies for Beef Cows." *Amer. J. Agr. Econ*. 76(November 1994):847-858.

Larson, J. A., D. L. McLemore, and J. R. Stokes. "A Dynamic Programming Analysis of the Purchase vs. Retain Replacement Heifers Decisions in Commercial Cow-Calf Production." Paper presented at the SAEA Annual Meeting, Lexington, KY, Jan. 29-Feb. 2, 2000.

Perrin, R. K. "Asset Replacement Principles." *Amer. J. Agr. Econ*. 54(February 1972):60-67.

Schroeder, T. C., and A. M. Featherstone. "Dynamic Marketing and Retention Decisions for Cow-Calf Producers." *Amer. J. Agr. Econ*. 72(November 1990):1028-1039.

Tronstad, R. and R. Gum. "Cow Culling Decisions Adapted for Management with CART." *Amer. J. Agr. Econ*. 76(May 1994):237-249.

Tronstad, R., R. Gum, D. Ray, and R. Rice. "Range Cow Culling: Herd Performance." *Ranch Bus. Mgmt*. (1993):27-31.

Whittier, J. "What About Replacements?" *Beef* (Spring 2000):32-36.

Van Arendonk, J. A. M., "Management Guides for Insemination and Replacement Decisions." *J. Dairy Sci*. 71(1988):1050-1057.

Van Arendonk, J. A. M., "Studies on the Replacement Policies in Dairy Cattle. IV. Influence of Seasonal Variation in Performance and Prices." *Livest. Prod. Sci*. 14(1986):15-28.

Van Arendonk, J. A. M., and A. A. Dijkhuizen. "Studies on the Replacement Policies in Dairy Cattle. III. Influence of Variation in Reproduction and Production." *Livest. Prod. Sci*. 13(1985):333-349.

United States Department of Agriculture. Animal and Plant Health Inspection Service. *Beef Cow/Calf Health Productivity Audit Part III: Beef Cow/Calf Health Management*. USDA:APHIS:VS Center for Animal Health Monitoring. Ft. Collins, CO: 1994.