

Value of Pregnancy Testing Range Cows

Russel Tronstad

Presented at Western Agricultural Economics
Association 1997 Annual Meeting
July 13-16, 1997
Reno/Sparks, Nevada

VALUE OF PREGNANCY TESTING RANGE COWS

by

Russel Tronstad

Russel Tronstad is an associate specialist in the department of Agricultural and Resource Economics at the University of Arizona, and a graduate of the University of Illinois.

Pregnancy information increases long term profitability by 7 to 11 percent using optimal culling rules. However, the more traditional strategy of keeping all pregnant cows and culling all open cows results in 8 to 18 percent less profit than optimal culling decisions with no pregnancy information.

VALUE OF PREGNANCY TESTING RANGE COWS

Determining when range cows should be culled and replaced is one of the most important decision problems faced by ranchers (Frasier and Pfeiffer). Related to the culling decision is the value of pregnancy testing. Tronstad and Gum found that under some market and age conditions, open cows should be kept and pregnant cows culled. These results indicate that pregnancy testing doesn't always have economic merit. The primary objective of this paper is to quantify the immediate one-period and long-run returns to pregnancy testing.

Biological, market, and cost information on which these pregnancy test and culling alternatives are evaluated include: cow age, recent history of calf fertility, replacement cost of bred heifers, calf prices, cull cow values, and the cost differential (feed and/or performance cost) between spring and fall calving. Biological productivity estimates were taken from Tronstad and Gum. Markovian price relationships were updated to incorporate more recent price changes and finer grid intervals. The cost differential between spring and fall calving is considered since the analysis has allowed for spring and fall calving. Allowing for biannual calving is an important economic factor since a cow has the potential to be productive six months earlier than under a strict annual calving system.

Decision Alternatives

Range cow culling and replacement decisions are driven by future cow productivity, feed costs, and the market value of replacements, calves, and slaughter cows. As the spread between market prices changes through time the value of pregnancy testing and optimal culling decisions also change. To simultaneously evaluate the dynamics of physical productivity, market prices, and production costs the stochastic dynamic programming model presented by Tronstad and Gum was extended. The model was primarily

extended in the form of decision alternatives evaluated and the added dimension of the cost differential between spring and fall calving considered. Decision alternatives evaluated were:

1. Whether to keep or cull a cow without a pregnancy test? Economics may conclude that older cows should be replaced or younger cows should be kept, irrespective of pregnancy status. If young cows are open, should they be bred immediately or at a later period?
2. If pregnancy testing has economic justification, what should be done with cows that are open? Should they be culled and replaced with a bred heifer now or at a later time in the future? Do market factors justify maintaining, expanding, or contracting herd size?

Decision alternatives evaluated by Tronstad and Gum were only to keep and breed immediately or replace open cows with a bred heifer.

Comparing Alternatives

In order to assess the value of pregnancy testing, the economic returns from making decisions with pregnancy test information are compared to returns generated without pregnancy test information. Without pregnancy test information, the likelihood that a cow is open or pregnant is made solely on the basis of cow age and recent calving history. These estimates were made from data collected from 1983 to 1990 on the San Carlos Apache Experimental Research Registered Herd, located at Arsenic Tubs, AZ (see Tronstad and Gum for a more detailed description of the data). The odds that a cow is pregnant or open with a sale calf at side were jointly estimated as

$$\begin{aligned}
 \text{Prob. Preg}_t | \text{Sale Calf at Side}_t &= 86.938 - .059857 * CA_t^2 \\
 &\quad (53.932) \quad (-2.468) \quad R^2=.98 \\
 \text{Prob. Open}_t | \text{Sale Calf at Side}_t &= 13.062 + .059857 * CA_t^2
 \end{aligned}$$

(1)

$$(8.103) \quad (2.468) \quad R^2=.45$$

where CA_t is cow age in time t , t is a six month time period, t -values are in parentheses below estimated parameters, and R^2 is the coefficient of determination between the observed and predicted values. Higher order terms of CA_t were evaluated. The most statistically insignificant constant, linear, quadratic, or cubic terms with respect to cow age were sequentially eliminated until all parameters were at least significant at a 0.05 level. Using this procedure, cow age was not found to be a factor that influenced whether a cow was open or pregnant if a cow had no calf at her side. No calf at side could be because the cow was previously open or lost her calf. Using notation as described above, the following relationship was estimated for cows that had no calf at their side.

$$(2) \quad \begin{array}{l} \text{Pr ob. Preg}_t \mid \text{NoSale Calf at Side}_t = 74.033 \\ \quad \quad \quad \quad \quad \quad \quad \quad (52.026) \quad \quad R^2=0.97 \\ \text{Pr ob. Open}_t \mid \text{NoSale Calf at Side}_t = 25.967 \\ \quad \quad \quad \quad \quad \quad \quad \quad (18.248) \quad \quad R^2=0.85 \end{array}$$

In calculating the value of pregnancy testing, the economic value associated with applying the same culling decision to all cows of a given age and calf status was first obtained. Say the decision under consideration is to keep and allow for immediate breeding of all cows 7.5 years of age that have a sale calf at their side. Given the information in (1), 83.57% are expected to be pregnant and 16.43% open. The economic value of making a keep decision is made by multiplying the value of keeping a pregnant cow by 83.57% and adding the value of keeping an open cow by 16.43%. Four non-pregnancy test alternatives for a given cow age and calf status are compared; (a) keep all and allow for immediate breeding, (b) replacing all with a bred heifer, (c) keep all cows but don't allow for breeding any open cows until 6 months from now, and (d) cull all cows and don't replace with a bred heifer this period. The

highest value from the four non-pregnancy testing alternatives is the best decision one can make without any information regarding pregnancy status. This value is compared to the best decision possible with pregnancy testing. Two economically viable options under pregnancy testing are; (a) keep all pregnant cows and replace open cows with a bred heifer, or (b) keep all pregnant cows and cull the open cows without replacing them with a bred heifer. The optimal decision is the highest value attained from evaluating all options. The model assumes a cost of \$2 per head for pregnancy testing.

The value of pregnancy testing is determined by subtracting the best uniform culling decision from the highest of the two pregnancy test alternatives. The value of pregnancy testing varies depending on market prices, cow age, calving season (spring or fall), the cost differential between spring and fall calving, and recent cow fertility. Whether a cow has a sale calf at her side or no calf at side is the information used for recent cow fertility. Cows that were sound with a newborn calf at side were automatically kept in the herd and thus not pregnancy tested.

Market Prices

Market prices for replacements (2.5 year old bred heifers), calves, and slaughter values are considered in the analysis. Price probabilities for replacement, calf, and slaughter prices are based on biannual prices (May and November) from 1971 through 1991. Following procedures outlined in Tronstad and Gum, estimated prices were

$$(3) \quad P_t^{\text{cull}} = -6.392 + .0419P_t^{\text{rep}} + .4161P_t^{\text{cull}} + \mu_{1t}$$

$$\quad \quad \quad (-1.848) \quad (6.256) \quad (5.943) \quad R^2=0.94$$

$$(4) \quad P_t^{\text{calf}} = 0.9078P_{t-1}^{\text{calf}} + 14.614DMAY_t + \mu_{2t}$$

$$\quad \quad \quad (41.803) \quad (6.221) \quad R^2=0.73$$

$$(5) \quad P_t^{\text{rep}} = 144.04 + 1.154P_{t-1}^{\text{rep}} - 0.3748P_{t-2}^{\text{rep}} + \mu_{3t}$$

$$(3.405) \quad (12.851) \quad (-4.215) \quad R^2=0.78$$

where P_t^{cull} is the monthly (May or November) average \$/cwt. price of slaughter cows, P_t^{calf} is a \$/cwt. combined steer and heifer price for California, $DMAY_t$ is a dummy variable for the month of May, P_t^{rep} is the \$/head replacement price of cows, and μ_{pt} ($p=1,2,3$) is a normally distributed error term with covariance $\sigma_{23} \neq 0$, and other terms are as described above. All prices were deflated by the consumer price index to equal 1993 real dollars (see Tronstad and Gum for a more detailed description of the price data and procedures). Cull cow values were made as a deterministic function of replacement and calf prices to eliminate the need for an additional state variable. The second order Markov process of P_t^{rep} was reduced to a first order as described in Burt and Taylor. Table 1 illustrates how price levels in November influence where prices will be the following May. Grid spaces for replacement and calf prices are also described in table 1.

Given a November calf price less than \$64 per cwt. and replacement costs between \$555 to \$645 per head, the odds of going to calf prices of \$80 to \$88 per cwt. and replacement prices between \$555 to \$645 is 2.27 percent. The odds of going to this same price combination in November starting with May calf prices <64 per cwt. and replacement

Table 1. November Transition Probabilities Given Calf Price <\$64 per cwt. and Replacement Price Between \$555-\$645 per Head.

Replacement Prices in May (\$/head)	May Calf Prices (\$/cwt.)						
	< 64	64-72	72-80	80-88	88-96	96-104	> 104
< 465	0.1272	0.0221	0.0053	0.0006	0.0000	0.0000	0.0000
465 - 555	0.1120	0.0615	0.0266	0.0054	0.0005	0.0000	0.0000
555 - 645	0.0776	0.0887	0.0651	0.0227	0.0037	0.0003	0.0000
645 - 735	0.0264	0.0580	0.0721	0.0426	0.0119	0.0016	0.0001
735 - 825	0.0042	0.0171	0.0362	0.0363	0.0172	0.0039	0.0004
825 - 915	0.0003	0.0023	0.0082	0.0140	0.0113	0.0043	0.0008
> 915	0.0000	0.0001	0.0009	0.0026	0.0038	0.0027	0.0012

prices between \$555 to \$645 is only .02 percent. This reflects the magnitude of the difference between spring and fall calf prices.

The value of pregnancy testing is based most heavily on current price levels since the impact of distant prices is reduced by a discount rate. Future returns are discounted at a real discount rate of 6 percent. Because current prices play the biggest role in determining the value of pregnancy testing, the value of pregnancy testing and optimal culling decisions are not very sensitive up to a 4 point increase or decrease in the discount rate.

Costs of Production

Costs directly influence the bottom line of profitability and the differential in feed costs for a replacement versus an older cow impacts the culling decision. Added feed costs of a first calving replacement heifer need to be evaluated against the performance of an older cow with lower feed costs. The model uses a feed cost of \$100 per head every six months except for replacements during their first year. An additional feed cost of \$25 per head every six months was added for replacements in the period that they gave birth and the following nursing period.

Costs of production are allowed to vary for spring versus fall calving. In general, spring calving is the norm since most areas in the U.S. can better match forage availability with the nutritional demands associated with a spring calving season. Lower calf prices in the fall than spring reflect this seasonal phenomena. In total, 11 different cost differentials of \$0.0, \$10, \$20, \$30, \$40, \$55, \$75, \$100, \$130, \$165, and \$205 were evaluated. A cost differential of \$30 implies that it costs \$30 more to calve a cow in the fall than the spring. High cost differentials favor a spring only calving system. The cost differential can be associated with more feed requirements, more labor, lower fertility, and/or lower calf weights.

Culling Decisions and Value of Pregnancy Testing

The number of possible price combinations (49, 7•7), age (3 to 12.5 years of age in .5 year increments), calf or no calf at side (2), spring or fall (2), and cost differentials (11) considered for evaluating culling decisions number 43,120 possibilities. Because this number is unduly large, these decisions have been categorized into a decision tree framework using Classification and Regression Tree Methodology (CART). CART methodology is a computer intensive classification system for grouping similar decisions into a common category by building a decision tree with binary splits (Breiman, et al).

Splits were made on the basis of one-period cost of mistake values rather than the Gini Index as in Tronstad and Gum. One period cost of mistake values are determined by comparing; (a) a non-optimal decision one period followed by optimal culling decisions, to (b) a continuous stream of optimal culling decisions. First, all 43,120 decisions were numerically searched over all variables and discrete levels to find the level and variable that would divide all decisions into two categories that would minimize the average cost of mistake for all decisions. Cow age of 9.25 years was the variable and level identified for the first split. Subsequent splits were made below each categorized split until the average cost of mistake for a node was less than \$5 or a split could not be found such that the number of cases in the smaller branch was at least 10 percent of the number of cases to be split at this point in the tree. Using this splitting criteria, all 43,120 possibilities were categorized into 110 terminal categories or nodes.

Figure 1 gives a sample of how the decisions were classified. The six possible culling decisions are defined as: 1) K - keep and breed immediately 2) R - replace with a bred heifer, 3) K6 - keep and breed in 6 months, 4) RN - cull and don't replace, 5) PR - pregnancy test

cows, keep pregnant cows and replace open cows with a bred heifer, and 6) PN - pregnancy test cows, keep pregnant cows and don't replace open cows that are culled at this time. In order to assess how much node impurity exists, average one period cost of mistake values are given in Table 2.

Figure 1. Illustration of Decision Tree Culling Recommendations, Cow Age < 9.25 years and Replacement Prices < \$555/head (see text above for legend).

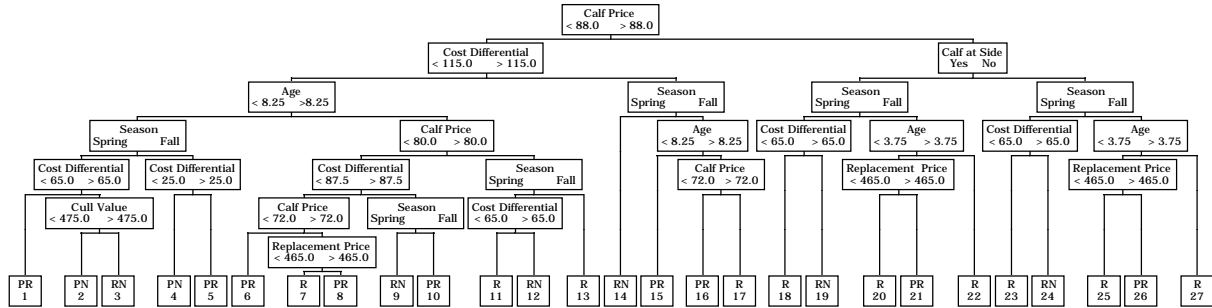


Table 2. Value of Pregnancy Testing, Present Value, and Cost of Mistake Values for Terminal Nodes in Figure 1 (see text above for Decisions).

Terminal Node Number	Recommended CART Decision	Average Value of Preg Testing by Node	Average Present Value by Node	Average Cost of Mistake Values For Different Decisions					
				K Decision 1	R Decision 2	K6 Decision 3	RN Decision 4	PR Decision 5	PN Decision
1	PR	\$16.0	\$1965.2	-\$35.9	-\$46.5	-\$46.0	-\$135.3	-\$4.2	-\$22.4
2	PN	\$2.9	\$1403.2	-\$9.1	-\$106.9	-\$23.2	-\$21.6	-\$20.2	-\$2.7
3	RN	\$0.6	\$1447.4	-\$33.8	-\$79.2	-\$42.6	-\$3.5	-\$29.5	-\$13.8
4	PN	\$3.7	\$1897.1	-\$5.0	-\$75.1	-\$9.1	-\$53.3	-\$7.0	-\$2.5
5	PR	\$14.2	\$1645.2	-\$34.6	-\$49.8	-\$26.3	-\$131.9	-\$2.8	-\$19.7
6	PR	\$8.5	\$1723.8	-\$31.8	-\$33.0	-\$30.6	-\$66.7	-\$6.7	-\$14.1
7	R	\$0.5	\$1834.5	-\$68.0	-\$8.4	-\$65.9	-\$92.0	-\$28.5	-\$46.9
8	PR	\$2.1	\$1779.1	-\$44.0	-\$20.8	-\$42.1	-\$51.5	-\$12.0	-\$18.8
9	RN	-\$1.8	\$1335.0	-\$47.2	-\$112.6	-\$49.7	-\$0.1	-\$46.8	-\$22.0
10	R	\$4.6	\$1439.8	-\$64.6	-\$9.0	-\$42.5	-\$110.0	-\$11.9	-\$34.2
11	R	-\$2.0	\$1958.6	-\$105.0	\$0.0	-\$107.6	-\$117.4	-\$46.3	-\$72.2
12	RN	-\$2.0	\$1440.8	-\$76.6	-\$55.8	-\$77.6	\$0.0	-\$54.6	-\$42.2
13	R	\$2.9	\$1886.5	-\$58.6	-\$9.8	-\$49.5	-\$79.9	-\$22.9	-\$38.4
14	RN	-\$1.9	\$1446.8	-\$48.2	-\$127.0	-\$58.5	-\$0.4	-\$59.8	-\$33.4
15	PR	\$18.0	\$1573.2	-\$67.8	-\$48.1	-\$33.4	-\$162.6	-\$3.3	-\$26.9
16	PR	\$7.9	\$1319.2	-\$69.0	-\$13.6	-\$32.2	-\$101.6	-\$5.3	-\$24.7
17	R	-\$2.0	\$1565.9	-\$113.3	\$0.0	-\$76.5	-\$141.0	-\$34.9	-\$66.0
18	R	-\$0.1	\$2361.8	-\$97.6	-\$2.1	-\$100.4	-\$163.4	-\$50.4	-\$75.7
19	RN	-\$1.9	\$1822.9	-\$83.4	-\$37.5	-\$86.0	-\$4.1	-\$66.5	-\$61.2
20	R	-\$1.0	\$2179.6	-\$71.3	-\$0.6	-\$62.0	-\$157.0	-\$32.4	-\$53.8
21	PR	\$9.7	\$2100.2	-\$37.5	-\$18.7	-\$29.1	-\$120.5	-\$4.8	-\$18.8
22	R	-\$0.2	\$2246.3	-\$84.9	-\$2.9	-\$73.1	-\$132.0	-\$42.6	-\$63.2
23	R	-\$0.1	\$1849.7	-\$123.9	-\$1.7	-\$128.8	-\$163.1	-\$44.9	-\$86.8
24	RN	-\$1.9	\$1310.8	-\$92.0	-\$37.5	-\$96.8	-\$4.1	-\$63.3	-\$54.7
25	R	-\$1.2	\$1688.5	-\$103.6	-\$0.5	-\$85.9	-\$156.9	-\$28.0	-\$68.6
26	PR	\$12.3	\$1609.1	-\$68.2	-\$16.0	-\$52.3	-\$117.8	-\$4.4	-\$30.8
27	R	\$0.1	\$1733.6	-\$107.8	-\$2.5	-\$88.7	-\$131.7	-\$38.1	-\$71.6

Terminal node 1 gives a culling recommendation of pregnancy test and replace open cows with a bred heifer. This category describes cows that are less than 8.25 years in age, replacement prices less than \$555/head, calf prices less than \$88/cwt., spring decision period, and a cost differential for spring calving that is \$65/head less than fall calving. The amount of node impurity associated with this decision is identified by looking at the cost of mistake value for the recommended decision. This value is \$4.17 (cost of mistake value for PR), about \$17 less than the next best decision of pregnancy test and not replacing open cows (PN). Under the conditions described, the decision of cull all and don't replace (RN) is the worst decision one

could make. The average cost of mistake for RN is \$135.30, significantly more than all the other possible decisions. Terminal node 17 has an average cost of mistake of \$0.00 for the decision R since none of the decisions are incorrectly classified.

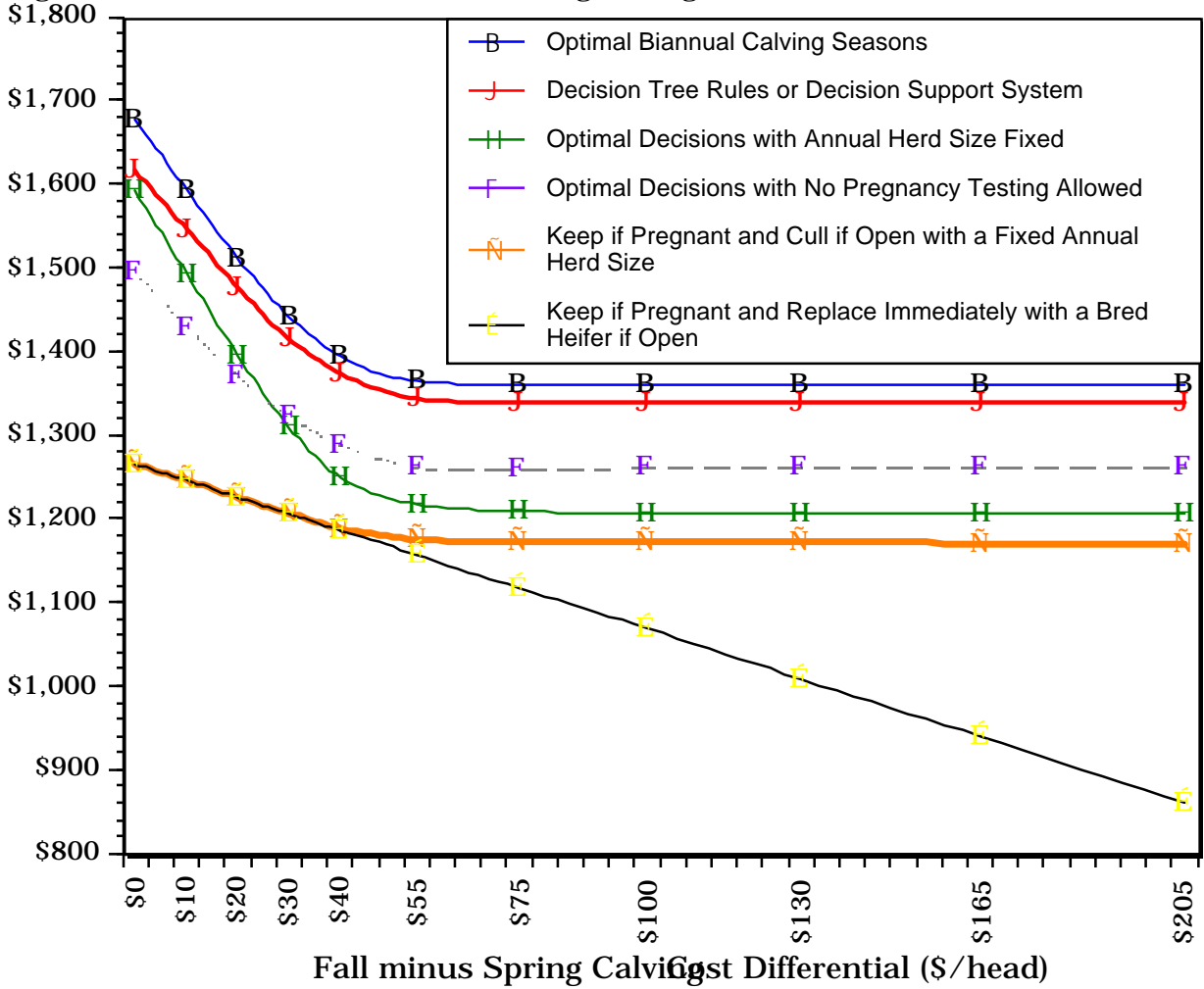
Table 2 also gives the present value for an animal unit that is classed into each terminal node (20 year planning horizon). The category with the highest present value is node 18, at \$2,362. This node represents the following; a cow less than 9.25 years of age with a sale calf at side, spring season, an operation where the cost of fall calving is not \$65/head more than spring calving, calf price is greater than \$88/cwt. and replacement prices less than \$555/head. This cow and calf are not worth \$2,362 but expected future returns from this starting point and subsequent optimal replacement decisions for a 20 year planning horizon yield a present value of \$2,362 (6% real discount rate utilized).

The value of pregnancy testing for one period is determined by subtracting the lowest cost of mistake value for pregnancy testing (i.e., PR, or PN) from the lowest uniform culling decision (i.e., K, R, K6, or RN) cost of mistake. For example, for node 1 the lowest uniform cost of mistake value is K at \$35.93. The lowest pregnancy test cost of mistake is PR at \$4.17. Subtracting \$4.17 from \$35.93 yields a value of pregnancy testing of \$31.76. Node 11 has a value of pregnancy testing equal to -\$46.28. The value of pregnancy testing can go much lower than -\$2/head or the assumed cost of pregnancy testing each cow. This is because pregnant cows are always maintained in the herd, even if market prices and biological factors are conducive to replacing these cows with a bred heifer or culling them and not replacing them in the current period. In addition, cows that test open are always culled from the herd even if market prices and age indicate that these cows should be maintained in the herd. The

lower limit of $-\$2/\text{head}$ would only occur if cows that tested open or pregnant were kept or culled according to optimal culling decisions.

Figure 2 compares the long run merits of pregnancy testing by comparing the economic merits that accrue to (i.e., present value of a 20 year planning horizon) six different culling strategies. The strategies considered are; 1) optimal culling decisions with pregnancy testing allowed and herd size variable, 2) decision tree rule generated with CART, 3) optimal culling decisions with a fixed annual herd size, 4) optimal culling decisions made with herd size variable

Figure 2. Present Value of Selected Culling Strategies

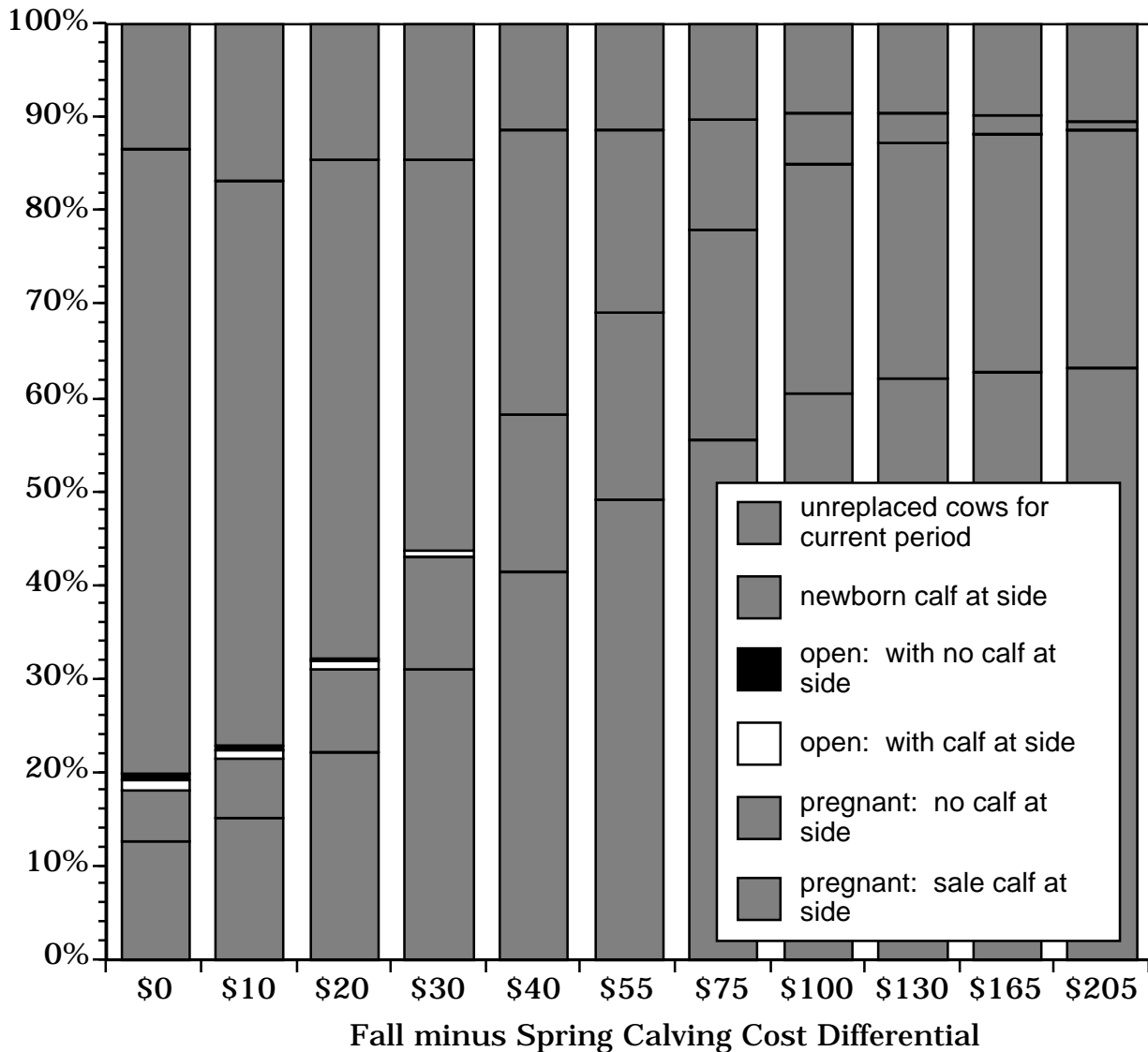


and no pregnancy test information, 5) keep if pregnant and cull if open culling decisions with a fixed annual herd size, and 6) keep if pregnant and replace open cows immediately with a bred heifer. The present value of a slot in the herd is at a maximum of \$1,678 if the cost differential between spring and fall calving is \$0.0 and optimal culling decisions are made with a variable herd size and pregnancy testing is allowed. The present value falls quite rapidly as the cost differential increases to \$55 and then levels off to a value of \$1,359 with a spring only calving season. A biannual calving season has an expected net worth of \$319 (\$1,678-\$1,359) more

than a spring only calving season when the cost of spring and fall calving are equal. Two items contribute to this increase in profitability. First, sale calf prices have been historically higher in the spring than fall. As described in Figure 3, on average around 70% of the herd should have a newborn calf at side in the fall. These calves will be sold in the spring at a relatively higher price than if they were sold in the fall. Second, open cows can be brought back into production six months earlier (by allowing the cow to switch calving seasons) than with a spring only calving system. As described in Figure 3, a small percentage of open cows are maintained in the herd when the cost differential of fall minus spring calving is less than \$40 or when biannual calving seasons are viable. Figure 3 indicates that about half of the calves should be born in the spring and the other half in the fall if the cost of fall calving is \$30 to \$40 greater than spring calving.

The decision tree culling rules shown in Figure 1 capture anywhere from 96.4% of the optimal returns with a \$0.0/head calving cost differential to 98.5% with a calving cost differential above \$40/head. The third management alternative evaluated is a biannual calving season with a fixed herd size. As shown in Figure 3, around 10% of the slots in a herd are not replaced immediately in the current period. This means that on average price conditions are often not conducive for immediately bringing a replacement into the herd. The impact of not allowing herd size to vary can be seen by comparing the present value of optimal decisions with herd size variable (strategy 1) and annual herd size fixed (strategy 3). The fixed herd size is 5% less profitable over the long run than optimal culling decisions with a \$0.0/head calving cost differential and decreases to over 13% less cumulative profit with a calving cost differential

Figure 3. Expected Long Term Composition of the Herd in the Fall.



greater than \$75/head. Size is fixed in an annual sense because replacements are not forced to take the place of a cow that may die or be determined physically unfit in the spring. That is, replacements are not forced into the herd to calve in the fall when the cost of fall calving is not economically viable.

Figure 2 quantifies the long run value of pregnancy testing by comparing the optimal returns generated when pregnancy testing is allowed (strategy 1) to those when pregnancy

testing is not allowed (strategy 4). The fourth management strategy considered allows for biannual calving and a variable herd size, but optimal culling decisions are made on the basis of not having the ability to obtain any pregnancy test information. The long run value of pregnancy testing is estimated at \$183 when the differential is \$0.0/head. This value falls to \$105 with a \$40/head calving cost differential and levels off at around \$98 with a cost differential above \$100/head. Although pregnancy testing is not always profitable, having the technology to obtain pregnancy status information at \$2/head allows for increasing long term ranch profitability from 7% to 11%.

The fifth management strategy keeps all cows that are pregnant and culls all open cows. Open cows must be replaced within a year since annual herd size is fixed. As seen in Figure 2, this strategy yields \$413 less expected wealth with a \$0 cost differential than optimal biannual calving seasons. As the calving cost differential increases above \$55, expected wealth is \$188 or about 13% less than optimal biannual calving seasons. Clearly, pregnancy testing alone is not the answer to increasing ranch profitability. In fact the more traditional management strategy of pregnancy testing all cows and culling all open cows (strategy 5) results in anywhere from 8% to 18% less profit than optimal culling decisions made without any pregnancy test information. The last management strategy considered forces open cows to be replaced with a bred heifer immediately. Plus cows that test pregnant must be maintained in the herd. As the cost of fall calving exceeds spring calving costs by over \$55, profits plummet in almost direct proportion to the increase in the cost of fall calving.

Results presented suggest that in general ranchers should pregnancy test and not maintain a constant herd size. Having the technology to attain pregnancy status can increase long term profitability from 7% (spring only calving) to 11% (\$0.0 cost differential between

spring and fall calving). However, pregnancy testing alone is not the answer to increasing ranch profitability since the more traditional management strategy of pregnancy testing all cows and keeping pregnant cows while culling all open cows results in anywhere from 8% to 18% less profit than optimal culling decisions with no pregnancy information. To simplify delivery of the CART culling recommendations a World Wide Web site has been set up to deliver these culling recommendations in an interactive format.

References

- Burt, O. R., and C. R. Taylor. "Reduction of State Variable Dimension in Stochastic Dynamic Optimization Models which Use Time-Series Data." *West. J. Agr. Econ.* 14(December 1989): 213-222.
- Breiman, L., J. H. Friedman, R. A. Olshen, and C. J. Stone. *Classification and Regression Trees*, Belmont CA: Wadsworth Publishing Co., 1984.
- Frasier, W. M. and G. H. Pfeiffer. "Optimal Replacement and Management Policies for Beef Cows." *Amer. J. Agr. Econ* 76(December 1994): 847-858.
- Tronstad, R. and R. Gum. "Cow Culling Decisions Adapted for Management with CART." *Amer. J. Agr. Econ* 76(May 1994): 237-249.