July 1975

Genetic Value of Sexed Semen to Produce Dairy Heifers

L. Dale Van Vleck
University of Nebraska-Lincoln, dvan-vleck1@unl.edu

R. W. Everett
Cornell University

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L. D. VAN VLECK and R. W. EVERETT
Department of Animal Science
Cornell University
Ithaca, NY 14853

ABSTRACT

Economic value of sexed semen due to increased intensity of selection on cows to produce replacements can be determined from a slight modification of a procedure used to predict net worth of semen of different costs from sires of different transmitting abilities. Table values corresponding to precision of sexing (selection intensity allowed for cows), discount rate, investment period, and conception rate are used in simple equations to determine the economic value of sexed or regular semen. The additional price that can be paid for sexed semen as compared to regular semen also can be determined. For example, sexed semen resulting in 80% heifers can increase transmitting ability of cows selected to produce heifers by 93 kg of milk or genetic gain by 8 kg per year. However, with a discount rate of 10%, 10 yr, a conception rate of 50% for both regular and sexed semen, an added value above feed costs of $.1005/kg, and an ampule cost of $6 for regular semen, the cost per ampule of sexed semen must be less than $15.67 for use of sexed semen to be profitable. Another example also is given in the text for comparing the expected economic returns for two bulls with different predicted difference milk, conception rates, and price per breeding unit of regular semen.

INTRODUCTION

Separation of semen into female and male producing sperm has attracted the interest of dairymen for many years. Scientific literature (1) has not supported claims by commercial concerns. If accurate sexing of semen does become a reality, then the question arises as to the genetic and economic advantages of producing all heifers or all bulls. That is, what is the profitable price for such semen? Skjervold (4) and Cunningham (2) have discussed the genetic consequences of changing the sex ratio. Everett (3) has developed a method for determining the value of semen from bulls of different transmitting abilities (one-half additive genetic value) which considers the bull's transmitting ability, semen cost, conception rate, net value per unit of additional milk, and survival rate of calves born as well as the crucial economic factors of discount rate for income and expenses and period of investment.

Everett's method can be used with only slight modification to answer the question of how much sexed semen is worth in terms of increased genetic progress because of allowing more intense selection of cows to furnish herd replacements. The value of individual matings to produce young bulls for use in artificial insemination studs or to produce calves for specific markets will not be considered.

METHODS

Assumptions similar to those by Everett (3) were as follows:

1) Bull and heifer calves from all sires have equal value for veal.

2) Probabilities that a cow will survive for additional lactations, given that she freshens as a heifer, will be the same for all daughters of all sires and are 1.00, .82, .68, .52, .34, .25, .16, and .11 for first through eighth lactations and 0 for later lactations.

3) Because genetic selection differentials and predicted transmitting abilities are mature equivalent, expected lactation milk yield was adjusted to an actual yield by multiplying by the inverse of Holstein age factors: .73, .85, .95, .98, .99, 1.00, 1.00, and 1.00 for first through eighth lactations.

4) Only .80 of conceptions result in births in the herd, and .83 of heifer calves born alive survive to freshening.

5) Interval between lactations is the same for daughters of all sires (1 yr). Conversion of these

Received July 3, 1975.

results to other constant calving intervals would be straightforward.

ECONONOMIC VALUE OF SEMEN

The procedure of Everett (3) is to find v, the predicted economic value for a specified time discounted back to time of insemination due to the genetic value for production of a heifer that calves in the herd. The matrix formulation is

$$v = s\mathbf{t}'\mathbf{l}$$

where s is a scalar that is the product of predicted transmitting ability of the donor of the semen and net value per additional unit of milk, $\mathbf{l}$ is an $n \times 1$ vector of ones, and $\mathbf{t}$ is an $n \times 1$ vector with elements describing the contribution of a heifer to the herd for each of n yr following first calving including production in several lactations and from descendants of future generations. In fact,

$$\mathbf{t} = \mathbf{Q}\mathbf{r}$$

where $\mathbf{Q}$ is the matrix to discount production in each year back to time of insemination, an $n \times n$ diagonal matrix with elements $1/[(1 + d)^i]$ for $i = 2, \ldots, n + 1$, and d equals the discount rate, e.g., .08, .10, .12, or .14. In addition,

$$\mathbf{r} = \mathbf{E}(\mathbf{j}_1 + \mathbf{j}_2 + \ldots + \mathbf{j}_m)$$

where $\mathbf{E}$ is an $n \times n$ matrix used to adjust expected lactation records made at different ages to actual yield and for probability of a cow surviving from one lactation to the next:

$$\mathbf{E} = \begin{bmatrix} 0 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 0 & \cdots & 0 \\ .73 & 0 & 0 & \cdots & 0 \\ .70 & .73 & 0 & \cdots & 0 \\ .65 & .70 & .73 & \cdots & 0 \\ \vdots & & .70 & \cdots & 0 \\ .11 & \vdots & \vdots & & \vdots \\ \vdots & & & & \\ 0 & 0 & 0 & \cdots & 0 \end{bmatrix}$$

The nonzero terms in each column are products of inverse age factors and probabilities of surviving for lactations one to eight, respectively, e.g., .73 equals probability of a first lactation (1.00) times inverse of the first lactation age factor (.73), and correspondingly .70 = (.82)(.85) for the second lactation. The zeros in the first elements of the columns of $\mathbf{E}$ transform contributions of the semen to each generation to 2 yr later when production actually begins. The $n \times 1$ vectors, $\mathbf{j}_k$ ($k = 1, \ldots, m$), correspond to the expected standardized yearly additive genetic contribution to yield by a heifer entering the milking herd to the kth generation of descendants. The elements of $\mathbf{j}_k$ are yearly contributions for that generation with $\mathbf{j}_1' = [1 \;\; 0 \;\; 0 \ldots \;\; 0]$. Thus, $\sum_{k=1}^{m} \mathbf{j}_k$ is an $n \times 1$ vector of expected standardized yearly contributions summed over m generations. Also, $\mathbf{j}_k = .5h\mathbf{D}\mathbf{j}_{k-1}$ where the scalar .5 represents halving of transmitting ability in each generation and $h = .34$ is a scalar representing fraction of calves born that actually enter the milking herd.

$\mathbf{D}$ is an $n \times n$ matrix with each column representing probabilities of survival of the corresponding generation in a specified year:

$$\mathbf{D} = \begin{bmatrix} 0 & 0 & \cdots & 0 \\ 0 & 0 & \cdots & 0 \\ 1.00 & 0 & \cdots & 0 \\ .82 & 1.00 & \cdots & 0 \\ \vdots & .82 & \cdots & 0 \\ .11 & & & \\ 0 & \vdots & & \vdots \\ \vdots & & & \\ 0 & 0 & \cdots & 0 \end{bmatrix}$$

For example, in generation 1, probability of survival in yr 3 is 1.00, given that the heifer calves in yr 3, but probability of survival in yr 4 is .82, etc. The zeros in the first elements of the columns of $\mathbf{D}$ transform the $\mathbf{j}$ vectors to the time when a first calf can be born from the previous generation. As an example of the $\mathbf{j}$ vectors suppose that $\mathbf{h}$ = .34 and $\mathbf{D}$ is defined above. Then, equations are in Fig. 1.

The expected standardized genetic contributions from the original milking heifer to the second generation are shown in $\mathbf{j}_2$. The first possible contribution is in year 3 when the first calf can be born, there is only a .5 chance a heifer is born and only a .34 chance the heifer will reach the milking herd ($1 \times .5 \times .34$) = .17. There is only a .82 chance the heifer will survive to produce a calf in year 4 ($.82 \times 1 \times .5 \times .34$) = .14. Generation 3 cannot be born until year 5. The .05 in year 6 is made up of the possible contribution of heifers born in years 3

$$j_2' = (0 \quad 0 \quad .17 \quad .14 \quad .12 \quad .09 \quad .06 \quad .04 \quad .03 \quad .02),$$

$$j_3' = (0 \quad 0 \quad 0 \quad 0 \quad .03 \quad .05 \quad .06 \quad .06 \quad .06 \quad .05), \text{ and}$$

$$j_4' = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad .00 \quad .01 \quad .02 \quad .03), \text{ so that}$$

$$\sum_{k=1}^{4} j_k' = (1 \quad 0 \quad .17 \quad .14 \quad .14 \quad .14 \quad .12 \quad .12 \quad .10 \quad .10).$$

FIG. 1. Expected standardized yearly additive genetic contributions to yield to the *k*th generation of descendants by a heifer entering the milking herd, $j_k = .5h\,Dj_{k-1}$ where h = .34.

and 4 of generation 2. The birth year genetic contributions for the first four generations are given by summing over generations. The expected production resulting from all lactations is found by multiplying by E.

Thus,

$$v = s[QE(j_1 + \ldots + j_m)]'1.$$

ECONOMIC VALUE OF SEXED SEMEN

Economic value predicted for each milking heifer resulting from sexed semen can be found similarly. Genetic economic value is sum of the value contributed by the semen and the value contributed by the egg. Predicted transmitting ability carried by the semen can be taken from a sire report. Predicted transmitting ability carried by the egg can be taken from cow evaluation reports, but for purposes of this paper, it will be assumed that transmitting ability of the egg is expected transmitting ability for cows selected to be inseminated with sexed semen. The fraction of cows bred with sexed semen will depend on precision of sexing, i.e., fraction of heifers which actually results from use of sexed semen. The results of this paper require knowledge of this precision so that selection differential for cows can be calculated.

Selection differentials in Table 1 were developed assuming that average correlation between true and predicted transmitting ability of cows is .65, standard deviation of transmitting ability is 283.5 kg, and fraction of cows needed to produce replacement heifers is as shown in the table. Cows not selected to produce replacements are assumed to be bred to bulls with low semen costs and possibly different conception rates.

Let *c* be average economic value of transmitting ability of selected cows, i.e., economic value for added unit of milk multiplied by average transmitting ability from Table 1. Thus, expected discounted income per milking heifer resulting from sexed semen used on selected cows is

$$v = (s + c)\ [QE(j_1 + \ldots + j_m)]'1.$$

Values of v, except for the scalar $s + c$, are in Table 2 for various discount rates and for years in the investment period of 5, 10, 15, and 20.

The equation for discounted income and Table 2 can be used to compare income expected from using sexed semen with income expected from using regular semen by using

TABLE 1. Average transmitting ability of cows selected to be bred with sexed semen for different precisions of sexing. Accuracy of predicting transmitting ability is assumed to be .65, and standard deviation of transmitting ability is assumed to be 283.5 kg.

Precision of sexing: % heifers	% Cows bred to sexed semen	Select top % of cows to produce replacements	Average transmitting ability for milk of selected cows (kg)
100	50	45	161.94
90	56	50	147.42
80	63	57	129.28
70	71	64	108.86
60	83	75	77.11
50	100	90	36.34

TABLE 2. Fraction of sire and cow superiority in transmitting ability per milking heifer age adjusted and discounted back to time of conception for four investment periods and four discount rates.

Years in investment period	Discount rate			
	.08	.10	.12	.14
5	1.621	1.504	1.399	1.305
10	3.327	2.987	2.691	2.442
15	4.021	3.532	3.126	2.791
20	4.313	3.745	3.282	2.903

appropriate values from Table 1; 36.34 kg of milk for cow selection with regular semen and, for example, 129.28 kg for cow selection when sexed semen produces 80% heifers, each milk differential to be multiplied by net income per additional unit of milk.

Such a comparison is valid if breeding costs of the herd are the same for sexed and regular semen. Sexing of semen is likely to incur added costs. Average insemination costs to produce a milking heifer from sexed and regular semen need to be known to make a valid comparison.

INSEMINATION COST PER MILKING HEIFER

Average cost of service from sexed semen per heifer reaching the milking herd is the sum of the costs of achieving conception in cows inseminated with sexed semen and with regular semen divided by number of heifers reaching the milking herd as the result of conception by sexed semen. This result can be written in symbolic terms as

$$x = [p_s a_s + (1 - p_s) a_r] / p_s h_s \ (.8)(.83)$$

where x is average breeding costs to produce a milking heifer, p_s is fraction of the herd bred with sexed semen, a_s is average cost per conception using sexed semen, a_r is average cost per conception using regular semen, and h_s is fraction of heifers born from conceptions using sexed semen (.8 is the assumed fraction of conceptions resulting in a birth, and .83 is the fraction of heifers born from sexed semen which survive to freshening); $h_s = .5$ is equivalent to using nonsexed semen on all cows. The relationship between p_s and h_s is such that their product is .5, i.e., one-half the calves born in the herd are heifers from cows bred with sexed semen in order to maintain the same number of heifers available as herd replacements as if using regular semen. Thus, the denominator of x is $(.5)(.8)(.83) = .332$.

Let w_s be probability of conception from a single service with sexed semen. Then, expected number of services with sexed semen per conception is approximately

$$c_s = 1 + \sum_{i=1}^{7} (1 - w_s)^i.$$

A reviewer has pointed out that c_s converges to $1/w_s$ if an infinite number of services are allowed. That result is close to the one for considering eight possible services.

Similarly,

$$c_r = 1 + \sum_{i=1}^{7} (1 - w_r)^i$$

approximates expected number of services with regular semen per conception when probability of conception from a single service is w_r.

If there is an insemination charge for all except second service (second services are free), the number of paid services per conception will be $c_s - (1 - w_s)$ with sexed semen and $c_r - (1 - w_r)$ with regular semen. Table 3 lists conception rates and corresponding services per conception and paid services.

Average cost of insemination per conception is made up of semen costs for each insemination and the inseminator's fee for all except second services. Let D_s be cost per breeding unit of sexed semen and D_r be cost per breeding unit of regular semen. Let S_s and S_r be the inseminator's fee for all except second services which are free. Then,

$$a_s = c_s D_s + [c_s - (1 - w_s)] S_s$$

and

$$a_r = c_r D_r + [c_r - (1 - w_r)] S_r$$

so that

TABLE 3. Number of services per conception and number of nonsecond services for various conception rates per service.

Conception rate per service w	Number services per conception c	Number of non-second services $c-(1-w)$
.70	1.43	1.13
.68	1.47	1.15
.66	1.52	1.18
.64	1.56	1.20
.62	1.61	1.23
.60	1.67	1.27
.58	1.72	1.30
.56	1.79	1.35
.54	1.85	1.39
.52	1.92	1.44
.50	2.00	1.50
.48	2.08	1.54
.46	2.17	1.63
.44	2.27	1.71
.42	2.38	1.80
.40	2.50	1.90
.38	2.63	2.01
.36	2.78	2.14
.34	2.94	2.28
.32	3.12	2.44

$$x = \Big\{p_s\Big\{c_sD_s + [c_s - (1 - w_s)]S_s\Big\} + (1 - p_s)\Big\{c_rD_r + [c_r - (1 - w_r)]S_r\Big\}\Big\}/p_sh_s(.8)(.83).$$

The equation reduces considerably for specific situations. For example, suppose that relatively inexpensive semen used on the part of the herd not bred with sexed semen costs c_r = \$2 per breeding unit and that S_s and S_r both are \$4. Also, assume that $w_s = w_r = .5$ so that $c_s = c_r = 2$ and number of paid services = 1.5. Now,

$$x = 6.024p_s(D_s - 2) + 30.20.$$

If a herd buys semen and does its own insemination (direct service), then the average cost per conception is the product of number of services per conception and the sum of purchase price per unit of semen and average cost of equipment, depreciation, and labor.

COMPARISON OF VALUE OF SEXED AND REGULAR SEMEN

Comparison of value of sexed semen and regular semen can be made using discounted return on investment, v, and service and semen cost per milking heifer, x. For example, suppose sexed semen results in .80 heifer calves so that $p_s = .62$. The corresponding average transmitting ability of selected cows would be 129.28 kg with a value of \$.1005/kg. Then, c = \$12.99. The value of average transmitting ability of cows if regular semen is used will be 36.34 kg and at \$.1005, \$3.69. Assume the same sire is used for both sexed and regular semen with estimated transmitting ability assumed to be zero and that $w_s = w_r = .5$. Further, assume that discount rate is .10. At yr 5, v = (1.504)(\$12.99) = \$19.54 for sexed semen, and v = (1.504)(\$3.69) = \$5.55 for regular semen. Other discounted income values are \$38.83, \$45.92, and \$48.68 for sexed semen and investment periods of 10, 15, and 20 yr, respectively. Regular semen results in income of \$11.02, \$13.03, and \$13.82 through yr 10, 15, and 20.

Service and semen cost per milking heifer is $x = 3.795D_s + 22.61$ for sexed semen with cost per unit of D_s, and $x = 6.024D_r + 18.15$ for regular semen with cost per unit of D_r.

Net return at yr 10 is $38.83 - 22.61 - 3.795D_s = 16.22 - 3.795D_s$ for sexed semen and $11.02 - 18.15 - 6.024D_r = -7.13 - 6.024D_r$ for regular semen of the same bull.

This procedure can be used to determine how much more can be paid per unit of sexed semen than for regular semen. For net return to be equal or greater from sexed semen at yr 10, $16.22 - 3.795D_s \geqslant -7.13 - 6.024D_r$, and, therefore, $D_s \leqslant 1.587D_r + 6.152$. If D_s is greater, then net return at 10 yr would be less with sexed semen, and if D_s is less, then net return would be greater with sexed semen. For example, if D_r = \$6.00, then for sexed semen to have an economic advantage, no more than \$15.67 could be paid for sexed semen.

Other values of insemination fees, milk price, conception rates of sexed and regular semen, accuracy of sexed semen, and discount rates can be considered to determine expected return over investment for sexed semen as compared to regular semen. If calves from beef sires were more valuable than from dairy sires, then an adjustment could be made to account for the value of calves from cows bred to regular semen of beef sires.

COMPARISON OF TWO BULLS WITH REGULAR SEMEN

The procedure can also be used to compare economic return from using one bull rather

than another. Predicted income per milking heifer will be the appropriate value from Table 2 corresponding to discount rate and years in the investment period multiplied by the sire's estimated transmitting ability multiplied by value per unit of additional milk.

Breeding cost per milking heifer for bull i will be

$$x_i = \left\{c_i D_i + [c_i - (1 - w_i)] S_i\right\} / (.5)(.8)(.83)$$

where as before c_i is number of services per conception with conception rate w_i, D_i is cost per breeding unit, and S_i is the inseminator's fee for all services except the second which is assumed to be free.

As an example, suppose the inseminator's fee is $4 for all except second services and that each added kg of milk has value $.1005. Sire A had PD = 226.80 kg milk with conception rate .60 and semen cost of $6. Sire B has PD = 362.88 kg with conception rate .50 and semen cost of $8. At yr 15 and discount rate of .10, expected net return from using A is

$$[(3.532)(226.80)(.1005)] - \left\{[(1.67)(6) + (1.27)(4)] / .332\right\} = \$35.05.$$

Expected net return from B is

$$[(3.532)(362.88)(.1005)] - \left\{[(2.00)(8) + (1.50)(4)] / .332\right\} = \$62.58.$$

Thus, sire B is expected to yield a higher return after 15 yr than sire A, despite having higher semen cost and lower conception rate.

To predict difference in net return for two bulls i and j, let $(s_i - s_j)$ be difference in estimated transmitting abilities multiplied by net value per added unit of milk and y be the appropriate value from Table 2. Then, difference in net return will be $(s_i - s_j)y - (x_i - x_j)$.

Another factor which perhaps should be considered is the increase in days open with a lower conception rate. In most cases, however, bulls used in artificial insemination are not greatly different in conception rates so that at a cost of $1.00 per added day open, the maximum difference between two bulls is likely to be $8.00 which could be included in $x_i - x_j$. The difference in cost of days open for conception rates of 70% and 50% with average service intervals of 40 days and a charge of $1.00/day open would be a maximum of $23.00 and only $12.00 if the service intervals were 21 days.

The cost of the difference in days open when using bull i rather than bull j would be $(c_i - c_j)$ (service interval) (cost of each added day open). This idea was suggested by another reviewer. In the previous example, $c_A - c_B = 1/.6 - 1/.5 = -.33$. If the service interval was 40 days and each added day open is valued at $1.00, then the difference in cost in days open of using B rather than A is (−.33) (40) ($1.00) = $−13.20. If the service interval was only 21 days, the difference in cost would be $−7.00. The advantage of B over A in the previous calculation thus would be reduced by between $7.00 and $13.20.

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