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Variability and Market Indicators of Breeding Values

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I. Introduction

Genetic resources or heritable traits are increasingly being viewed as scarce resources which should be carefully managed. The awareness of the "genetic vulnerability" of U.S. crop production was heightened by the crop losses resulting from the introduction of a new strain of corn blight to a crop that was uniformly susceptible. Also, many of the recent gains in world food production have resulted from rice and wheat genetic improvements. Efficiently managed genetic resources are expected to play a large part in future food production gains (National Academy of Sciences, 1977).

Much of the genetic research is conducted in the public sector. This follows from the scale economies to conducting the research. Also, the information on novel genetic material and combination methods has public good characteristics making it difficult for private firms to capture all returns. In the U.S. there is a combination of public research and private development and distribution of most agricultural genetic resources. In other countries the entire process is more centralized. A prominent concern is how well does each system function when there is a wide range of environments in which the genetic material must produce. Evanson, et.al., (1976) have examined this question for rice breeding.

The purpose of this paper will be to explore the information on traits and how they are used in purchase decisions in one private genetic market, that for dairy semen. Many indices of trait levels are compiled and made available to agricultural producers. Is the information on the relative desirability of traits by producers being used as one of the guides in investment in public research? Are there improvements that can be made in indices of genetic merit

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which will help producer genetic choices? The risks of adopting new genetic materials also seem to warrant attention, especially when perennials or stock problems are important. See Ladd and Gibson (1978) for an alternative approach to livestock breeding index formation.

This paper proceeds in four sections. The first reviews both the recent theory of demand for characteristics and aspects of supply of genetic improvement used in agriculture. The second section presents an application of the characteristics model and a portfolio model to the market for dairy traits. Data from dairy sire selection are used to determine which genetic traits enter the purchase decisions. Risk aversion, costly information and profit maximization are assumed. The last section draws conclusions and discusses limitations of the present paper.

II. Demand and Supply of Genetic Traits

The relatively new theory of demand for characteristics or traits (Lancaster, 1971) seems to fit the market for agricultural genetic resources quite directly.[1] In this model of behavior, producers would be expected to equate the marginal value product of each trait, or the services that the trait renders, with its implicit price. Consider the following model with only the genetic input (X_1 = semen or seeds) assumed to have multiple traits:

$$\Pi = P_y \cdot Y(X_1(t_i), X_2 \ldots X_j \ldots) - \Sigma_j r_j X_j(t_i), \qquad (1)$$

where Π is annual profits, P_y is the single product price, Y is yield, r_j are input prices and X_j are purchased inputs with the genetic input (X_1) having traits t_i, i = 1, 2, ... I. Both the mix of purchased inputs and traits are <u>assumed to affect</u> yield.[2] In a more complete model the mix of traits might

[1] This section also benefits from suggestions by George Ladd. See his and Martin's 1976 paper on demand for input characteristics.

[2] Both quantity and trait mix of the genetic input X_1 could be considered variable. But for simplicity amount of genetic input is held constant.

also affect product price and the marginal products of other inputs such as labor and feed. Computing first order conditions, one obtains the usual condition for purchasing the genetic input (X_1) as:

$$r_1 = P_y \cdot \delta Y/\delta X_1. \tag{2}$$

This can be expressed in terms of traits of the genetic input as:

$$X_1 = \Sigma_i(\delta Y/\delta t_i \; P_y \div \delta r_1/\delta t_i). \tag{3}$$

Equation (3) states that the marginal value product of the i^{th} trait ($\delta Y/\delta t_i \cdot P_y$) will be set equal to its marginal cost ($X_1 \cdot \delta r_1/\delta t_i$).

Breeding values could be found by estimating $\delta r_1/\delta t_i$. Given a number (k) of sources for observing semen prices (r_{1k}) and levels of various traits per unit of genetic input (t_1, $t_2 \ldots t_i \ldots$), then a form of Equation (2) is $r_{1k} = \Sigma_i b_i t_{ik}$, where b_i is $\delta r_1/\delta t_i$. This form of Equation (2) will be used in the estimation of equations to follow with sources being different dairy sires. Estimates of b_i can indicate what values producers are placing on the marginal value product of a trait (i) per unit of input. $\delta r_1/\delta t_i$ or b_i might be thought of as the market expression of individual trait breeding values.[1]

There are several important features of the supply of genetic resources that will shape the analysis to follow. First, genetic traits are discovered by a stochastic search process. Evanson and Kislev (1975) have shown that this process of discovery has diminishing returns, thus, genetic traits are costly to produce and disseminate. Secondly, traits are biologically linked on the same chromosomes with other traits. This means that purchase of traits can't be made independent of other traits. For example, many pest resistance traits can only be incorporated in commercial crop varieties at a sacrifice in yield

[1] Breeding values are usually thought of for a particular sire, whereas, b_i is an average across a set of individual sires in a market.

(in the absence of the pest). To the extent that correlation of genetic traits are known these can be incorporated into models for optimizing genetic selection. Porterfield (1974) has shown how this can be done with a modified linear programming procedure for the case of pine trees. Tai (1977) has specified a covariance model for incorporating correlated genetic characteristics in selection of potato varieties.

A final feature of the supply of genetic traits is the high degree of uncertainty in the transmission of traits to offspring. This arises especially in livestock breeding. The uncertainty is enhanced by the difficulty and lengthy period involved in determining the degree to which a trait has in fact been transmitted. There are complex interactions between genetic traits and controllable and uncontrollable environmental factors in the production process. All of this indicates a large role for genetic information and information processing.

Animal scientists and agronomists have developed indicators of genetic merit. Some draw readily on market prices such as for milk and milk fat (Norman and Dickinson, 1971; Norman, 1979). Other indices of genetic value have attempted to incorporate probability of crop harvest loss (Rosielle and Frey, 1975), and dairy animal type characteristics that affect health and milking costs (Bell and McDaniel, 1976). Some of the attempts to find genetic trait - market price relationships have been mere exercises in the use of step-wise regression (Palmer and Mao, 1977; Danker, et.al., 1976).

Often explicit market values are not present for genetic traits. Do the indices of genetic merit and animal performance which agricultural researchers are using and providing to farmers reflect the marginal trait pricing conditions given above? Are there improvements that can be made in the indices of value that are rapidly evolving in some genetic markets? The next section examines the dairy semen market since it is one with a large quantity of genetic and price data available.

III. Variability in the Dairy Semen Market

A large part of the gain in milk yield per cow that has taken place in the past several decades is attributed to sire or semen selection. Some specialists place the relative value of sire selection to that of improvements in cows and culling practices at about 75 to 85 percent (Skjerivold and Langholz, 1964). This follows from the relatively short milk producing period which the average cow spends in herds (3 to 3.5 gestations) after milk production begins.

One would expect that the purchase of dairy semen would follow the usual assumptions of asset purchase under risk. First, this is an asset purchase decision because semen quality affects the quality of all of the female offspring of a cow if female calves are kept for replacements. The risk part of the asset decision arises because of the natural genetic variability in herds, and from the fact that semen can be purchased from a variety of bulls with varying degrees of tests on their progeny.

If the dairy operator is assumed to be a risk averse profit maximizer, then his utility function can be approximated by a mean-variance utility function. Even though assuming this utility function can lead to irrational decisions with skewed distributions it may provide a reasonable approximation in this case. This is so because the distribution of genetic traits and the net return distribution which follows from it is usually approximately normally distributed (Anderson, 1974; Falconer, 1960). The price of an asset like dairy semen will be negatively related to the variance (σ_i^2) of receiving a given genetic trait (i).

The final aspect of the semen market that needs to be considered before a price equation can be specified is the short-term supply conditions. Semen supply of a given sire has an upper physiological limit in a given time period.

The elasticity of supply can be expanded somewhat by storage and some artificial environmental conditions. However, one would expect a sharply rising marginal cost of supply at prolonged sales quantities (Q_k) above physiological limits.

The various genetic characteristics, risk and supply effects are depicted in Figure 1. Price per ampule of semen increases from P_0 to P_1 as trait (t_i) increases to t_i^+. The amount of semen price shift from a given investment in trait t_i, other traits constant, reflects the marginal value product of that trait relative to levels of that trait available from other sires. Also, higher levels of variability (σ^{2+}) in receipt of a trait will lower the price of semen for a sire, other things equal. This is shown as the price effect P_0 to P_2. The influence of semen supply on price is illustrated by the rapidly rising supply schedule of semen as the physiological limit of supply per unit of time (Q_k*) is approached.

A reduced form price equation for semen of sire k can be specified by adding variance and quantity variables to Equation 3 and assuming that semen prices are set to clear the market as:[1]

$$r_k = a + \Sigma_i b_i t_{ik} - \Sigma_i c_i \sigma_{ik}^2 + dQ_k + e_k. \tag{4}$$

a, b_i, c_i and d are constants to be estimated. e_k is a random term to reflect unmeasured and omitted price effects. Product price and other input prices are not included as they are assumed constant for a cross-section of sires.

IV. Results from the Dairy Semen Market

The model of Equation 4 was applied to 3 sets of sires from the U. S. dairy semen market. Both private firms and regional cooperatives supply

[1]Note that the quantity variable would not be in this reduced form if a linear supply curve was postulated.

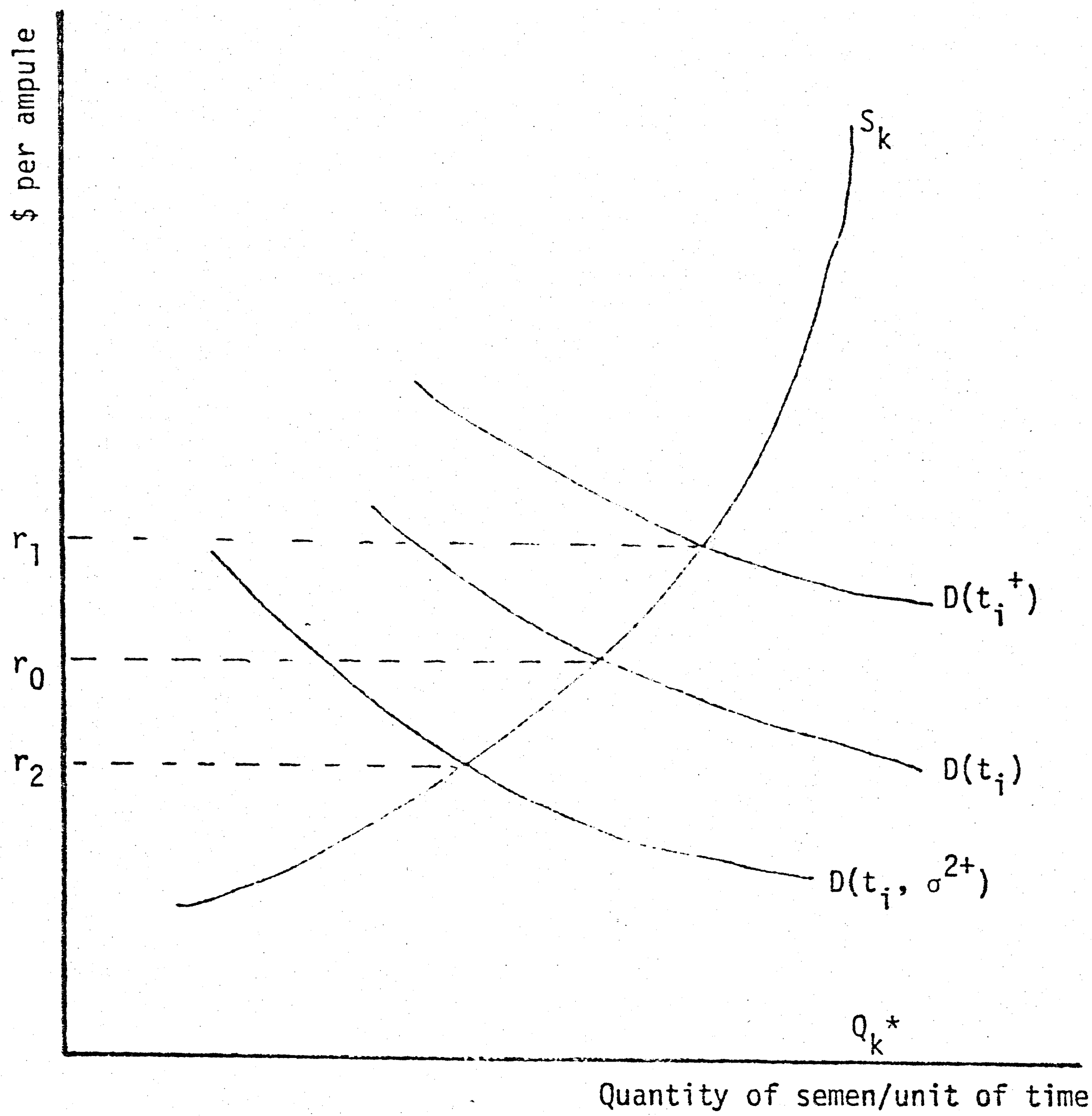

Figure 1. Semen Prices for Various Genetic Traits, Risks and Supply Conditions

dairy semen. Data from one large eastern U. S. cooperative were available. It contained both young sires (y) and proven sires (p). Information on two genetic traits - milk quantity and milk fat, variability in expected value of milk gain, and semen sales quantity was available. A third set of sires from a private stud gave information on milk, fat and type. Type is an index of health, milking ease and calving ease. No sales data were available on data set three.

The milk traits of dairy sires are customarily given in terms of expected milk gain, E(MG), and fat gain, E(FG), from dam (D) to daughter (d) for all (n) tested daughters of sire k:

$$E(MG)_{kp} = \Sigma_j^n (M_{Dj} - M_{dj})/n, \tag{5}$$

and

$$E(FG)_{kp} = \Sigma_j^n (F_{Dj} - F_{dj})/n. \tag{6}$$

For young sires (y), without progeny records, the expected milk gain is computed as a weighted average of the sire's mother (dam index = DI) and the predicted difference of the progeny (say m of them) of the young sire's sire:

$$E(MG)_{ky} = [DI_k + \Sigma_j^m (M_{Dj} - M_{dj})]/2. \tag{7}$$

The same average fat gain variable can also be computed for young sires.

Information given to dairymen on sires usually combines expected milk gain and expected fat gain by using the market prices for milk (P_M) and premiums for fat content (P_F) (Norman and Dickinson, 1971):

$$E(M\$)_k = P_M\, E(MG)_k + P_F\, E(FG)_k. \tag{8}$$

Thus, the main trait that is expected to increase semen prices is expected milk value gain, E(M$), which is used for t_1 in Equation 4 above, in the following analysis.

Risk in genetic transmission was expected to differ widely for young sires and proven sires. Proven sires have reported "repeatabilities" for traits like expected gain by milk value.[1] Repeatability for sire k (R_k) is converted into a standard deviation of expected dollar gain in milk traits by combining estimates of the variances of the two component traits and an estimated

[1] Repeatabilities are computed for each sire by regressing traits of mothers and daughters on one another by managers of the breeding stock.

correlation between milk and fat traits ($r_{MF} = .65$) from the literature (McDaniel, et.al., 1968; Butcher and Legates, 1976):

$$\sigma_{1k} = \sigma_1 \cdot \sqrt{1 - R_k}, \tag{9}$$

where

$$\sigma_1^2 = P_M^2\sigma_{MG}^2 + P_F^2\sigma_{FG}^2 + 2P_MP_Fr_{MF}\sigma_{MG}\sigma_{FG}. \tag{10}$$

Repeatabilities are not available for young sires since they have no or very few progeny. For all young sires accuracy of pedigree indexes are assumed to be .45 from the work of Butcher and Legates (1976). Thus, an equal measure of repeatability was assumed for each young sire ($R_k = .2 = \sqrt{.45}$). Note that this piece of information is not available in the sales information of the sires.

Table 1 shows the means of variables and least square regression estimates of parameters of Equation 4. The means show that semen prices are less expensive for young sires, but that young sires have higher expected milk gains than do the proven sires ($75.50 > $47.60). But investments in proven sires have less risk than for the group of young sires (σ_p = \$20.00 < σ_y = \$35.80). The risk averse dairyman has the usual tradeoff to make in choices from this investment frontier set.

The sign of each of the parameter estimates was found to be just as hypothesized in the above model. The more risky sires, especially the young ones, are priced much lower. The coefficient on risk (σ_1) rises from .12 to .21 when young sires are added to the data set (compare Equations 2 and 3). The increments in semen price from higher levels of expected dollar gain from milk and milk fat (t_1) are consistent and statistically significant at high levels. Dairymen to seem to be including both expected genetic gain and variance in gain in their purchases. It is interesting to note that the

Table 1. Estimates of Semen Price Equations: Young and Proven Holstein Sires

Model	Sample Size	Independent Variables[a]: Expected Milk Gain (t_1)	Risk (σ_1)	Sales Volume (Q)	R^2
I. Proven Sires - linear	31	.117 (4.76)[b]	-.075 (1.10)	-	.46
II. Proven Sires - linear	31	.105 (2.92)	-.121 (1.38)	.09 (1.42)	.51
III. Proven and Young Sires - linear	48	.091 (3.36)	-.208 (2.57)	.11 (2.59)	.50
IV. Proven and Young Sires - log-log form	48	.573 (3.71)	-.370 (2.81)	.391 (4.58)	.59

[a]Mean values for proven (p) and young (y) sires, respectively, were: P_p = \$4.4, t1P = \$47.60, σ_p = \$20.00, Q_p = \$27.53, P_y = \$2.0, t1Y = \$75.50, σ_y = \$35.8, Q_y = \$10.76.

[b]Figures in parentheses are "t" ratios.

magnitude of these coefficients on mean and standard deviation is not unlike the ratios of tradeoff that are found in analysis of stock portfolios.

Sales volume (Q) does have a statistically significant impact on semen price. This is expecially true when the form of the relationship is specified as a constant percentage (log-log) relationship. The sales volume coefficient of .391 in Equation 4 can be interpreted roughly as a supply elasticity of 2.56. Sales volume could reflect both physical scarcity as noted above and prevalence of information for more popular sires.

The analysis of the 3rd data set permitted the examination of the effects of both milk traits and type traits. The estimated model for 62 proven sires was:

$$P_k = 56.20 + \underset{(2.90)}{.168T1} + \underset{(1.42)}{.256R_{k1}} + \underset{(3.88)}{1.70T2} + \underset{(.62)}{.093R_{k2}}, \quad R^2 = .42. \tag{11}$$

T1 is expected milk gain (mean = \$82.0), defined as above. T2 is an index of type (mean = 16.9) compiled from published data distributed to farmers on these characteristics for each sire. Repeatabilities R_{k1} and R_{k2} are included for both milk and type traits, respectively. Repeatability is expected to have a positive effect since higher repeatabilities give lower standard deviations as shown in Equation 9 above.

This data set and model show a statistically significant effect of both type and milk gain. The effect of type (T2) is large and highly significant. Producers do not merely examine expected value of milk gain traits. The coefficient on expected milk gain is about 60 percent higher than for the other two data sets. The risk aspect of the asset model is not strongly supported, though each variable has the correct sign, and the R_{k1} variable is significant at the 8 percent level (with a 1-tailed test). With only proven sires there is not as much variability in repeatabilities to isolate risk aversion tendencies on the part of dairymen.

The absence of quantity data (Q) for the third data set (a large private dairy stud) probably explains part of the price variability left unexplained.

V. Conclusions and Shortcomings of the Model

This analysis indicates that the private semen market can tell us something about what various genetically transmitted traits are valued at. Dairymen do exhibit that they are using published information on mean and standard deviation of traits in their asset purchase decisions. Risk aversion does seem to help explain why variability in genetic transmission is discounted. This is especially true when unproven sires were included in the analysis.

The derived measure of risk for unproven bulls seems to indicate that producers are heavily discounting young sires. Dairymen could probably benefit from information on pedigrees for young sires.

There seem to be many other factors influencing the genetic trait markets besides the most common performance measures. Type, sales volume and risk in various traits are only part of the market.

This analysis did not attempt to examine how the dynamics of information processing affects genetic trait prices. More research is needed with genetic indices and prices through time. This will help explain the lags between availability of a trait measure and its incorporation into producer purchase decisions. Extension, research and testing services need this type information.

Little attention was given in this model to the pricing strategies of the genetic trait suppliers. Cooperatives do have tie-in sales with genetic delivery services (artificial insemination service, primarily). There are constraints on volume of purchases per sire for both cooperative members and non-members. One may wish to consider more explicitly such supply aspects as storage and quotas. There is rapidly expanding genetic trait information in testing stations for beef bulls, swine and other livestock. Many crop characteristics are available from varieties developed at USDA laboratories and in land-grant universities. Agricultural economists and plant and animal breeders have a large role to play in analyzing the implicit markets for genetic traits.

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