# RURAL ECONOMY

**Hedonic Pricing of Dairy Bulls - An
Alternative Index of Genetic Merit**

Timothy J. Richards and Scott R. Jeffrey

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# PROJECT REPORT

**Department of Rural Economy**
Faculty of Agriculture, Forestry,
And Home Economics
University of Alberta
Edmonton, Canada

# Hedonic Pricing of Dairy Bulls - An Alternative Index of Genetic Merit

**Timothy J. Richards[1]**
and
**Scott R. Jeffrey[2]**

**Project Report 95-04**

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[1]     Assistant Professor, Center for Agribusiness Policy Studies, Arizona State University.  Tempe, Arizona.

[2]     Project Leader and Associate Professor, Department of Rural Economy, University of Alberta.  Edmonton, Alberta.

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**ACKNOWLEDGEMENTS**

# ABSTRACT

This study investigates the use of hedonic pricing to identify the value of relevant production and type traits for dairy bulls in Alberta. A hedonic pricing model is estimated that models semen price as a function of individual production and longevity characteristics for a sample of Holstein bulls. This model corrects for sources of statistical bias in the data (i.e., censored data and endogenous supply problems).

The results suggest that the most important characteristics in valuing dairy bulls are milk volume, protein and fat content, general conformation, body capacity, the popularity of the bull, and the probability that the bull's semen may be in short supply. This methodology may be used to establish a method of forecasting semen prices for newly proven bulls. The valuation procedure may be easily updated and adjusted as producers' breeding objectives change over time due to the changing economic environment. Further extensions of this method may be done to incorporate other characteristics and/or to assess shifts in producer breeding objectives over time. The results of this analysis suggest that hedonic pricing may be a superior method of placing a value on production and type characteristics for dairy bulls than the Lifetime Profit Index, currently being used by the Canadian dairy industry.

# HEDONIC PRICING OF DAIRY BULLS:

# AN ALTERATIVE INDEX OF GENETIC MERIT

## Introduction

The science of genetics is of great practical importance to the Canadian dairy industry.  At

the producer level, breeding decisions are often made with the objective of improving certain

physical (i.e., phenotypic) characteristics by "upgrading" the gene pool (i.e., the genotype) within

the dairy herd.  These enhancements provide value, in terms of increased milk production and/or

improved body "type"[1], both of which can lead to improved financial performance (i.e., greater

profit from the sale of milk and cattle) and increased financial value for the dairy herd (i.e.,

breeding stock value).

Given these considerations, it is useful to have a straightforward method of measuring and

reporting the genetic value of dairy bulls.  This would provide dairy producers with an additional

tool to be used in making breeding decisions, in order to improve the genetic quality of their herd

and thereby improve their profitability.  Such a system would also be of value to managers of

artificial insemination (AI) units and other related businesses, by providing an alternative to

existing methods used to set standards by which breeding stock, semen, embryos, etc., may be

valued for marketing purposes.

The Lifetime Profit Index, or LPI, is a measure of genetic value that is currently being

used by the AI industry in Canada to rank dairy bulls.  The LPI makes use of information

concerning production and type scores to provide an index of the expected contribution of a bull's

offspring to dairy enterprise profitability.  However, the LPI suffers from some weaknesses,

related to its construction and the representativeness of the index for all Canadian dairy producers.

This study examines an alternative approach in measuring genetic value. Specifically, hedonic pricing is used to determine the value of genetic traits for purebred Holstein dairy bulls in Alberta. A statistical analysis of market price data for semen is carried out to identify the value of individual relevant production and type traits, based on Alberta production and marketing characteristics. This is the primary objective of the study. A secondary objective is to suggest ways in which this information may be used by the dairy industry to evaluate the genetic quality of dairy bulls. The analysis used in this study directly addresses two data problems common to many hedonic pricing studies; endogeneity of supply and censored data.

The remainder of this paper is divided into six parts. First, the origin, structure and limitations of the LPI are discussed briefly. An alternative method, the hedonic pricing of semen, is then presented in terms of its basis in economic theory, its application to similar problems and its potential relevance to the semen pricing problem. Building on this framework, the third section presents an econometric model of dairy bull service pricing which corrects for sources of statistical bias in the data set (i.e., censored data and endogenous supply problems). This is followed by a description of the data and methods used to estimate the implicit value of each bull. Fifth, the results of econometric estimation of the model are presented and discussed. Finally, study conclusions and implications for future development of genetic indices are provided and recommendations for further research given.

**The Lifetime Profit Index**

The link between selection for genetic characteristics and the economic value of those characteristics in identifying methods of measuring genetic value has been recognized for many years. Hazel (1943) noted that when selecting for improvement in multiple traits, each characteristic should be weighted by its economic value. Agricultural economists and other researchers have proposed and tested alternative economic models for measuring genetic value.[2]

Historically in Canada, the genetic value of dairy bulls has been measured through a set of production and type proofs. Each bull is scored for a series of characteristics (e.g., milk and fat production, feet and legs, capacity, mammary system) based on milk and fat production records and subjective assessments of type traits for its daughters. The score for each production characteristic is based on performance relative to the breed class average (BCA), while type traits are determined relative to the average conformation of the breed. However, the dairy industry has sought a method by which these production and type components can be combined into a single measure or index that also incorporates the economic value of the individual traits.

The Lifetime Profit Index (LPI) is an example of this type of measure. As noted earlier, the LPI measures the expected contribution of a bull's offspring to dairy enterprise profit over a five year period, using a combination of production and longevity characteristics. The current formulation of the LPI is based on research by Gibson et al (1992). Using data from Ontario dairy farms, the relative values of various milk components (e.g., fat and protein) are estimated using dairy production costs and returns, incorporating the presence of production quota for these components. The resulting values are used to develop economic weights and a single selection index, based on milk production traits for the bull.

The version of the LPI being used by the dairy industry is based on a combination of production and type proofs, using BCA and type scores for each bull. The value to a farmer of using a bull with an improved set of genetic traits is estimated by projecting the changes in profit from increasing the production value per animal. The resulting index is calculated as follows:

$$LPI = 6[3 \times FAT + 8 \times PRO] + 4[3 \times FC + 4 \times MAM + 2 \times FL + CAP] \tag{1}$$

where FAT and PRO represent BCA scores for fat and protein components, respectively, of milk production. FC, MAM, FL and CAP represent type scores for final class, mammary system, feet and legs, and capacity, respectively. The LPI thus attributes a relative weight of 60 percent to the production component of the bull's proof scores and 40 percent to the type, or longevity, component. Each of these, in turn, is composed of weighted sums of scores for individual traits. The LPI is currently being used by AI units in Canada as an overall measure of genetic merit.

The LPI is an appealing measure, as it combines production and type proofs into a single index. However, this approach has four fundamental weaknesses. First, the costs and returns of the representative (average) farm derived from the Ontario data are not likely to be representative of all dairy producers in Canada. Second, the Ontario records yield estimates of the average cost associated with a given change in milk production, whereas producers concerned with improving their profits should consider the incremental, or marginal costs, of genetic improvements. Third, although the longevity traits of each bull will be different, the relevant lifetime of the offspring for every bull is defined to be five lactations. In fact, longevity traits will be closely related to the type scores. Finally, the weights for each component of the LPI are determined on an ad hoc basis; that is, they have no basis in optimal economic behaviour. This is another way of stating

that the method assumes a fixed production technique even though the level of technology is constantly changing in the industry.

**Hedonic Pricing Models**

The value of a dairy bull, or its semen, is determined by the genetic production and type characteristics for that bull. Thus, an economic model that expresses genetic worth as a function of individual product characteristics would be appropriate for use. This is the approach taken when using hedonic pricing models.

Hedonic pricing is based on theoretical work by Becker (1965), Lancaster (1966) and Rosen (1974), among others. A hedonic pricing model considers the demand for a product or input as a function of its characteristics. For example, in the case of a firm producing a single product, y, a production function for y may be defined as follows:

$$y \ = \ f(z) \tag{2}$$

where z is an m-vector of input characteristics. The firm is assumed to maximize profits, as follows:

$$\pi \ = \ pf(z) \ - \ w'x \tag{3}$$

where p is the output price, while w and x are n-vectors of input prices and quantities, respectively.

First-order conditions for profit maximization require:

$$\frac{\partial \pi}{\partial x_i} = p \sum_{j=1}^{m} \left[ \frac{\partial f}{\partial z_j} \frac{\partial z_j}{\partial x_i} \right] - w_i = 0 \quad \forall i = 1, 2, \ldots n \tag{4}$$

For any particular input $x_i$, (4) may be rearranged to obtain the following relationship:

$$w_i = \sum_{j=1}^{m} \left[ T_j \frac{\partial z_j}{\partial x_i} \right]$$

$$\text{where} \quad T_j = p \frac{\partial f}{\partial z_j} \tag{5}$$

$T_j$ represents the value of the marginal yield of the $j^{th}$ characteristic. Equation (5) states that the price of input i is equal to the sum of the marginal implicit values for each characteristic multiplied by the marginal yield of that characteristic with respect to input i. The relationship in (5) represents a hedonic price function. Given appropriate data, this function can be estimated to determine the effects of changing physical characteristics on input prices, and thus demand for the input; that is, to determine the implicit marginal value of characteristics ($T_j$'s).

Agricultural markets provide many opportunities to value outputs and inputs with non-tradable attributes. Hedonic pricing approaches have been used to estimate the value of characteristics for a variety of agricultural products. Examples of these studies include Bowman and Ethridge (1992; cotton), Brorsen et al (1984; rice), Espinosa and Goodwin (1991; wheat), Ethridge and Davis (1982; cotton), Ethridge and Neeper (1987; cotton), Jordan et al (1985; tomatoes), Lenz et al (1994; milk), Perrin (1980; milk), Tronstad et al (1992; apples) and Veeman

(1987; wheat).

The hedonic pricing approach is equally valid in investigating the derived demand for production inputs (e.g., Ladd and Martin 1976). The demand for livestock sires is an example of a production input that may be valued using hedonic methods. Livestock sire demand is derived from producers' demands for the genetic traits that the sire is expected to bring to the herd. Walburger and Foster (1994), for example, determine the implicit prices paid for various boar traits by treating the selling price of a boar as a function of backfat, loineye area, average daily gain, feed conversion, and the numbers farrowed and weaned from the boar's litter.

Using a similar approach, Kerr (1984) develops a hedonic pricing model of genetic improvement for Canadian beef cattle. Output per bull is assumed to depend upon several non-genetic inputs such as feed or labor, as well as a set of genetic traits that increase production independent of the variable inputs. Assuming that competitive producers will pay the marginal value product for all inputs, the market value for each bull is determined by the sum of the value of each of its genetic traits to the producer. Given a set of bull prices and the characteristics of each bull, the genetic values of each trait are determined using simple econometric models.

In contrast to the beef and pork industries, there is no comparably liquid market for dairy herd sires. Producers typically buy frozen genetic material from artificial insemination (AI) units in the form of a vial or straw. Schroeder et al (1992) use a hedonic pricing model to estimate the marginal values of several purebred dairy bull traits. Published bull proofs are used to explain the price for a dose of a bull's semen in the U.S. Their approach forms the basis for the hedonic pricing model used in the current study, which extends the hedonic pricing analysis to Alberta dairy sires.

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**A Hedonic Pricing Model for Evaluating Genetic Merit of Dairy Bulls**

A hedonic pricing model may be expressed mathematically with the price of a bull's semen being defined as the sum of the values for each of the genetic characteristics. Cows are bred in the expectation that their offspring will produce for several years and that the offspring will, in turn, transmit their genetic traits to future generations. Thus, breeding decisions are made with a goal of maximizing not just the current flow of profits from the cow, but the present value of the dairy herd as a whole. The marginal value of a genetic improvement can be expressed as the increment to the maximum present value of the farm from increasing the herd's milk productivity, milk composition, and/or longevity. An expression for the maximum present value of the farm may be defined as follows, where the producer is assumed to solve an investment problem with an infinite time horizon:[3]

$$V(p,w,R,z,t) = \max_{x} \int_{0}^{\infty} e^{-rt} \left[ pf(z,t) - wx(t) - Rz(t) \right] dt \tag{6}$$

$$s.t. \quad \dot{z}(t) = g(x(t))$$

Here, the decision variable is x, defined as the addition to the quality of the herd's genetic stock through artificial insemination services. The index of genetic "quality" for the herd is z, where the rate of change in z() is a function of x. Component corrected milk production per year for the herd is represented by f() and is a function of z and a time index, t. As well, p is the component corrected milk price, w is the price of breeding services, R is the "rental price" of cattle[4] of a genetic level indexed by z, and r is the annual interest rate.

The use of dynamic programming to solve the optimization problem expressed by (6)

yields the following Bellman equation:[5]

$$rV(p,w,R,z,t) = \max_{x}[pf(z,t) - wx(t) - Rz(t) + V_z g(x(t)) + V_t] \tag{7}$$

Equation (7) may be totally differentiated with respect to the genetic quality index (z) to yield an expression for the marginal current value of genetic improvement:

$$rV_z = pf_z - R + (V_{zz} g(x(t)) + V_{tz}) \tag{8}$$

The rate of change for the dynamic shadow value of the genetic index may be determined by totally differentiating $V_z$ with respect to time:

$$\frac{dV_z}{dt} = \dot{V}_z = V_{zz}\dot{z} + V_{zt} \tag{9}$$

Equation (9) describes the marginal value of an increase in the genetic merit of the dairy herd. Equations (8) and (9) may be combined (using the relationship between $\dot{z}$ and x) to provide an expression for $V_z$; that is, the marginal present value of investing in genetic improvement. This is provided by the following relationship:

$$V_z = \frac{pf_z - R + \dot{V}_z}{r} \tag{10}$$

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Equation (10) suggests that the marginal present value of investing in genetic improvement is equal to the discounted value of an annual stream of benefits from higher current milk production less the opportunity cost of resources used to improve the genetic makeup of the herd plus the value of improving the genetic value of all future generations. This present value, in equilibrium, is the market price that farmers are willing to pay for an increase in the genetic quality of their herd.

The index of overall genetic quality, z, is constructed from the performance of cows sired by several different bulls. Each of these bulls has a unique vector of genetic characteristics defined by the N-vector, c. Therefore, the value of each trait is given by its marginal impact on the price associated with the z index. Assuming that the z index is constructed in such a way that it is homogeneous of degree one in the characteristics, Euler's theorem suggests that the price paid for a given index level (i.e., a given level of z) may be written in terms of the marginal values of the component characteristics:

$$P_z = \frac{1}{r} \sum_i^N (p f_z z_{c_i} + \dot{V}_z z_{c_i}) \tag{11}$$

where $P_z$ is the price (i.e., value) of a given level of genetic quality z, $z_{c_i}$ is the marginal impact of the $i^{th}$ characteristic on the level of z, and all other variables are defined as before.

In this way $P_z$ measures not only the "lifetime" value of breeding an improved cow as the LPI claims to do, but also measures the value of a breeding program over the investment horizon of the farmer. As this investment horizon extends beyond the lifetime of one cow, the hedonic approach is constructed from a more plausible assumption concerning the motivation underlying producers' breeding decisions. This specification (11) provides the basis for the empirical model

that is estimated in this study.

**Empirical Hedonic Pricing Model**

*Data*

The data used to estimate the implicit proof characteristic prices represent a cross sectional sample of 692 purebred Holstein bulls. The source of this information is the July, 1994 volume of the *Who's Who* sire guide. Obtained from Western Breeders' Service, the *Who's Who* records provide detailed data for the proofs of all listed bulls. Available production proof data consist of milk, fat, and protein BCA deviations for each bull, as well as fat and protein percentage predicted deviations. The proofs for milk, final class, and milking speed are all measured by the deviation from breed average and use a "rolling base" for comparison. Protein or fat deviation is the contribution that a chosen sire would be expected to make in increasing an offspring's production for the particular component above that of her cohort, expressed in terms of a percentage deviation from herd average.

Unfortunately, "repeatability" measures for production and type proofs are not included in these data. However, daughter and herd numbers provide acceptable proxies for measuring the reliability of the proof. Herd and daughter numbers differ slightly depending upon whether the type or production proof values are used, and numbers for type proofs are used in this study. Type proofs consist of all major and minor traits. For those traits that include both a numerical and qualitative description, only the numerical value is included in the statistical model.

Semen price data are obtained from SEMEX Canada, the cooperative marketing organization consisting of all major Canadian artificial insemination firms. SEMEX reports prices

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in terms of dollars per straw.  These prices are for export purposes and do not necessarily

represent Canadian domestic prices.  However, only one instance of a difference between the two

lists was found; specifically, the export price was $5 more than the domestic price.  In this case,

the domestic price is used.

Hedonic pricing models generally require price data obtained from competitive bidding in

an open market framework.  In Canada, semen prices are set by individual AI units in order to

allocate their supplies among producers.  However, some AI units are producer-owned

cooperatives.  These cooperatives operate on a not-for-profit basis, so that the price they charge

should be the minimum price possible (i.e., the competitive price).  This "competitive yardstick"

effect refers to the ability  of cooperatives to discipline rival investor oriented firms from charging

more than the minimum cost price.  As a result, semen prices should behave as if they are

determined through a purely competitive bidding process.

*Empirical Model Specification*

Most hedonic price model applications do not specify an a priori functional form for the

price index.  In the current study, however, the model is restricted to the general class of

homogeneous functions.  Whether or not the particular function chosen is homogeneous of degree

one is tested as part of the estimation procedure.  Initially, the semen price index is specified as a

double-log, or Cobb-Douglas, function of the proof characteristics:

$$\ln P_s = \alpha_o + \sum_{i=1}^{N} \beta_i \ln(C_i) + u \tag{12}$$

where $P_s$ is the observed price of a bull's semen, $C_i$ is the value of  the $i^{th}$ characteristic, and u is a

random error term, herein assumed to be log-normally distributed.

Two potential sources of statistical bias exist if the basic model described above is used to

estimate the implicit value of characteristics.  First, if a bull cannot command at least a price of $5

in the market, it is not included on the SEMEX "active list".  As a result, no price is recorded for

80.5 percent of the bulls in the sample.  In other words, the sample of observed prices is said to be

censored at $5, so the expected value of the error term will be positive.  Walburger and Foster

(1994) confront a similar problem in that their boar characteristic observations include several

boars that do not receive a minimum $300 bid and are, therefore, not sold.  Their solution for this

problem is to estimate unbiased marginal characteristic values using a Tobit approach.  A Tobit

model is also adopted in this study.

In the Tobit model, the dependent variable is observed as either positive or zero, with a

large cluster of observations at zero.  In this case, $P^*$ is the price that is expected in the log-linear

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function (12).  The observed price will equal this expected price only if the expected price is

greater than the censoring, or limit, value of $5.  Below this value, the observed price will be zero.

Equation (13) describes this logic, using the notation developed above:

$$\ln P_s = \begin{pmatrix} \alpha_o + \sum_{i=1}^{N} \beta_i \ln(C_i) + u & P_s^* \geq 5 \\ \\ 0 & P_s^* < 5 \end{pmatrix} \tag{13}$$

A maximum likelihood procedure is used to estimate the parameters of this Tobit model.

Because of the censored sample, the log likelihood function (LLF) must be broken into

components describing the positive observations and the limit observations, as follows:

$$LLF(P_i, C_i, \beta, \sigma) = \sum_{i}^{N} (1 - Z_i) \log F\left( \frac{K_i - \alpha_o - \sum_j \beta_j C_{kj}}{\sigma} \right)$$
$$- Z_i\left( \frac{1}{2} \log(2\pi\sigma^2) \right) - Z_i \frac{1}{2\sigma^2} \sum_{i}^{N} \left( \frac{P_{si} - \alpha_o - \sum_j \beta_j C_{ij}}{\sigma} \right)^2 \tag{14}$$

where $K_i$ is the censoring point, $F_i$ is the cumulative normal distribution function, $Z_i = 1$ if $P_s^* < 5$,

and is zero otherwise, and all other parameters are defined as in (12).

A second potential source of bias arises from the fact that SEMEX officials feel that the

supply of a bull's semen is often considered to be a factor in determining its price.  The usual

assumption in hedonic models is that the supply of the commodity is fixed for the time period

under consideration so that the price of each characteristic is entirely determined by its demand.

Rosen (1974) develops a general framework within which the marginal value of a commodity is

determined both by the supply and demand of each characteristic. Bowman and Ethridge (1992) incorporate this notion in their study by specifying a structural model of cotton characteristics wherein the price-dependent hedonic price equations are estimated simultaneously with a series of quantity-dependent characteristic supply equations.

For the purposes of the semen pricing problem, the supply of each characteristic cannot be exactly determined, as SEMEX does not record inventories of semen on hand at the unit level. Instead, an alternative method is used to account for possible supply pressures. SEMEX officials are able to make a qualitative assessment as to whether or not the supply of a given bull represents a constraint that is likely to affect the price charged for the semen. Based on this information, a dummy variable is constructed that is equal to one when supply may be a limiting factor, and zero when it is not. However, this dummy variable cannot be assumed to be exogenous. Besides the isolated cases of premature death of the bull, the decision to collect and market semen is made simultaneous to the pricing decision. Again, if this "self selection" behavior is not accounted for in the empirical model, the estimated parameters will be biased.

Several methods exist to correct for the endogeneity of a dummy variable. This study uses the two-stage estimation method of Heckman (1979). In the first stage, a bull's proof is used to establish a latent or unobserved variable measuring the potential for supply to influence the price. For example, if a bull's proof is very strong, the demand for its services is likely to be high. If semen for this bull is in relatively short supply, then the tendency for supply to be a factor in determining the market price is expected to be significant. If this unobserved value is greater than a threshold level determined by the marketer, then the dummy variable will take on a value of one. Otherwise, the dummy variable will be equal to zero. This is illustrated as follows:

$$S = \begin{bmatrix} 1 & if \ \ S^* = \sum_m \gamma_m C_{im} \geq L \\ 0 & if \ \ S^* = \sum_m \gamma_m C_{im} < L \end{bmatrix} \tag{15}$$

where $S^*$ is the estimated unobserved value defined above, and L is the threshold value.

In this first stage, a probit model is used to estimate the marginal contribution made by each proof element, in addition to the LPI value for each bull, to the probability that the supply of a bull may be a limiting factor. The fitted probabilities from the probit model are then used in the second stage hedonic pricing model as instruments for the unobserved supply factors. In terms of the Tobit log likelihood function (LLF), the fitted probabilities are included as right hand side variables in the pricing equation:

$$LLF(P_i, C_i, \beta, \sigma) = \sum_i^N (1 - Z_i) \log F\left( \frac{K_i - \alpha_o - \delta_o \hat{S}_i - \sum_j \beta_j C_{kj}}{\sigma} \right) \\ - Z_i \left( \frac{1}{2} \log(2\pi\sigma^2) \right) \\ - Z_i \frac{1}{2\sigma^2} \sum_i^N \left( \frac{P_{si} - \alpha_o - \delta_o \hat{S}_i - \sum_j \beta_j C_{ij}}{\sigma} \right)^2 \tag{16}$$

Consistent estimates of the hedonic model are obtained by maximizing (16) with respect to each of the parameters. The resulting parameter estimates are corrected for both the censored sample and the endogeneity of the supply dummy variable.

Estimates of the optimal parameter vector are obtained by maximizing the log likelihood function (16) with the non-linear solver in SHAZAM (White et al 1990). Starting values for each parameter are supplied by a preliminary OLS regression. The first stage probit estimates are

established using the probit procedure within SHAZAM.  Several alternative specifications are estimated for this model in order to determine the set of variables which best explain AI units' semen allocation behavior.

In the second stage of the analysis, the Tobit procedure within SHAZAM is used to estimate the parameters for the hedonic pricing model.  The results of the first stage are incorporated through the inclusion of the fitted supply constraint probability values.  Alternative variables are considered for the repeatability proxies, the fat and protein content variables, and several closely related type variables.  One problem common to all of the models is the presence of multicollinearity between many of the type variables and final class.  The final variable set is selected on the basis of not only goodness of fit, but also the consistency of coefficient estimates with their a priori expected signs (i.e., positive or negative).

Finally, a Tobit model is estimated with only the LPI as an explanatory variable for the price of semen.  The LPI is converted to a logged value (i.e., ln(LPI)) in order to allow a direct comparison between the models.  If the fit with this model proves better than the fit with the hedonic price specification, then the LPI can be concluded to be a superior measure of genetic merit, and vice versa.  The basis for the comparison between the two models is the correlation between the observed semen price vector and the predicted semen price; that is, the measure of the predictive ability for each model.

**Results and Discussion of the Semen Pricing Problem**

*Estimation Results*

Results from the first stage probit model are presented in Table 1.  The estimated coefficients reported in Table 1 can be used to determine the marginal contribution made by each variable to the probability that semen supply may be a limiting factor.  Conceptually, the supply decision should include the complete information set of the semen marketer, including all proof elements and the LPI.  Although many of the proof traits are found to be insignificant in this initial analysis, they remain in the final model based upon a priori expectations of their relevance to the semen buying decision.  For example, the "feet and legs" variable does not appear as a significant independent influence on the perceived marketability of a bull when 'final class' is already included, but a reputation for transmitting poor legs can shorten a bull's active career.  Thus, it remains as an explanatory variable in the probit and Tobit analyses.

The $\gamma_m$ parameter estimates in Table 1 do not directly indicate the marginal increase in the probability of supply influencing the price due to a one-unit change in the given characteristic, but depend upon the initial values of all other explanatory variables.  If P is the probability, then the marginal impact of the $m^{th}$ characteristic ($C_m$) on P is shown by:

$$\frac{\partial P}{\partial C_m} = f(\delta_o + \sum_m \gamma_m C_m)\gamma_m \qquad \textbf{(17)}$$

where f is the normal probability density function.

**Table 1:    First Stage Probit Model Results**

| Variable[a] | Coefficient | T-Ratio |
|---|---|---|
| CONSTANT | -6.672 | -5.739 |
| MILK | 0.526 | 2.384 |
| FAT | 4.158 | 1.207 |
| PROTEIN | 19.808 | 1.995 |
| FINAL CLASS | 0.071 | 0.396 |
| CAPACITY | 0.058 | 0.622 |
| FEET AND LEGS | 0.145 | 2.35 |
| MAMMARY SYSTEM | 0.28 | 1.68 |
| DAUGHTERS | -0.0002 | -0.041 |
| LPI | -0.005 | -1.705 |
| Log Likelihood | -21.824 | |
| Cragg-Uhler $R^2$ | 0.622 | |

[a]    Most of the variables included in this analysis represent various components of the bull proofs.  For example, MILK refers to milk production, FINAL CLASS refers to the BCA score for final class assigned to the bull, etc.  DAUGHTERS refers to the number of daughters for each bull, and is used as a proxy for repeatability.  LPI refers to the Lifetime Profit Index for each bull.

Table 2 presents the second stage results from the Tobit model.  These are the parameter estimates for the hedonic pricing model.  As both the price and the explanatory variables are in logs, the coefficients may be interpreted as elasticities.  For example, the coefficient for the milk proof variable is 0.707, which implies that a 10 percent change in the milk proof will cause the expected price of semen to rise by 7 percent.  If a bull currently has a milk proof of +10 and its semen sells for $20/straw, then another bull that is similar in all other respects, with a milk proof

**Table 2:** **Tobit Model Estimates - Marginal Characteristic Values**

| Variable[a] | Coefficient | T-Ratio |
|---|:---:|:---:|
| CONSTANT | -19.519 | -5.148 |
| MILK | 0.707 | 4.289 |
| FAT | 7.719 | 4.458 |
| PROTEIN | 6.986 | 2.033 |
| FINAL CLASS | 0.418 | 2.072 |
| CAPACITY | 0.138 | 1.592 |
| FEET AND LEGS | -0.122 | -1.725 |
| MAMMARY SYSTEM | -0.188 | -1.147 |
| DAUGHTERS | 0.14 | 2.834 |
| PROBABILITY | 0.221 | 6.278 |
| r | 0.72 | |
| σ | 1.983 | |

[a]   Most of the variables included in this analysis represent various components of the bull proofs.  For example, MILK refers to milk production, FINAL CLASS refers to the BCA score for final class assigned to the bull, etc.  DAUGHTERS refers to the number of daughters for each bull, and is used as a proxy for repeatability.  PROBABILITY is the variable used as a proxy for the effect of supply on the price of semen (i.e., the probability of being in short supply).

of +11 should be expected to have a semen price of $21.40.   Similar interpretations may be made

for the other coefficient estimates.

As discussed above, the negative coefficients for feet and legs and mammary system

should be interpreted carefully.  Because "final class" is an all-encompassing measure of type, it is

influenced by the quality of an animal's feet and legs and mammary system.  Therefore, the

marginal effect of a plus deviation bull for the more detailed class categories (e.g., feet and legs) is

small when final class is included as an explanatory variable. One possible interpretation for these negative coefficients would be to suggest that feet and legs and mammary system are over-represented in the marginal value of the final class characteristic.[6]

The effect of supply on the price of semen is measured by the coefficient for the PROBABILITY variable in Table 2. If the probability of being in short supply increases by 10 percent, the price of semen would be expected to rise by 2.2 percent. If an AI unit decides to take a previously active bull out of service, for example, this probability could conceivably rise from 0 percent to 100 percent. The price of semen would then be expected to rise by 22 percent, on average. Future research in this area, however, would benefit from more complete data on the supply of each characteristic. Perhaps an index of the aggregate stock of each characteristic could be constructed to measure the marginal effect of each bull on this supply.

Despite the negative coefficients for the two type traits, each of the estimated coefficients is within tolerable limits of what is expected, so there do not appear to be any missing variables exerting undo bias on these results. Further reductions in the potential bias due to omitted variables are achieved only at the cost of increasing the collinearity between the explanatory variables.

Table 3 presents the results obtained from applying the Tobit model to a double-log pricing equation with only the LPI as an explanatory variable. As suggested by the coefficients in Table 3, the LPI represents a highly significant explanatory variable for the semen price. However, the explanatory ability of the LPI index is inferior to the hedonic pricing model. This conclusion is based upon a comparison of the correlation between the observed semen prices and those predicted by the model. A correlation coefficient of 0.56 is achieved with the LPI model,

**Table 3:     Tobit Model Results - Lifetime Profit Index as the Explanatory Variable**

| Variable | Coefficient | T-Ratio |
|---|---|---|
| Constant | -19.947 | -11.534 |
| Lifetime Profit Index | 2.864 | 11.334 |
| r | 0.56 | |
| σ | 23.132 | |

 whereas the fitted hedonic pricing model yields a correlation of 0.72.  The superiority of the

hedonic price model over the LPI is supported by comparing the values of the likelihood function

between the two models.  While the hedonic price model produces a log-likelihood function value

of -384.549, the maximum value using the LPI variable is -711.922.

*Implications and Extensions*

These results suggest that the hedonic pricing model provides a better explanation of

semen price than does the LPI.  The hedonic model may be a superior sire selection tool in several

other respects as well.  Rational decision makers will utilize an information source only up to that

point where the marginal benefit of additional information equals the marginal cost of obtaining

that information.  The low cost and simplicity of the hedonic pricing method means that bull

rankings may be updated more frequently than with the LPI.  In this respect, the LPI seems to be

a "black box" for most potential users.  Its construction, output, and interpretation are somewhat

of a mystery, so it may be less likely to be trusted as a source of information.  Furthermore, the

hedonic pricing model is derived from semen prices that are determined by market-sensitive AI

units reacting to buying pressures from profit-maximizing farmers.  Rather than being told what the value of a given genetic trait should be, the model measures what the value of that trait actually is to all members of the trade.

In determining the value of a bull's genetic contribution to the herd, the hedonic pricing model suggests that farmers buy semen as if they regard only a few components of the proof breakdown as critically important.  The most important considerations are the ones included in the final version of the hedonic pricing model (i.e., Table 2).  These include  milk volume, protein content, fat content, general conformation, some measure of body capacity, the "popularity" of the bull, and the probability that the bull's semen may be in short supply.  These results suggest that producers regard the number of daughters sired by a bull as a good indicator of the reliability of the proof.  In doing so, farmers appear to allow popularity to stand as an indicator of the intangible aspects of a bull's genetic value.

One of the advantages that has been attributed to the LPI is its role as a measure of the lifetime contribution of the offspring for a given sire.  In the context of the LPI, lifetime simply means that the index is constructed by assuming five lactations of production, the profits from which are discounted into present terms.  Longevity considerations in the hedonic pricing model are more consistent with economic theory, as producers choose between bulls at least partly on the basis of expected lifetimes for their daughters.  In particular, a bull that has a reputation of siring long-lived daughters, or that has a package of type traits suggesting problems with feet and legs or the mammary system are not likely to arise, will sell for more than one noted for siring "one lactation wonders".  Implicitly, farmers realize that a sire with a favorable type proof may sire daughters that produce slightly less milk, but will be consistent producers in the herd over a

longer lifetime.  In this way, the hedonic pricing model implicitly embodies the multi-period consequences of any breeding decision.

Similarly, the hedonic price implicitly measures producers' tendency to be risk averse.  A young sire will sell for less due to the uncertainty over the longevity of his daughters.  Risk aversion at least partly explains the significance of the DAUGHTERS variable (i.e., number of daughters) in the Tobit model results.

This method is not restricted to estimating the values of only quantifiable traits; that is, traits that are assigned numerical proofs.  Qualitative traits may be included, and would act to "shift" the whole function up or down.  For instance, suppose that the value of semen for a red factor bull is to be examined using this type of model.  Since there is no numerical value for "red", treating it in a similar manner as other traits is impossible.  However, an equation similar to the one provided earlier for the Tobit analysis could be estimated that includes a characteristic indicator variable for the red factor.  This variable would take on the value of 0 when the bull is black and 1 when it is red.  This results in an equation being estimated for all bulls, but with a premium or a discount incorporated for the red factor.  Other trait values could also be determined in this way (e.g., an eastern bull versus a western bull, Holstein versus Ayrshire).

The hedonic method discussed and used in this study can, in itself, constitute a powerful marketing tool in determining the price for bulls that have just received their first proof or are just coming on to the system.  However, this method also has a further value to the industry as a whole in helping to design a new method of ranking bulls according to their relative genetic value.  Instead of creating a 'synthetic' value for bulls based upon farm financial records as with the LPI, the price index estimated for each bull using this method constitutes a direct estimate of how each

trait should be reflected in terms of increased profit for the dairy farmer. If the price is set according to the estimates from this model, the price itself indicates the total value to the producer of buying that dose of semen. If the price does not reflect this, then producers are not making the most profit from buying and using semen in their herds. Therefore, it is a simple matter to create an index from the hedonic price estimates as the price itself already is the best index that could possibly be used!

This hedonic pricing model has uses beyond those as a marketing tool for AI units, or as a selection tool for producers. This model may also be used as an indirect test of the effect of policy on genetic progress in the dairy industry. Conversations with industry members regarding the trends in selection between production and type by Canadian dairy breeders suggest that breeders are now selecting bulls more for production than type, as compared to a decade ago. At that time, the GATT had not ruled against Canadian import quotas on yogurt and other dairy products, and Article 16, Section 11 of the GATT was inviolable. The future of supply management, and the virtual guaranteed return on investment in dairy, was assured. With the threat of having to deal with competition in dairy products from the U.S., breeders in Canada have begun to emphasize productivity gains over aesthetics.

The hedonic pricing model may be used to test this hypothesis directly. Using identical methodology, an equation may be estimated for the year 1993 and another for 1983 to yield two different sets of trait valuations. These valuations may be compared using formal statistical tests to show whether the relative valuation of type traits versus production traits has changed over the ten year period. In fact, if the data are available, an equation may be estimated for each year. Comparing the trends in trait valuation over time would be a very valuable exercise in predicting

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the future needs of producers. From the perspective of the AI unit, these predictions could be used in selecting prospective mates for future bulls. Rather than using intuition, the market could help to guide mating decisions.

**Conclusions**

In conclusion, a hedonic pricing model represents a simple, powerful method of determining the value of the contribution for each component of a bull's genetic proof to the overall price of semen. Decomposing semen prices in this way is shown to provide a better indicator of the actual value of genetic traits to the producer when compared to the LPI index. Rather than creating a synthetic profitability ranking of bulls, the hedonic pricing model ranking is directly correlated with the implicit expected increment to farm profit. As it also implicitly includes considerations of the "lifetime" contribution of the offspring of a sire, the hedonic pricing model achieves all of the goals of the LPI, but at a substantially lower cost and in a far more understandable way.

As an alternative to the LPI, the hedonic pricing model could prove to be a valuable tool for both AI units' marketing managers and dairy breeders alike. AI units can use the model to forecast a possible market price for semen from a young sire exhibiting a given set of proof characteristics. Breeders will be able to obtain a true index of the likely contribution to the profit of their herd made by any combination of proof characteristics using a simple, low-cost, easy to understand calculation.

Additional applications of the hedonic pricing model include the ability to test for changes in breeders selection criteria over time. For example, if producers in Alberta expect multiple

component pricing for milk to be instituted in the near future, this should be reflected in a higher implicit value for the protein proof of a given sire. The changes in these valuations can be linked to expected changes in policy and the expected environment within which producers must manage their farms.

## NOTES

1.     Type is important because it is used as a proxy for longevity; that is, the ability of a bull to sire daughters that will have a long useful life in the herd.

2.     Besides the LPI and the econometric hedonic pricing technique used in this study, linear programming has also been used to value genetic traits in livestock. Ladd and Gibson (1978) and Melton et al (1994) use parametric linear programming to measure the incremental change in optimal farm profit of improvements in genetic traits in swine and beef, respectively.

3.     This investment problem is defined using continuous time concepts. An equivalent expression could be defined in terms of discrete time intervals. This investment problem is consistent with the original assumption of profit maximization, as defined in (3), that is used to develop the basic hedonic pricing model. The difference in this expression (6) is that the optimization is dynamic (i.e., over multiple time periods). Additionally, there are only two inputs; the change in genetic stock achieved through artificial insemination services, and the dairy cattle.

4.     Dairy cattle are not actually rented by the producer. The parameter R represents the opportunity costs associated with having cattle of a certain genetic level (z).

5.     Subscripts in the following set of equations (i.e., 7, 8, 9 and 10) refer to first and/or second derivatives with respect to various arguments. For example, $f_z = \dfrac{\partial f}{\partial z}$, while $V_z = \dfrac{\partial V}{\partial z}$ and $V_{tz} = \dfrac{\partial^2 V}{\partial t \partial z}$. Similar interpretations may be made for $V_{zz}$ and $\dot{V}_z$.

6.     A similar effect is noted in preliminary model estimates where size and stature are included with the capacity variable as explanatory variables. All appear to be measures that are highly correlated with one another in measuring the expected productivity of the cow.

## REFERENCES

Becker, G. 1965. "A Theory of the Allocation of Time." *Economic Journal* 75:493-517.

Bowman, K.R. and D.E. Ethridge. 1992. "Characteristic Supplies and Demands in a Hedonic Framework: U.S. Market for Cotton Fiber Attributes." *American Journal of Agricultural Economics* 74:991-1002.

Brorsen, B.W., W.R. Grant and N.E. Rister. 1984. "A Hedonic Price Model for Rough Rice Bid/Acceptance Markets." *American Journal of Agricultural Economics* 66:164-69.

Espinosa, J. and B. Goodwin. 1991. "Hedonic Price Estimation for Kansas Wheat Characteristics." *Western Journal of Agricultural Economics* 16:72-86.

Ethridge, D.E. and B. Davis. 1982. "Hedonic Price Estimation for Commodities: An Application to Cotton." *Western Journal of Agricultural Economics* 7:293-300.

Ethridge, D.E. and J.T. Neeper. 1987. "Producer Returns from Cotton Strength and Uniformity: An Hedonic Approach." *Southern Journal of Agricultural Economics* 19:91-97.

Gibson, J.P., N. Graham and E.B. Burnside. 1992. "Selection Indexes for Production Traits of Canadian Dairy Sires." *Canadian Journal of Animal Science* 72:477-91.

Hazel, L.N. 1943. "The Genetic Basis for Construction of Selection Indexes." *Genetics* 28:476.

Heckman, J.J. 1979. "Sample Selection Bias as a Specification Error." *Econometrica* 47:153-61.

Jordan, J.L., R.L. Shewfelt, S.E. Prussia and W.C. Hurst. 1985. "Estimating Implicit Marginal Prices of Quality Characteristics of Tomatoes." *Southern Journal of Agricultural Economics* 17:139-46.

Kerr, W.A. 1984. "Selective Breeding, Heritable Characteristics and Genetic-Based Technological Change in the Canadian Beef Cattle Industry." *Western Journal of Agricultural Economics* 9:14-28.

Ladd, G.W. and C. Gibson. 1978. "Microeconomics of Technical Change: What's a Better Animal Worth?" *American Journal of Agricultural Economics* 60:236-40.

Ladd, G.W. and M.B. Martin. 1976. "Prices and Demands for Input Characteristics." *American Journal of Agricultural Economics* 58:21-30.

Lancaster, K.J. 1966. "A New Approach to Consumer Theory." *Journal of Political Economy*

74:132-56.

Lenz, J.E., R.C. Mittelhammer and H. Shi.  1994. "Retail Level Hedonics and the Valuation of Milk Components." *American Journal of Agricultural Economics* 76:492-503.

Melton, B.E., W.A. Colette and R.L. Willham.  1994.  "Imputing Input Characteristic Values From Optimal Commercial Breed or Variety Choice Decisions." *American Journal of Agricultural Economics* 76:478-91.

Perrin, R.K.  1980.  "The Impact of Component Pricing of Soybeans and Milk." *American Journal of Agricultural Economics* 62:445-55.

Rosen, S.  1974.  "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition." *Journal of Political Economy* 82:34-55.

Schroeder, T.C., J.A. Espinosa and B.K. Goodwin.  1992.  "The Value of Genetic Traits in Purebred Dairy Bull Services." *Review of Agricultural Economics* 14:215-26.

Tronstad, R., L.S. Huthoefer and E. Monke.  1992.  "Market Windows and Hedonic Price Analyses: An Application to the Apple Industry." *Journal of Agricultural and Resource Economics* 17:314-22.

Veeman, M.  1987.  "Hedonic Price Functions for Wheat in the World Market: Implications for Canadian Wheat Export Strategy." *Canadian Journal of Agricultural Economics* 35:535-52.

Walburger, A. and K. Foster.  1994.  "Using Censored Data to Estimate Implicit Values of Swine Breeding Stock Attributes." *Review of Agricultural Economics* 16:259-68.

White, K.J., S.D. Wong, D. Whistler and S.A. Haun.  1990.  *SHAZAM User's Reference Manual Version 6.2.*  New York:McGraw-Hill.