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Hedonic Price Analysis of Thoroughbred Broodmares in Foal

Leigh J. Maynard and Kelly M. Stoeppel

Thoroughbred broodmares are the foundation of a successful racing operation. This study estimated the impact of breeding, racing, and market characteristics on broodmare auction prices. Data represent 604 in-foal broodmares sold in Keeneland's 2005 sale. Prices were highly responsive to the sire's stud fee, the broodmare's age, and progeny performance in graded stakes races, with pronounced day-of-sale effects. The stud fee marginal value was substantially lower than one break-even estimate, suggesting possible disincentives for investment in stallion services. Out-of-sample forecasts were far superior to naïve forecasts but were not accurate enough to use in isolation from other decision aids.

Key Words: broodmare, forecasting, hedonic price analysis, Thoroughbred

In 2005, over 7,800 Thoroughbred horses were sold for over $744 million through Keeneland auctions alone (Keeneland Association, Inc., 2006a), and dozens of additional Thoroughbred auctions occur annually throughout the U.S. The buying and selling of Thoroughbreds can have a substantial impact on some local economies, especially in Kentucky, where the majority of Thoroughbred horses are owned. With so much money riding on Thoroughbreds, quantitative evidence about their price determinants may be directly useful to industry participants and indirectly helpful for economic development in some locales.

Broodmares are the foundation of a racehorse breeding program, and they represent a substantial capital investment. To date, the only econometric analysis of broodmare price determinants appears to be Neibergs (2001), who performed a hedonic price analysis on data from the 1996 Keeneland November broodmare sale. Marginal values and price flexibilities were estimated for breeding, racing, genetic, and market characteristics. Neibergs cautioned that his results were only applicable to 1996, however, because the data were generated early in a period of prolonged price recovery. Broodmare prices are generally much higher now, and one would expect marginal values to follow suit.

The objectives of this study were to update estimates of broodmare attribute marginal values and price flexibilities, to focus on price determinants of broodmares

Leigh J. Maynard and Kelly M. Stoeppel are associate professor and former undergraduate student, respectively, in the Department of Agricultural Economics at the University of Kentucky.

in foal as opposed to barren broodmares, and to test whether a hedonic pricing model forecasts sufficiently well out-of-sample to be a useful tool for broodmare buyers and sellers. The analysis was performed using data from the 2005 Keeneland November breeding stock sale (Keeneland Association, Inc., 2005), the largest broodmare sale in the world.

Background

Thoroughbred broodmares are differentiated products that bring different prices depending upon the perceived value of the broodmare. Lancaster (1966) developed a theoretical model in which consumers, given budget constraints, purchase goods that deliver a utility-maximizing bundle of attributes. Thus, a product-price function exists that contains measurable product attributes as arguments (Rosen, 1974). Ladd and Martin (1976) developed this theme in the context of demand for agricultural inputs, while Ladd and Suvannunt (1976) focused on consumer goods. Both demand-side and supply-side models produce an equation explaining price as a function of quality and quantity of characteristics associated with the product (Schroeder, Espinosa, and Goodwin, 1992).

Many studies have examined agricultural products using hedonic pricing models. Buccola and Iizuka (1997) created a variant of a hedonic pricing model that established values for each of the characteristics of milk and tested whether producers responded to the market value of protein in their management decisions. Kristofersson and Rickertsen (2004) estimated characteristic demand for quality in Icelandic fishing auctions by using a random coefficient model. Schroeder, Espinosa, and Goodwin (1992) explained price variation in purebred dairy bulls by examining the heritable production and offspring physical traits that affect the price of bull semen. Schroeder, Jones, and Nicholas (1989) studied the price of feeder pigs and the various characteristics that discounted the price over time.

Hedonic pricing models have also been applied to equine industries, primarily Thoroughbred yearlings. Chezum and Wimmer (1997) tested whether there is adverse selection in Thoroughbred yearling auctions when some sellers have both bred and raced Thoroughbreds. A hedonic pricing model was used to price each significant characteristic exhibited by the yearling, and the expected value of the yearling was compared to the actual price. Vickner and Koch (2001) evaluated yearling characteristics and established marginal values of each explanatory variable in their model. Neibergs and Thalheimer (1997) created a hedonic pricing model that incorporated both price expectations and market restraints to estimate supply and demand in the Thoroughbred yearling market. Purse winnings were found to be the most significant variable impacting price.

Commer's (2000) informal study of factors affecting Thoroughbred yearling sale prices suggested that the most salient factors were the quality of the sire, the quality of the dam, foaling date, whether the foal was nominated for the Breeders Cup, where the foal was born, and where the yearling was sold. Taylor et al. (2004)

examined the price determinants of show quality Quarter Horses, finding that genetic and physical traits, individual performance, and performance of the offspring all affected the price of the Quarter Horse.

Vercken de Vreuschman (2005) was the only study to include conformation as an explanatory variable in a Thoroughbred yearling hedonic pricing model. Conformation was represented as a dummy variable based on an industry expert's opinion about the suitability of each horse's physical structure for racing. Despite the subjective nature of judging conformation, the variable was statistically and economically significant in the model, suggesting that informed visual inspection may be necessary for complete model specification.

Buzby and Jessup (1994) identified the effects of macroeconomic variables on Thoroughbred yearling price and found that yearling-specific variables were the most significant but that other variables such as tax and interest rates were price determinants as well. Similarly, Karungu, Reed, and Tvedt (1993) found evidence that exchange rates and tax law changes impacted Thoroughbred yearling prices.

The importance of the broodmare in the production of quality racehorses was shown by Laughlin (1934) when he established that the majority of characteristics that make a horse successful on the track are inherited from its parents. Hedonic pricing in regional Thoroughbred markets contributed to the finding that the dam plays a role in the pricing of yearlings (Robbins and Kennedy, 2001). The success of the broodmare's previous progeny was a stronger determinant of price than the performance of the broodmare herself.

Neibergs (2001) is, to our knowledge, the only study to have applied hedonic pricing to Thoroughbred broodmares. He categorized attributes as breeding, racing, genetic, and market factors, used data from the Keeneland broodmare sales, and estimated marginal values and price flexibilities for each of the explanatory variables. The results suggested that the most important factors were the number of races the broodmare had won and the number of races the broodmare's existing foals had won.

Hedonic Pricing Model

The maintained assumption of the following hedonic pricing model is that the price of a broodmare in foal is a function of attributes signaling the future racing performance of her foals. The dependent variable is the price (or a transformation of price) for which the broodmare sold at auction. Independent variables are classified as characteristics of the broodmare, her previous foals, or the sire of the foal she is currently carrying. The set of independent variables also includes dummy variables indicating the day on which the mare was auctioned during the 12-day sale. The specific variables collected for this study are presented in table 1 and are described in order below.

Table 1. Variables, Expected Signs on Parameters, and Descriptive Statistics

Variable	Exp. Sign	Mean	Std. Dev.	Min.	Max.
Dependent Variable					
Price ($)	n/a	137,924.50	290,817.24	1,500.00	3,700,000.00
Mare Characteristics					
Age (years)	−	9.01	3.74	4.00	20.00
# of Foals out of Mare	−	2.72	2.80	0.00	14.00
Expected Mare's Sire Value	+	21.27	118.40	1.00	1,025.91
Mare Graded Stakes	+	0.09	0.29	0.00	1.00
# Races Mare Won	+	2.22	2.90	0.00	22.00
# Races Mare Placed	+	1.79	2.42	0.00	15.00
# Races Mare Showed	+	1.65	2.20	0.00	14.00
Total Mare Earnings ($)	+	77,688.47	132,485.35	0.00	1,150,410.00
Foal Characteristics					
Foal Stakes Winner	+	0.09	0.28	0.00	1.00
Foal Graded Stakes	+	0.06	0.24	0.00	1.00
# of Foal Wins	+	2.28	4.96	0.00	45.00
Total Foal Earnings ($)	+	67,654.89	214,333.14	0.00	3,599,843.00
Avg. Earnings per Foal ($)	+	10,969.42	32,823.09	0.00	389,100.00
Foal's Sire Characteristics					
Stud Fee ($)	+	35,900.26	57,150.57	1,250.00	500,000.00
Number of Foals Sired	+	182.53	251.90	0.00	1,583.00
Expected Foal's Sire Value	+	8.60	42.95	1.00	492.34
Number of observations			604		

Note: Independent variables include day of sale (11 binary variables for Day 2 – Day 12), expected to have negative parameters. The randomly drawn sample is approximately uniformly distributed across days, ranging from 6.5% on Day 2 to 10.4% on Day 1.

The age of the mare in years reflects her potential future earnings from foal production. The younger the mare, the more foals she is capable of producing, suggesting that age negatively influences price. The number of other foals that the broodmare has produced can indicate how easily bred the mare is, but it can also correlate highly with age. Each year, *The Blood-Horse* (2005a) compiles a list of 150 "Leading Broodmare Sires" containing information useful in evaluating the broodmare's sire. Following a similar approach used by Neibergs (2001), an index called "expected mare's sire value" was created for the present study. The formula for the index (*EMSV*) is one plus the number of stakes winners attributable to broodmares sired by the stallion (*SW*), multiplied by an index of earnings by the sire's broodmares' progeny relative to the average of all runners (*AE*), multiplied by an index of earnings by the progeny relative to the average of other stallions' progeny from the same mares (*COMP*), divided by the ranking on the leading broodmare sires list (*R*).

$$(1) \qquad EMSV = 1 + SW \times AE \times COMP \, / \, R.$$

If a stallion did not appear on the leading broodmare sires list, it was assigned a value of one. The construction of the index allows natural logs to be taken, and each component of the index is provided in the Leading Broodmare Sires list.

Mare characteristics also include the mare's own racing performance, which is expected to be partially hereditable. The broodmare's total earnings are one measure of success on the racetrack. Her racing record can be measured with variables for the number of races in which the mare won, placed, and showed. Having won a stakes race is expected to improve a broodmare's value substantially, as is placing in a graded stakes race, the most prestigious of races.

For the broodmares that already have foals of racing age, the performance of these foals is an indicator of the racing success of the mare's future foals. The number of races the broodmare's foals have won and dummy variables for winning a stakes race or placing in a graded stakes race measure racing success. Total foal earnings, converted into U.S. dollars using 2005 average exchange rates, and average earnings per foal are additional guides to expected racing success of future foals.

The quality of the sire bred to the broodmare is expected to be important in determining the price of the broodmare. The sire's stud fee is a measure of the market's valuation of the stallion's genetics. One would expect higher stud fees to be correlated with higher-value foals, thus increasing the value of the broodmare. One might also expect a positive relationship between broodmare price and the number of foals sired by the stallion to which she was bred. Finally, an index analogous to the Expected Mare's Sire Value was created using data in the 2005 "Leading Sires" list (*The Blood-Horse*, 2005b) and is called Expected Foal's Sire Value.

The day on which a broodmare is sold may affect the price of the mare even holding all other attributes constant. Higher quality mares are scheduled to be sold earlier in the sale, but the variables described above should control for many of the attributes that justify price variation. If there are significant day of sale effects, either the other variables do not adequately capture the broodmares' qualities, or the price varies systematically by day regardless of broodmare attributes. Buyer fatigue and the perception that the most valuable horses have already been sold are potential causes of price declines as the sale continues.

The sale catalog indicated whether each horse was pregnant ("in foal") at the time of the 2005 sale. Several of the independent variables discussed above would be zero vectors for barren broodmares (i.e., those that were not pregnant). Thus, it is neither practical nor valid to model the two types of broodmares using the same regression; we focused on broodmares in foal.

The emphasis on mares in foal deserves discussion because it diverges from Neibergs (2001), who assigned stud fee values of zero to barren broodmares, arguing that a zero value reflected the expected value of a nonexistent foal. Neibergs' approach implicitly assumed that the marginal impact of the stud fee (and all other variables) on broodmare price was the same for barren mares and mares in foal. This assumption might not be valid because one would not expect buyers to weigh missing information about a variable as heavily as an observed zero value. As Neibergs himself explained, barren mares are discounted not because their foals inherit inferior characteristics (which would be the case if the sire truly had a zero stud fee), but because of delayed earnings, higher costs, and risk of reproductive difficulty. Thus, we expect the data generating process for a hedonic pricing model of barren mares vs. mares in foal to be different enough that the two types of horses should not be combined in the same dataset.

The Box-Cox transformation was used to select a specific functional form. The dependent variable *Price* was transformed as follows (Box and Cox, 1964):

(2) $$Price^{(\lambda)} = \begin{cases} \dfrac{(Price)^{\lambda} - 1}{\lambda} & \text{when } \lambda \neq 0, \\ \ln(Price) & \text{when } \lambda = 0. \end{cases}$$

The parameter λ was allowed to vary from −2.0 to +2.0 by increments of 0.1, and for each of these values, the transformed dependent variable was regressed on the independent variables. The transformation returning the highest log-likelihood value was λ = 0.0, which corresponds with a dependent variable of ln(*Price*) and a semi-log functional form. Neibergs (2001) also found the semi-log form to be most appropriate. Broodmare prices are positively skewed so that the mean far exceeds the median, but as figure 1 shows, broodmare prices assume a more symmetric distribution when logged.

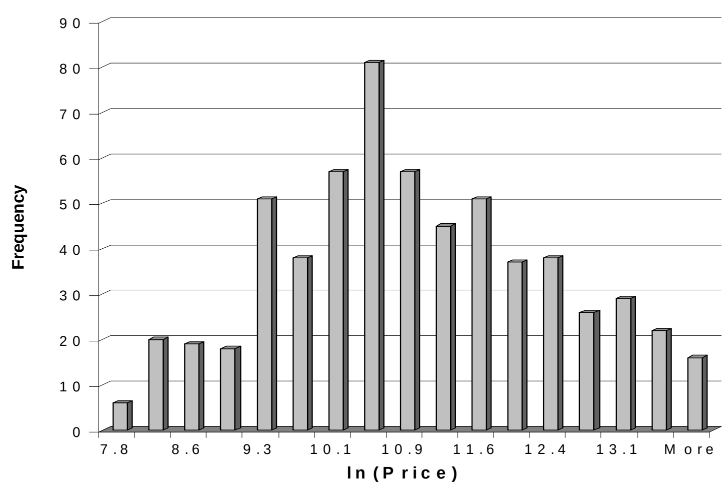

Figure 1. Distribution of the logarithm of 2005 in-foal broodmare prices

Several independent variables were highly correlated, causing severe multicollinearity (as suggested by variance inflation factors exceeding 10) when they were all included in the model. Thus, dropping several variables improved parameter efficiency and the model's parsimony, without reducing explanatory power, as measured by adjusted R^2. Explanatory power was markedly higher when the stud fee and expected mare's sire value were logged. As with most of the remaining variables, total foal earnings were often zero, so this variable could not be logged, but a quadratic term was included to allow a nonlinear relationship with the log of price. Accordingly, the estimated empirical model was as follows:

$$\begin{aligned} \ln(Price) = {} & \beta_0 + \beta_1 Age + \beta_2 TotalFoalEarnings + \beta_3 (TotalFoalEarnings)^2 \\ & + \beta_4 \ln(Expected\ Mare's\ SireValue) + \beta_5 \ln(Stud\ Fee) \\ & + \beta_6\ Number\ of\ Foals\ Sired + \beta_6 Total\ Mare\ Earnings \\ & + \beta_7\ Mare\ Graded\ Stakes + \beta_8\ Progeny\ Graded\ Stakes \\ & + \beta_9 Day2 + ... + \beta_{19} Day12 + \varepsilon. \end{aligned} \tag{3}$$

Marginal values and price flexibility estimates are more meaningful than the parameter estimates alone. The marginal value of a variable is the change in broodmare price given a one-unit increase in the independent variable. In cases where the independent variable was logged, the marginal value represents the impact of an increase in the un-logged level of the variable. Marginal values were calculated at sample means of all the continuous variables and at zero values for all dummy variables except the variable under consideration. Price flexibilities represent the percentage change in broodmare price given a 1% increase in an independent variable and were calculated for each continuous variable at sample means.

Misspecification testing was performed using the joint conditional mean and joint conditional variance tests suggested by McGuirk, Driscoll, and Alwang (1993). Individual tests maintain the possibly unreasonable assumption that all other econometric assumptions are not violated, whereas joint tests limit the number of such assumptions. The joint conditional mean test regresses estimated residuals against all of the independent variables in the original model, plus a time trend (to test parameter stability), squared and cubed fitted values (i.e., a RESET test of functional form), and lagged residuals (to test serial independence). If the regression is jointly statistically significant, the individual test parameters can be examined to identify the likely source of violation.

The joint conditional variance test regresses squared residuals against an intercept, a time trend (to test variance stability), squared fitted values (to test static homoskedasticity), and lagged squared residuals (to test for ARCH errors). The normality of the residuals was tested separately using four common normality tests, two additional heteroskedasticity tests were reported, and multicollinearity was tested using the rule of thumb that variance inflation factors exceeding 10 indicate severe multicollinearity.

Because the purpose of this study was to assist future buyers and sellers of broodmares, it was important for the model to have not only acceptable in-sample explanatory power but also acceptable out-of-sample predictive power. Using numbers randomly generated from a uniform distribution, five subsamples of 40 observations were drawn from the full sample of 604 in-foal broodmares. In each case, the model was re-estimated using only the 564 in-sample observations. The resulting parameter estimates were then used to predict sale prices for the out-of-sample broodmares.

Theil's *U*-statistic was used to evaluate performance for each of the five out-of-sample forecasts. Theil's *U* compares the root mean squared errors of the model forecast to those from a naïve forecast. In this case, the most reasonable naïve forecast appeared to be the mean of the in-sample broodmare prices. A ratio of zero implies a perfect forecast, a ratio of one implies that the model performs no better than the naïve forecast, and a ratio greater than one implies that the model performs worse than the naïve forecast.

Data

The Keeneland November Breeding Stock Sale is the largest sale of Thoroughbred broodmares in the world. To facilitate the sale of the 4,477 broodmares in the 2005 November Breeding Stock Sale, Keeneland produced a sales catalog describing each horse. Data obtained from the sales catalog consist of the mare's age in years, whether the mare was in foal at the time of the sale, the number of foals the mare had previously borne and the foals' total earnings, the number and type of races won by the mare's foals, the number and type of races in which the mare herself won, placed, and showed, the mare's total earnings, and the day (1–12) on which the mare was sold. Each broodmare's sale price was obtained from the Keeneland 2005 November Breeding Stock Sales results (Keeneland Association, Inc., 2006b). Data on 2005 stud fees were obtained from the "Stallion Register" published by *The Blood-Horse* (2006). Data regarding sires were collected from the 2005 "Leading Broodmare Sires" list (*The Blood-Horse*, 2005a) and the 2005 "Leading Sires" list (*The Blood-Horse*, 2005b).

Bidding on many horses registered for the sale did not meet the seller's reserve price, and other horses were pulled from the sale. Of the remaining horses, many were unbred broodmare prospects or stallion prospects. The population of in-foal broodmares sold in the auction was 1,475. Complete data were collected on 604 randomly selected broodmares, about 40% of the population. Random selection was performed by assigning each mare a random draw from a uniform distribution on the unit interval. If the random draw was lower than a pre-selected threshold, then the mare was included in the sample.

Summary statistics are presented in table 1. The average broodmare price was almost \$138,000, with prices ranging from \$1,500 to \$3,700,000. The average stud fee was almost \$36,000 with a range from \$1,250 to \$500,000. The average mare was 9 years old and had produced an average of 2.72 foals that had won an average of 2.28 races and earned over $67,000. The broodmares themselves had won an average of 2.22 races and earned over $77,000. Broodmare earnings ranged from $0 to $1.15 million.

Results

Table 2 shows no evidence of significant econometric violations, with the exception that two of the four residual normality tests were rejected. An *F*-test failed to reject the joint hypothesis of zero values for parameter stability, functional form, and serial dependence parameters in the joint conditional mean test, and none of the individual parameters were significant at the .05 level. Similarly, the joint conditional variance regression was not significant, nor were any of the individual parameters. The null hypothesis of homoskedasticity was not rejected under multiple tests, and the maximum variance inflation factor of 6.94 suggested an absence of severe multicollinearity.

Table 2. Misspecification Test Results

	Test Value	Pr > Critical Value
Joint Conditional Mean Test		
Stability of β	1.66	0.10
Serial dependence	1.71	0.09
Functional Form (RESET2)	−0.13	0.90
Functional Form (RESET3)	0.27	0.79
Joint test	1.55	0.19
Joint Conditional Variance Test		
Stability of σ^2	−0.24	0.81
ARCH errors	0.84	0.40
Heteroskedasticity	0.43	0.67
Joint test	0.54	0.71
Additional Heteroskedasticity Tests		
White	146.70	0.71
Breusch-Pagan	14.65	0.80
Normality of Residuals Tests		
Shapiro-Wilk	1.00	0.18
Kolmogorov-Smirnov	0.03	0.13
Cramer-von Mises	0.16	0.02
Anderson-Darling	0.86	0.03

Multicollinearity: Max. Variance Inflation Factor = 6.94 < 10.

Table 3 presents the parameter estimates, marginal values, and price flexibilities. The adjusted R^2 was 0.82, compared to the 0.74 value found by Neibergs (2001). The difference is likely due in part to our study's tighter focus on broodmares in foal.

Table 3. Parameter Estimates, Marginal Values, and Price Flexibilities

Variable	Parameter Estimate	Marginal Value	Price Flexibility
Intercept	5.90** (0.52)[a]		
Age	−0.13** (0.01)	−11,833.54	−1.14
Total Foal Earnings[b]	1.28** (0.31)	0.12	0.08
Total Foal Earnings squared[b]	−0.30** (0.10)		
ln(Exp. Mare's Sire Value)	0.15** (0.02)	663.90	0.15
ln(Stud Fee)	0.65** (0.04)	1.70	0.65
Number of Foal Sired[b]	−0.04** (0.01)	−35.98	−0.07
Total Mare Earnings[b]	1.74** (0.25)	0.16	0.14
Mare Graded Stakes	0.14 (0.11)	14,255.20	
Progeny Graded Stakes	0.43** (0.14)	50,644.02	
Day 2	0.13 (0.13)	12,527.23	
Day 3	−0.22 (0.13)	−18,605.41	
Day 4	−0.29* (0.13)	−23,319.79	
Day 5	−0.65** (0.13)	−44,786.68	
Day 6	−0.68** (0.14)	−46,500.39	
Day 7	−0.94** (0.15)	−57,225.94	
Day 8	−1.12** (0.15)	−63,122.90	
Day 9	−1.16** (0.15)	−64,376.93	
Day 10	−1.41** (0.16)	−71,041.27	
Day 11	−1.48** (0.17)	−72,427.85	
Day 12	−1.67** (0.17)	−76,160.22	
Adjusted R^2	0.82		

Note: Single and double asterisks (*) denote statistical significance at the .05 and .01 levels, respectively.
[a] Standard errors in parentheses.
[b] For clarity of presentation, parameter estimates reflect rescaling of total foal and total mare earnings variables by 10^{-6}, and number of foals sired by 10^{-2}, but marginal values are not rescaled (e.g., an additional dollar of mare earnings increases sale price $0.16).

All of the parameters except *Day2*, *Day3*, and *Mare Graded Stakes* were statistically significant at the .05 level, and all but *Day2* and *Number of Foals Sired* had the expected sign. Moreover, most of the independent variables appear to be economically significant. Each additional year in a broodmare's age reduced her value by an average of almost $12,000, holding all else constant. At the mean, each additional dollar won by a mare's foals increased the mare's value by 12 cents, on average. Likewise, each additional dollar won by the mare herself increased her value by an average of 16 cents. Having a foal that had placed in a graded stakes race dramatically increased a broodmare's value by over $50,000 on average. Even holding other breeding, racing, and genetic factors constant, the day on which a broodmare was sold strongly affected her sale price. The marginal values of the day of sale parameters generally followed the same increasingly negative pattern observed in Neibergs's results, but the magnitudes were much larger, consistent with substantial inflation in broodmare prices between 1996 and 2005.

Price flexibility estimates were higher in absolute value than those estimated by Neibergs (2001), and the expected reason is that our parameter estimates were not influenced by barren mares with zero values for several variables. Variables that returned higher absolute flexibilities included age (−1.14 vs. −0.86), expected mare's sire value (0.15 vs. 0.05), and total mare earnings (0.14 vs. 0.10). A major difference between our results and those of Neibergs is that our focus on broodmares in foal suggests a much stronger role for the stud fee in broodmare valuation. We found that an additional dollar of stud fee raised the broodmare's value by $1.70 (vs. Neibergs's $0.37), with a price flexibility of 0.65 (vs. Neibergs's 0.21).

After randomly drawing each set of 40 out-of-sample observations, the model was re-estimated using the remaining 564 in-sample observations. This process was repeated five times, and the parameter estimate vectors were generally robust across samples. Out-of-sample price forecasts were generated from the in-sample parameter estimates, and the following Theil's *U*-statistics were calculated for the five out-of-sample data sets: 0.41, 0.43, 0.48, 0.43, and 0.46, with lower values indicating better forecasting performance. All five *U*-statistics were less than one, indicating much better performance than the naïve forecast. Figure 2 provides a visual representation of forecasting performance in the best-performing scenario. Even in this scenario, however, after taking anti-logs of the forecasts, the mean absolute percentage error was 61%, consistent with the magnitude of in-sample errors.

Discussion

Over 80% of variation in broodmare auction prices can be explained by a regression model, at least within the in-foal sample evaluated here. The model was exceptionally well-behaved statistically, and both the signs and the magnitudes of the parameters were consistent with reasonable expectations. As a description of typical broodmare valuation, the model appears quite adequate.

We intended this study to be an updated companion to Neibergs (2001) that buyers and sellers would find useful. Neibergs was concerned that his 1996 results might not

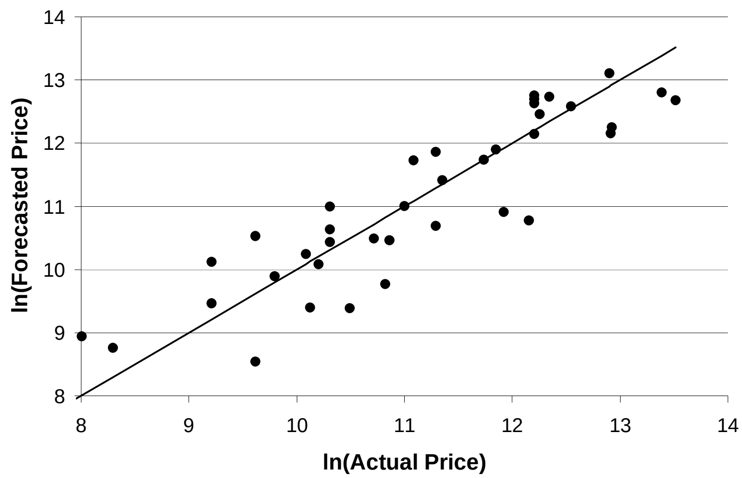

Figure 2. Example of out-of-sample forecasting performance, Theil's *U* = 0.41

be applicable to future years because of unusual industry conditions at the time. Most of our price flexibilities were only modestly higher in absolute value than Neibergs's, perhaps because we did not include barren mares in our dataset. Our results, however, suggest much greater importance of the stud fee as a broodmare price determinant. Not only is the price flexibility of 0.65 much higher than Neibergs's 0.21, we estimated a marginal value of $1.70 vs. Neibergs's $0.37.

At first glance, the marginal value of $1.70 seems to suggest that broodmare sellers should invest as much as possible in stallion services because the stud fees will be more than recouped in the broodmare sales price. After accounting for consignor and sales company commissions, mare depreciation, and other expenses, however, an estimate developed by industry experts (*The American Thoroughbred Review*, 2006) indicates that a marginal value of about $2.60 is needed to break even on stud fee investments.

If the $1.70 marginal value and the $2.60 break-even estimates are valid, then the broodmare market fails to fully capitalize stud fees into broodmare prices, and a strategy of breeding broodmares to stallions with low stud fees appears rational from a risk-neutral or risk-averse perspective. When the stud fee marginal value was calculated for each observation, 480 broodmares (79%) failed to meet the $2.60 break-even threshold. More than any other result in this analysis, the stud fee estimate has the greatest implications for business strategy, and additional research targeting this issue is warranted. A starting point would be a more in-depth budgeting analysis of breeding costs beyond the stud fee.

Forecasting performance is the true measure of how useful hedonic pricing models can be for agribusiness purposes. In this study, Theil's *U*-statistics suggested that the regression model was much superior to a naïve forecast, but mean absolute error percentages exceeding 60% are too high to justify relying only on the model as a guide for strategic decision making. It is not uncommon for regression models with good in-sample explanatory power to show unacceptably low out-of-sample forecasting ability, but in this case, the in-sample and out-of-sample accuracy was almost identical. Sometimes models with fewer independent variables are superior forecasting tools because they are more robust, but forecasting performance only worsened when we omitted variables from the model shown in table 3.

A useful topic for future research would be to calculate Theil's *U* against forecasts made by an industry expert, as opposed to naïve forecasts. One possible outcome is that, given only the quantitative data available for this study, an expert could not outperform the regression model. If he or she were able to do so, the model reported here would be severely misspecified, despite its exemplary performance in the battery of misspecification tests. An alternative outcome is that an expert could only outperform the model by having access to additional information, perhaps including a visual inspection of the broodmare's conformation, as suggested by the findings in Vercken de Vreuschman (2005).

Agricultural economists are sometimes dismayed by the lack of reliance on statistical analysis by agribusiness industry participants. The stud fee result offers a convenient example of why economists believe regression analysis can be relevant for business decisions. The expected return from stud fee investments was found to be lower than an estimated break-even value, after controlling for other factors. A simple regression that does not control for omitted relevant variables, however, produces an estimated stud fee return of $3.19, which substantially exceeds the break-even threshold. For the purpose of choosing a breeding strategy, only one of these answers can be correct. The multiple regression approach produces a recommendation that is much more likely to be the correct one and could have a large impact on profitability.

With its large but volatile money flows, its abundant data availability, its recognition that outcomes depend on multiple factors, and its familiarity with stochastic outcomes, the Thoroughbred industry has motive and opportunity to use regression analysis in business strategy formulation. Yet a tour through the industry media shows a marked reliance on anecdote and casual data analysis. One challenge for future equine-related work involves understanding if and when careful statistical analysis has practical business value.

References

The American Thoroughbred Review. (2006, May). "Understanding 'value' in stallion fees." Online. Available at http://www.thoroughbredreview.com/ValuesInStudFees.htm. [Retrieved November 2006].

———. (2005a). "2005 leading broodmare sires." Blood-Horse Publications. Online. Available at http://breeding.bloodhorse.com/sirelists/national05/broodmare1.asp. [Retrieved March 2006].

———. (2005b). "2005 leading sires." Blood-Horse Publications. Online. Available at http://breeding.bloodhorse.com/sirelists/national05/leading_sire.asp. [Retrieved March 2006].

———. (2006). "Stallion register online." Blood-Horse Publications. Online. Available at http://www.stallionregister.com. [Retrieved March 2006].

Box, G. E. P., and D. R. Cox. (1964). "An analysis of transformations." *Journal of the Royal Statistical Society. Series B (Methodological)* 26(2), 211–252.

Buzby, J., and E. Jessup. (1994). "The relative impact of macroeconomic and yearling-specific variables in determining Thoroughbred yearling price." *Applied Economics* 26, 1–8.

Buccola, S., and Y. Iizuka. (1997). "Hedonic cost models and the pricing of milk components." *American Journal of Agricultural Economics* 79, 452–462.

Chezum, B., and B. Wimmer. (1997). "Roses or lemons: Adverse selection in the market for Thoroughbred yearlings." *The Review of Economics and Statistics* 79, 521–526.

Commer, M. (2000). "Price factors and sales trends affecting the mid-atlantic Thoroughbred market." Fact Sheet 665, Maryland Cooperative Extension, College Park, MD.

Karungu, P., M. Reed, and D. Tvedt. (1993). "Macroeconomic factors and the Thoroughbred industry." *Journal of Agricultural and Applied Economics* 25, 165–173.

Keeneland Association, Inc. (2005). *2005 November Breeding Stock Sales Catalog*. Lexington, Kentucky: Keeneland Association, Inc.

———. (2006a). "Annual sales summaries." Lexington, Kentucky. Online. Available at http://www.keeneland.com/livesales/summaries.asp. [Retrieved November 2006].

———. (2006b). "Keeneland sales results: 2005 November breeding stock sale." Lexington, Kentucky. Online. Available at http://www.keeneland.com/livesales/showsale.asp?saleid=200603. [Retrieved March 2006].

Kristofersson, D., and K. Rickertsen. (2001). "Efficient estimates of hedonic inverse input demand systems." *American Journal of Agricultural Economics* 86, 1127–1137.

Ladd, G., and M. Martin. (1976). "Prices and demand for input characteristics." *American Journal of Agricultural Economics* 58, 21–30.

Ladd G., and V. Suvannunt. (1976). "A model of consumer goods characteristics." *American Journal of Agricultural Economics* 58, 504–510.

Lancaster, K. J. (1966). "A new approach to consumer theory." *Journal of Political Economy* 74, 132–157.

Laughlin, H. (1934). "Racing capacity of the Thoroughbred." *Scientific Monthly* 38, 310–321.

McGuirk, A. M., P. Driscoll, and J. Alwang. (1993). "Misspecification testing: A comprehensive approach." *American Journal of Agricultural Economics* 75, 1044–1055.

Neibergs, S. (2001). "A hedonic price analysis of Thoroughbred broodmare characteristics." *Agribusiness* 17, 299–314.

Neibergs, S., and R. Thalheimer. (1997). "Price expectations and supply response in the Thoroughbred yearling market." *Journal of Agricultural and Applied Economics* 29, 419–435.

Robbins, M., and P. Kennedy. (2001). "Buyer behavior in a regional Thoroughbred yearling market." *Applied Economics* 33, 969–977.

Rosen, S. (1974). "Hedonic prices and implicit markets: Product differentiation in pure competition." *Journal of Political Economy* 82(1), 34–55.

Schroeder, T., J. M. Jones, and D. A. Nichols. (1989). "Analysis of feeder pig auction price differentials." *North Central Journal of Agricultural Economics* 11, 253–263.

Schroeder, T., J. Espinosa, and B. Goodwin. (1992). "The value of genetic traits in purebred dairy bull services." *Review of Agricultural Economics* 14, 215–226.

Taylor, M. R., K. C. Dhuyvetter, T. L. Kastens, M. Douthit, and T. L. Marsh. (2004). "Price determinants of show quality quarter horses." Paper presented at the annual meetings of the Western Agricultural Economics Association, Honolulu, HI.

Vercken de Vreuschman, C. A. (2005). "Are pinhooked yearlings different? A hedonic pricing analysis of yearlings at the select auctions." Unpublished M.S. thesis, Department of Agricultural Economics, University of Kentucky, Lexington.

Vickner, S., and S. Koch. (2001). "Hedonic pricing, information and the market for Thoroughbred yearlings." *Journal of Agribusiness* 19(2), 173–189.