Hedonic Price Analysis of Thoroughbred Broodmares in Foal

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Abstract

Thoroughbred broodmares are the foundation of a successful racing operation. This study estimated the impact of breeding, racing, genetic, and market characteristics on broodmare auction prices. Data represent 298 broodmares in foal that were sold in Keeneland's 2005 sale. Prices were most responsive to the sire's stud fee and the broodmare's age, with pronounced day-of-sale effects. Overall valuation structure appeared similar to Neibergs' results using 1996 data. Out-of-sample forecasts were far superior to naive forecasts, but were not accurate enough to use in isolation from other decision aids such as visual inspection of the horse.

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

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Introduction

In 2004, horses contributed over $100 billion and 1.4 million jobs to the U.S. economy (The Jockey Club, 2006). Thoroughbreds contributed over 33% of the economic impact, even though they represent only 14% of the horse population. With over a million Thoroughbreds and half of them involved in the racing industry, 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. Whether the relative importance of broodmare price determinants has evolved in the last decade is a testable hypothesis.

The objectives of this study were to update estimates of broodmare attribute marginal values and price flexibilities, to determine if the overall structure of broodmare valuation is approximately stable despite changing economic conditions, to focus on price determinants of broodmares in foal as opposed to barren broodmares, and to test whether a hedonic pricing

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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, the largest broodmare sale in the world.

Background

Thoroughbred broodmares are differentiated products that bring a different price for each horse depending upon the perceived value of the broodmare. Lancaster (1966) developed a theoretical model in which consumers purchase goods delivering a utility-maximizing bundle of attributes, subject to a budgent constraint. Thus, a product price function exists containing measurable product attributes as arguments (Rosen, 1974). Ladd and Martin (1976) developed this theme in the context of demand for agricultural inputs, while Martin 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 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 affecting the price of bull semen. Schroeder, Jones, and Nicholas (1989) studied the price of feeder pigs

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and the various characteristics that discounted the price over time.

Hedonic pricing models have also been applied to the equine industries, with the most emphasis on Thoroughbred yearlings. Chezum and Wimmer (2001) tested whether there is adverse selection in Thoroughbred yearling actions when some sellers 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 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

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conformation, the variable was statistically and economically significant in the model, suggesting that informed visual inspection may be necessarily 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 other variables such as tax and interest rates were price determinants. 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) was, to our knowledge, the only study applying 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 won.

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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. To facilitate comparison, we follow Neibergs' (2001) categorization of independent variables into breeding, racing, genetic, and marketing factors. Breeding factors include the racing performance of a mare's existing foals, and measures of the sire's quality. The mare's racing record signals hereditable expectations of her foals' racing performance. Genetic factors refer mainly to the mare's placement on the spectrum of speed and stamina. In this study, marketing factors consist of the day on which the mare was auctioned during the 12-day sale. The specific variables collected for this study appear in Table 1, and are described in order of appearance below.

< TABLE 1 ABOUT HERE >

The age of the mare in years reflects her potential future earnings from producing more foals. The younger the mare, the more foals she is capable of producing, suggesting that age negatively influences price. 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 other foals that the broodmare has produced can indicate how easily bred the mare is, but it can also correlate highly with age. Because purse winnings are the easiest way to judge the quality of a racehorse, total foal earnings reveals the success of the mare's previous foals, with all earnings converted into U.S. dollars using March 2006 exchange rates. The number of races the broodmare's foals have won, and average earnings per foal, are

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alternative guides to expected success of future foals on the racetrack.

The quality of the broodmare's sire and the sire bred to the broodmare are expected to be important characteristics in determining the price of the broodmare. The dollar amount of 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 carrying the foal. One might also expect a positive relationship between broodmare price and the number of foals sired by the stallion to which she was bred.

Each year, *The Blood-Horse* compiles a Leading Sires list of the top 150 stallions ranked by that year's foal earnings. An index called "expected foal's sire value" was created to compare the stallions to whom the broodmares were bred. The formula for the index (*EFSV*) is one plus the number of stakes winners sired by the stallion (*SW*), multiplied by an index of earnings by a stallion's progeny relative to the average of all runners (*AE*), multiplied by an index of earnings by a stallion's progeny relative to the average of other stallions' progeny from the same mares (*COMP*), divided by the ranking on the leading sires list (*R*). That is, $EFSV = 1 + SW * AE * COMP / R$. If a stallion did not appear on the leading sires list, it was assigned a value of one. The construction of the index allows natural logs to be taken. Neibergs (2001) used a similar index to measure sire quality, and each component of the index is provided in the Leading Sires list. An analogous index called "expected mare's sire value" was calculated for each broodmare's sire, using data contained in the 2005 Leading Broodmare Sires list.

The broodmare's racing history indicates her capability as a racehorse, which is expected to be partially hereditable. The broodmare's total earnings are one measure of

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success on the racetrack. Her racing record can also be measured with separate variables for the number of races the mare won, placed, and showed.

Three measures of each broodmare's genetic attributes were collected. The dosage index is a computation of the projected speed and stamina of a horse based upon the dosage values of the stallions in the horse's pedigree. The higher the dosage index, the more likely the horse is to be a sprinter, while low dosage values suggest better stamina. The center of distribution is an alternative scoring system using the same pedigree information, with higher values also suggesting better performance in shorter races. The Genetic Strength Value is a multi-attribute measure of pedigree performance extending five generations back (Pedigree Online, 2006). Higher values indicate greater likelihood of winning higher-class races. Unlike dosage and the center of distribution, the genetic strength value incorporates information about the mares in a horse's pedigree.

The day of the sale on which a broodmare is sold may affect the price of the mare even holding all other attributes constant. Higher quality mares are scheduled for sale early in the sale, but the variables described above should control for many of the breeding, racing, and genetic attributes that justify price variation. If there are significant day of sale effects, it implies either that the other variables do not adequately capture the broodmares' qualities, or that 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 wears on.

About three quarters of the auctioned broodmares were pregnant ("in foal") at the time of the 2005 sale. Seven of the nine breeding variables listed in Table 1 are zero vectors for

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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, and we focus 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. Put another way, barren mares were treated as if they had been bred to sires so undesirable that their stud fees were zero. 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 weight missing information about a variable as heavily as an observed zero value for that variable. 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 rather 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 sufficiently different 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):

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

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 $\lambda = 0.0$, 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 are approximately log-normally distributed.

< FIGURE 1 ABOUT HERE >

Severe multicollinearity (as suggested by variance inflation factors exceeding 10) occurred when multiple racing and genetic characteristics were included in the model. Based on contribution to adjusted R^2, the mare's center of distribution was selected to represent genetic characteristics, and total mare earnings was selected to represent racing characteristics. Four breeding characteristics (age, stud fee, expected mare's sire value, and total foal earnings) could be retained in the model without producing severe multicollinearity. Explanatory power (as measured by adjusted R^2) was markedly higher when the stud fee and expected mare's sire value were logged. In many cases, total foal earnings were 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:

$$
\begin{aligned}
\ln(Price) = {} & \beta_0 + \beta_1 Age + \beta_2 TotalFoalEarnings + \beta_3 (TotalFoalEarnings)^2 \\
& + \beta_4 \ln(Expected\ Mare's\ Sire\ Value) + \beta_5 \ln(Stud\ Fee) + \beta_6 Total\ Mare\ Earnings \\
& + \beta_7 Center\ of\ Distribution + \beta_8 Day\,2 + ... + \beta_{18} Day\,12 + \varepsilon.
\end{aligned}
$$

Marginal values and price flexibility estimates are more meaningful than the

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parameter estimates alone. The marginal value of a variable is the change in broodmare price given a one-unit increase in the independent variable. Formulas used to calculate marginal values for a given variable x_i are as follows, where overbars denote sample means of continuous variables and $e^{\overline{x}\beta}$ equals the predicted broodmare price on Day 1 of the sale at the sample means of all continuous variables:

$$\frac{\partial Price}{\partial x_i} = e^{\overline{x}\beta}\beta_i \qquad\qquad\qquad \textit{if } x_i \textit{ not logged, with no quadratic term}$$

$$\frac{\partial Price}{\partial x_i} = e^{\overline{x}\beta}(\beta_i + 2\beta_{ii}\overline{x}_i) \qquad\qquad \textit{if } x_i \textit{ not logged, with quadratic term}$$

$$\frac{\partial Price}{\partial x_i} = \frac{e^{\overline{x}\beta}\beta_i}{\overline{x}_i} \qquad\qquad\qquad \textit{if } x_i \textit{ is logged}$$

$$\frac{\partial Price}{\partial x_i} = (e^{\overline{x}\beta} \mid x_i = 1) - (e^{\overline{x}\beta} \mid x_i = 0) \qquad \textit{if } x_i \textit{ is binary.}$$

Price flexibilities represent the percentage change in broodmare price given a one percent increase in an independent variable, and were calculated for each continuous variable using the following formulas:

$$\frac{\partial \ln Price}{\partial \ln x_i} = \beta_i \overline{x}_i \qquad\qquad\qquad \textit{if } x_i \textit{ not logged, with no quadratic term}$$

$$\frac{\partial \ln Price}{\partial \ln x_i} = (\beta_i + 2\beta_{ii}\overline{x}_i)\overline{x}_i \qquad\qquad \textit{if } x_i \textit{ not logged, with quadratic term}$$

$$\frac{\partial \ln Price}{\partial \ln x_i} = \beta_i \qquad\qquad\qquad\qquad \textit{if } x_i \textit{ is logged.}$$

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

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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, and multicollinearity was tested using the rule of thumb that variance inflation factors exceeding 10 indicate severe multicollinearity.

Since the purpose of this study is to assist future buyers and sellers of broodmares, it is not only important for the model to have acceptable in-sample explanatory power, it must also have acceptable out-of-sample predictive power. Using numbers randomly generated from a uniform distribution, five subsamples of 20 observations were drawn from the full sample of broodmares in foal. In each case, the model was re-estimated using only the 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:

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$$U = \sqrt{\dfrac{\displaystyle\sum_{i=1}^{20}(\ln P_i - \ln \hat{P}_i)^2}{\displaystyle\sum_{i=1}^{20}(\ln P_i - \ln \overline{P})^2}} \ .$$

Theil's U compares the root mean squared errors of the model forecast to those from a naive forecast. In this case the most reasonable naive forecast appeared to be the mean of the in-sample broodmare prices. A ratio of zero implies a perfect forecast, while a ratio of one implies that the model performs no better than the naive forecast, and ratios greater than one imply that the model performs even worse than the naive 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 and the foals' total earnings, the number of races won by the mare's foals, the number 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, 2006). Data on 2005 stud fees were obtained from the "Stallion Register" published by *The Blood-Horse*. Data regarding sires were collected from *The Blood-Horse* "2005 Leading Sires" list and the 2005 "Leading Broodmare Sires" list. The dosage index, center of distribution, and genetic strength value variables were acquired from Pedigree Online's "Thoroughbred Database."

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Of the 4,477 horses registered for the sale, bidding on many horses did not meet the seller's reserve price, and other horses were pulled from the sale, resulting in 2,400 sales. Complete data were collected on 409 randomly selected broodmares, of which 298 were in foal and therefore retained for analysis.

Summary statistics appear in Table 1. The average broodmare price was almost $170,000, with prices ranging from $1,700 to $3,700,000. The average stud fee was almost $42,000 with a range from $1,250 to $500,000. The average mare was 9 years old, and had produced an average of 2.76 foals that had won an average of 2.43 races and earned over $73,000. The broodmares themselves had won an average of 2.22 races and earned over $82,000. Broodmare earnings ranged from $0 to $1.15 million.

Results

Table 2 shows no evidence of significant econometric violations. An F-test failed to reject the joint hypothesis of zero values for the parameter stability, functional form, and serial dependence parameters in the joint conditional mean test, and none of the individual parameters were significant. Similarly, the joint conditional variance regression was not significant, and neither were any of the individual parameters. The null hypothesis of normally-distributed residuals could not be rejected, and the maximum variance inflation factor of 9.49 suggested an absence of severe multicollinearity.

< TABLE 2 ABOUT HERE >

Table 3 presents the parameter estimates, marginal values, and price flexibilities. The adjusted R^2 was 0.83, which is similar to the 0.74 value found by Neibergs (2001). The

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difference is due to our study's focus on broodmares in foal. Out of curiosity, we estimated a model using the full sample including barren mares, and also found an adjusted R^2 of 0.74.

< TABLE 3 ABOUT HERE >

All of the parameters except *Day2*, *Day3*, *Day4*, and *Center of Distribution* were statistically significant at the 1% level, *Day4* was significant at the 10% level, and all but *Day2* had the expected sign. Moreover, most of the independent variables appear to be economically significant. Each additional year that a broodmare ages reduced her value by an average of almost $14,000, holding all else constant. At the mean, each additional dollar won by a mare's foals increased the mare's value by 18 cents, on average. Likewise, each additional dollar won by the mare herself increased her value by an average of 20 cents. 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' 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 (-1.13 vs. -0.86), total foal earnings (0.12 vs. 0.08), expected mare's sire value (0.15 vs. 0.05), and total mare earnings (0.15 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

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additional dollar of stud fee raised the broodmare's value by $1.79 (vs. Neibergs' $0.37), with

a price flexibility of 0.69 (vs. Neibergs' 0.21).

After randomly drawing each set of 20 out-of-sample observations, the model was re-

estimated using the remaining 278 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: 0.40, 0.34,

0.52, 0.40, 0.50, with lower values indicating better forecasting performance. All five U-

statistics were less than one and indicate much better performance than the naive 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 51 percent.

< FIGURE 2 ABOUT HERE >

Conclusions

In conversations with Thoroughbred industry participants, it is not unusual to hear the

opinion that valuation of horses cannot be reduced to a mathematical formula. In the case of

broodmares in foal, over 80 percent of variation in auction prices can in fact be explained by a

regression model, at least within the 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

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and sellers would find useful. Neibergs was concerned that his 1996 results might not be applicable to future years because of unusual industry conditions at the time, but except for inflation and differences attributable to modeling choices, the basic structure of broodmare valuation appears stable over time. Most of our price flexibilities were only modestly higher in absolute value than Neibergs', perhaps because we did not include barren mares in our dataset and assign zero values to foal-related variables. Our results, however, suggest much greater importance of the stud fee as a broodmare price determinant. Not only is the price flexibility of 0.69 much higher than Neibergs' 0.21, we estimated a marginal value of $1.79 vs. Neibergs' $0.37. This is relevant for broodmare sellers because it suggests that additional money spent breeding a mare to a higher-quality stallion will be more than recouped when the mare is sold.

Forecasting performance, however, is the true measure of how useful hedonic pricing models are for agribusiness purposes. In this study, Theil's U-statistics suggested that the regression model was much superior to a naive forecast, but mean absolute error percentages exceeding 50 percent are too high to justify relying only on the model as a guide to strategic decisions. It is not uncommon for regression models with good in-sample explanatory power to show unacceptably low out-of-sample forecasting ability. 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 our model.

A useful topic for future research would be to calculate Theil's U against forecasts made by an industry expert, as opposed to naive forecasts. One possible outcome is that, given only the quantitative data available for this study, an expert could not outperform the

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regression model. If he or she were able to do so, it would suggest that the model reported here is 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 Vercken de Vreuschman's (2005) results.

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

Variable (N = 298)	Exp. sign	Mean	Std. Dev.	Min.	Max.
Dependent Variable					
Price ($)	n/a	169,735.23	358,986.22	1,700.00	3,700,000.00
Breeding Characteristics					
Age (years)	-	9.01	3.94	1.00	20.00
# of Foals out of Mare	-	2.76	2.95	0.00	14.00
Total Foal Earnings ($)	+	73,326.91	252,358.02	0.00	3,599,843.00
# of Foal Wins	+	2.43	5.02	0.00	33.00
Avg. Earnings per Foal ($)	+	10,404.06	30,198.83	0.00	359,984.30
Expected Mare's Sire Value	+	25.57	133.01	1.00	1,025.91
Stud Fee ($)	+	41,970.64	61,895.67	1,250.00	500,000.00
# of Foals by Sire	+	168.72	263.13	0.00	1,583.00
Expected Foal's Sire Value	+	13.15	59.24	1.00	492.34
Racing Characteristics					
# Races Mare Won	+	2.22	2.95	0.00	18.00
# Races Mare Placed	+	1.86	2.48	0.00	15.00
# Races Mare Showed	+	1.69	2.25	0.00	14.00
Total Mare Earnings ($)	+	82,469.60	145,266.74	0.00	1,150,410.00
Genetic Characteristics					
Mare's Dosage Index	?	2.85	2.05	0.33	23.00
Mare's Center of Distribution	?	0.68	0.36	-1.00	1.83
Mare's Genetic Strength Value	+	65.62	7.49	44.57	79.41

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 6.0% on Day 7 and Day 10 to 9.7% on Day 5.

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Table 2. Misspecification Test Results

| Joint Conditional Mean Test	Test value	Pr > Critical Value
Stability of β	-0.91	0.36
Serial dependence	-1.25	0.21
Functional Form (RESET2)	0.38	0.71
Functional Form (RESET3)	-0.35	0.73
Joint test	0.61	0.66
Joint Conditional Variance Test		
Stability of σ^2	0.35	0.73
ARCH errors	0.34	0.73
Heteroskedasticity	-0.51	0.61
Joint test	1.27	0.29
Normality of Residuals Tests		
Shapiro-Wilk	0.99	0.20
Kolmogorov-Smirnov	0.05	0.13
Cramer-von Mises	0.07	>0.25
Anderson-Darling	0.51	0.20
Multicollinearity: Max. Variance Inflation Factor = 9.49 < 10		

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

Variable	Parameter Estimate		Marginal Value	Price Flexibility
Intercept	5.31	*** [a]		
	(0.74) [b]			
Age	-0.13	***	-13,695.45	-1.13
	(0.02)			
Total Foal Earnings	1.72E-06	***	0.18	0.12
	(4.57E-7)			
(Total Foal Earnings)^2	-4.00E-13	***		
	(1.32E-13)			
ln(Expected Mare's Sire Value)	0.15	***	8.52	0.15
	(0.03)			
ln(Stud Fee)	0.69	***	1.79	0.69
	(0.06)			
Total Mare Earnings	1.86E-06	***	0.20	0.15
	(2.85E-7)			
Center of Distribution	0.15		16,602.78	0.10
	(0.11)			
Day 2	0.08		9,261.85	
	(0.17)			
Day 3	-0.22		-21,929.46	
	(0.17)			
Day 4	-0.38	*	-33,962.23	
	(0.20)			
Day 5	-0.82	***	-61,268.72	
	(0.18)			
Day 6	-0.58	***	-48,034.58	
	(0.20)			
Day 7	-0.98	***	-68,027.41	
	(0.22)			
Day 8	-1.07	***	-71,511.15	
	(0.21)			
Day 9	-1.03	***	-70,163.09	
	(0.22)			
Day 10	-1.22	***	-76,808.58	
	(0.24)			
Day 11	-1.39	***	-82,054.70	
	(0.24)			
Day 12	-1.56	***	-86,078.74	
	(0.24)			
Adjusted R^2	0.83			

[a] *, **, and *** denote statistical significance at the .10, .05, and .01 levels, respectively
[b] standard errors in parentheses

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Figure 1. Broodmare Prices are Approximately Log-Normally Distributed*
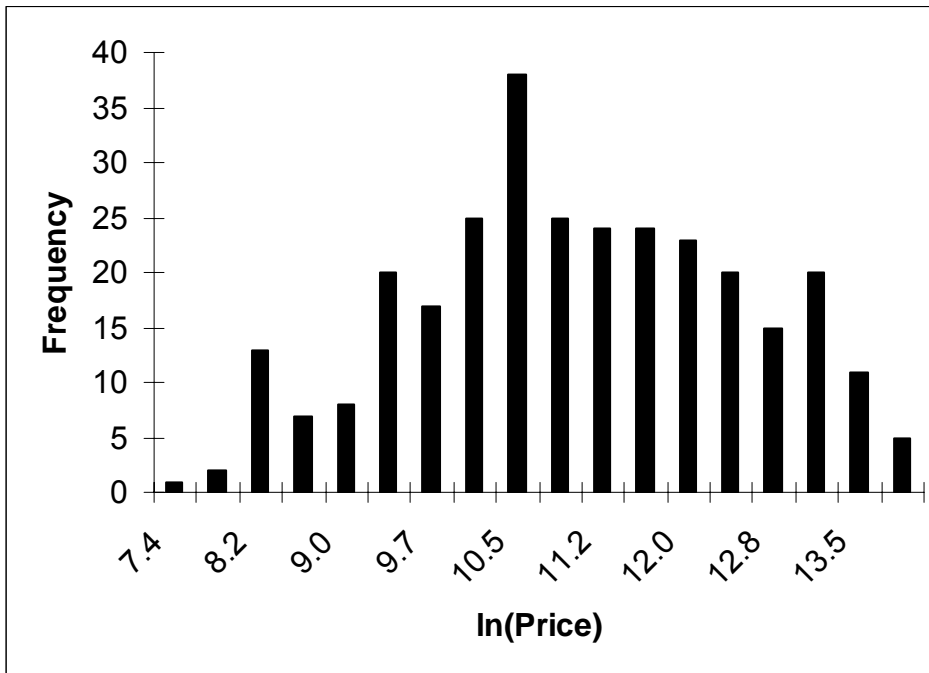
* null hypothesis of normality not rejected at .10 level by Cramer-von Mises and Anderson-Darling tests, and not rejected at .05 level by Shapiro-Wilk and Kolmogorov-Smirnov tests

Figure 2. Example of Out-of-Sample Forecasting Performance, Theil's U = 0.34