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Hedonic pricing and the role of stud fees in the market for thoroughbred yearlings in Australia*

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Using data from one of Australia's largest thoroughbred auction houses, we investigate the price determinants of thoroughbred yearlings sold at auction. We include novel key variables to construct hedonic pricing models and examine the relative role of stud fees compared to the wide range of attributes in the pricing of yearlings. We find that the price effect of stud fees is influenced by the value buyers place on both the characteristics of sires and the characteristics of sire side siblings. The findings imply that the quality of dams a sire has been matched within the breeding market has consequential effects on yearling prices through the sire's stud fee and progeny.

Key words: auction, hedonic pricing, stud fee, thoroughbred yearling.

JEL classifications: Q11, Q13, D44, D46

1. Introduction

Horse racing is among the most lucrative sporting industries. In Australia, for example, as the second most popular sport by spectator attendance, it contributes over 0.5 per cent to gross domestic product ($6 billion) annually, involves approximately 250,000 employees and participants, and generates nearly $1.2 billion in taxes annually (Australian Racing Board 2010, 2014).[1] The significance of the horse racing industry to the US economy is similar. It contributed over 0.6 per cent to gross domestic product (US$ 122 billion), supported 1.74 million full-time jobs and generated US$ 79 billion in total salaries, wages, and benefits in 2017 (American Horse Council 2017).

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[1] The currency used in this paper is the Australian dollar, unless it is differently specified.

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In the thoroughbred industry, horses are generally bred for the purpose of racing. Mare owners typically pay service fees or stud fees to stallion owners for the right to breed. Some of the horses produced are then offered for sale in the thoroughbred auction market as yearlings, that is, horses between 1 and 2 years old, before they begin their racing career. Sires known to have a good pedigree, conformation, track record, and any other characteristics associated with quality yearlings are likely to be highly sought after by mare owners and thus will command higher stud fees. The extent to which owners of stallions are able to capture the value buyers of yearlings place on both the characteristics of sires and siblings on the sire side is therefore crucial to the viability of the thoroughbred industry.

This paper uses a hedonic pricing approach to estimate and examine the relative role of stud fees compared to various attributes of yearlings in influencing the prices of yearlings. Using data from the sales results of one of Australia's largest thoroughbred auction houses, William Inglis & Son, we contribute to the literature on hedonic pricing of thoroughbred yearlings.

First, we demonstrate the important role of stud fees, elusive in the current literature, in explaining the significant price variations observed at Australian yearling auctions. We find that the stud fee alone contains more information about the sale price of yearlings than the characteristics of sires. Although the stud fee is considered to be a superior proxy for sire quality (Ng *et al*. 2013; Plant and Stowe 2013), the information is not always available and has therefore been excluded from past studies using Australian data, such as Hastings (1987) and Ng *et al*. (2013). While US and UK studies (Chezum and Wimmer 1997; Robbins and Kennedy 2001; Vickner and Koch 2001) find the stud fee to be an important determinant of yearling prices, less attention has been paid to whether stud fees contain more information about yearling prices than sire characteristics. An exception is Stowe (2013), who uses US data to examine the explanatory power of the average yearling sale price and career performance measures of a sire's progeny in explaining stud fees.

Second, we investigate how the price effect of stud fees changes when various attributes of yearlings are incorporated into our hedonic pricing models. We introduce previously unused information about sibling prices into our models by collating the previous sale prices of each yearling's siblings on both the sire and dam sides. Although we find that stud fees contain more information about the sale price of yearlings than the characteristics of sires alone, we also find that sire characteristics provide additional information about the price of yearlings after stud fees are included in the model. Furthermore, the price effect of stud fees changes when the average sale price of a yearling's siblings on the sire side is included in the model. However, the effect of stud fees is not sensitive to the average sale price of a yearling's siblings on the dam side. These results imply that the stud fee charged by the owner of a sire is not only influenced by the value directly generated by the sire's characteristics but also the value indirectly generated by the different dams with which the sire has been matched by breeders in the thoroughbred market. Thus, the quality of the dams with which a sire has been matched in the breeding market has consequential effects on yearling prices through the sire's stud fee and progeny.

Finally, we find that racing performance of a yearling's siblings on the dam side is important in explaining auction price variation even after controlling for stud fees. The results support previous hedonic pricing analyses in thoroughbred markets, which generally find the career performance of their progeny to be important predictors of yearling prices (Hastings 1987; Lansford *et al*. 1998; Robbins and Kennedy 2001).

2. Background: The thoroughbred racing industry

The risk associated with buying racehorses is undoubtedly part of the thrill that the industry offers to its participants. As in any market, a buyer of a horse may aim to maximise the net present value of the horse's expected cash flows given the costs of owning and running the horse. The buyer may also gain nonpecuniary utility from participating in the racing game (Gamrat and Sauer 2000). As most racehorses are purchased as yearlings and have never been raced before, buyers face considerable uncertainty in their decision-making. Of particular importance to sellers is the breeding and raising of foals, as a horse's growth is essential to maximising returns at yearling sales, where breeders obtain a significant portion of their revenue (Morel *et al*. 2007).[2]

A stallion is the primary agent involved in the breeding process and is perhaps the most important asset of a breeding operation. Only horses with a sufficiently high racing quality become stallion prospects. These horses are known to have a good pedigree, conformation, and track record (Samper 2008). Stallions often command high stud fees, paid by the owner of a mare to the stud farm on which the stallion stands for the right to breed to it. In this case, the breeder has the important job of facilitating the reproductive process and foaling the horse for the owners.

Thoroughbred horses are generally bred for the purpose of racing, but this may not always occur. If it turns out that a female yearling (filly) lacks racing ability, the owners may decide to keep her off the racetrack and to breed her as an unraced mare in future. This practice would be more profitable for a subset of fillies with strong pedigrees than breeding to a mare with a poor race record. Breeders also produce their own stock to sell at yearling auctions, but they can operate on different scales. Some breeders may be heavily involved in racing and will retain a portion of their stock for that purpose. Such breeders are generally hobbyists who do not operate on the scale of major thoroughbred farms and make their money in the racing business (McManus *et al*. 2012). In

[2] The term 'breeder' is more broadly defined for the Australian thoroughbred industry, as it is not restricted to only mare owners. Breeders are people or businesses that engage in the careful selection of thoroughbreds to sexually reproduce offspring with specific qualities and characteristics.

general, these hobbyists are likely to have good results on the racetrack as they are mostly race top end stock. Such heterogeneity in market participants has motivated tests for adverse selection to determine whether these sellers who both breed and race command a lower price at auction, as buyers may assume they are offering lower quality stock (Chezum and Wimmer 1997; Vickner and Koch 2001). The majority of commercial breeders, however, aim to sell all of their stock each year, as their main source of income comes from selling horses (McManus *et al.* 2012). Putting larger numbers of high-quality horses through auctions will result in higher earnings for breeders. These commercial breeders might only race their stock that they were unable to sell at auction, or if they have a particularly attractive female yearling from a well-liked pedigree, they may decide to retain it for future breeding purposes.

Nowadays, a lot of presale inspection takes place before and on the date of an auction event and vendors are required by the auction house to disclose any surgical procedures undergone by a yearling to alleviate information asymmetry. During inspections, agents and buyers attempt to judge the horse based on its temperament and conformation. Conformation refers to a yearling's physical makeup as reflected in its muscular build and its skeletal characteristics such as the straightness and circumference of its leg bones. Essentially, buyers look for an athletic-looking horse that moves fluently and takes a big stride (Eberhart 2009). These factors all contribute to an individual's judgement of a yearling's racing potential. Nevertheless, the art of horse judging is an extremely challenging one to master, and while buyers are able to request X-rays and veterinary reports, there is no objective measure for the physical appearance of a horse that can be used for the purpose of price prediction. As such, characteristics in the yearling's bloodline are generally the most significant factors to study outside of its conformation (Siu 2007).

The Appendix S1 shows a sample from the sales catalogue of the William Inglis & Son 2014 Australian Easter Yearling Sale. Sales catalogues include information on the yearling's sire, such as its racing performance and progeny. The yearling's maternal lineage is given particular attention in the catalogues, summarising the career and progeny records of the 1st, 2nd and 3rd dam (i.e. its mother, grandmother, and great grandmother). To a degree, extensive knowledge of a yearling's pedigree can be used to describe the yearling without actually being seen. Pedigree is particularly important for female yearlings. They have more significant residual breeding value than males, since males must be top-class performers to be stallion prospects. Some male horses are gelded for behavioural or physical reasons in order to make better racers (McManus *et al.* 2012). Horse owners may choose not to geld their male horses until their residual breeding value can be ascertained. Male horses that are not gelded and have a successful career are valuable to breeders and generally command extremely high sale prices at the end of their careers. Finally, the best indication of the sire's quality and therefore a yearling's racing potential is usually the sire's prior racing performance (Hastings 1987). Accordingly, the number of races won by the yearling's sire and dam is a useful measure of its potential and is often included in pricing models to calculate the amount of the sale price that can be attributed to the success of sires and dams. Likewise, the racing performance of a yearling's siblings is an indicator of its potential and can explain a portion of the sale price, reflecting the level of talent in the pedigree.

3. Hedonic pricing theory

We use the hedonic pricing framework to estimate the effects of various attributes of yearlings on their price. Hedonic pricing theory, originating from the work of Lancaster (1966) and Rosen (1974), has long been applied to agricultural commodities. Examples of these applications include Schroeder *et al*. (1988) and Todd and Cowell (1981) in the cattle industry and Nolan *et al*. (2014) in the wool industry. There are two related lines of the hedonic pricing approach. The first is a consumer goods approach that views individual characteristics to be utility providing attributes in a consumer's utility maximisation problem. The second approach considers each individual characteristic as an input into a production process. Under the second approach, a yearling is demanded by profit-maximising firms (e.g. stud farms and racers) because it possesses particular characteristics of interest to them (Neibergs 2001). While both approaches derive a hedonic price function which expresses a yearling's market price as a function of the quality and quantity of the yearling's attributes, we follow the second approach to establish a hedonic price equation.

A firm maximises a profit function subject to a production function $f_z(w)$ which has the quantity of each input characteristic w_k, $k = 1, \ldots, K$, as an argument. The first-order conditions of the profit maximisation problem yield a hedonic pricing model:

$$Price_y = R_z \sum_{k=1}^{K} \left(\frac{\partial f_z(w)}{\partial w_k} \frac{\partial w_k}{\partial y} \right), \tag{1}$$

where $Price_y$ is the price of the input y, which is a yearling in our case, R_z is the price of output z, $\partial w_k / \partial y$ is the marginal yield of the k^{th} attribute of y in the production of z, and $R_z \partial f_z(w)/\partial w_k$ is the marginal implicit price of the k^{th} characteristic, or 'hedonic price.'

By assuming that $\beta_k = R_z \partial f_z(w)/\partial w_k$ and $x_k = \partial w_k / \partial y$ are constant, we can rewrite Equation 1 as a linear hedonic price function:

$$Price_y = \sum_{k=1}^{K} \beta_k x_k. \tag{2}$$

By regressing the input price (yearling price) on input characteristics, we can obtain the effect of each of the characteristics on the price paid for the input.

The regression gives us the estimated marginal implicit values (hedonic prices) of the characteristics.

4. Data and empirical specification

4.1 Sample

We source the data for this study from the results of one of Australia's largest thoroughbred auction houses, William Inglis & Son (Inglis), between January 2014 and April 2015. Before an auction, Inglis publishes a sale catalogue containing detailed information for each lot on offer. The catalogue includes a yearling's basic characteristics such as colour, sex, and birthday, as well as its pedigree chart and the track record of its ancestors and siblings. After the sale, the auction results are published online. This data set is the primary source of information for our hedonic pricing analyses and includes final sale prices, whether a yearling was passed in or withdrawn from sale, highest bids/reserve prices if passed in, the information about vendors and buyers, yearlings' characteristics, and the name of sires and dams.[3] Several sales events include thoroughbreds of all ages (such as weanlings and broodmares), and thus, observations for nonyearlings are omitted from the original sample.

The original sample contains a total of 4,718 yearlings, where 3,500 yearlings were sold, 723 yearlings were passed in and the rest were withdrawn from sale. If a horse is withdrawn from sale or if it is passed in, no sale price is recorded and these observations are thus omitted for our main analysis. Among the 3,500 yearlings sold, 1,665 yearlings have at least one foreign parent. Due to limited data accessibility (in particular, the unavailability of the detailed race record of many foreign parents and stud fees of some foreign sires), yearlings with foreign sires or dams are also excluded from our main sample.[4] In a robustness checks section, we examine the sensitivity of our main findings to excluding yearlings that were passed in and yearlings with foreign parents, as well as to restricting the sample to 2014 data only. The final main sample used to form the hedonic pricing models consists of 1,835 observations.[5] We present the description and summary statistics of key variables in Table 1.

[3] A yearling is passed in when the bidding at an auction does not reach the vendor's reserve (the minimum price that the vendor is willing to accept). This term is equivalent to 'reserve not attained (RNA)' in the United States.

[4] Note that the average sale price and stud fees do not differ across yearlings with foreign parents and yearlings with domestic parents. The average sale prices of yearlings with domestic parents and foreign parents are $93,114 and $97,536, respectively. The difference is statistically insignificant with a *P*-value of 0.394. The average stud fees of sires of yearlings with domestic and foreign parents are $17,527 and $22,334, respectively. The difference is statistically insignificant with a *P*-value of 0.145.

[5] According to the Australian Racing Fact Book's statistics in 2013/2014 and 2014/2015 seasons, there were approximately 8,900 yearlings sold in Australia between July 2013 and June 2015. Thus, for the 16-month sample period, there were roughly 5,900 yearlings sold in Australia and our sample of yearlings represents approximately 31 per cent of them.

Table 1 Summary statistics

Variable	Description	Mean	SD	Min.	Max.
Sale price					
Sale price	Price of yearling sold at auction	93,114	159,987	400	2,200,000
Log of sale price	Log of price of yearling at auction	10.561	1.464	5.991	14.604
Yearling characteristics					
Age	Age of yearling measured in the fraction of years	1.472	0.127	1.055	1.994
Female	Indicator for yearling's sex as female	0.462	0.499	0	1
Bay	Indicator for yearling that is bay in colour	0.567	0.496	0	1
Brown	Indicator for yearling that is brown in colour	0.117	0.321	0	1
Chestnut	Indicator for yearling that is chestnut in colour	0.190	0.392	0	1
Grey	Indicator for yearling that is grey in colour	0.020	0.140	0	1
Black	Indicator for yearling that is black in colour	0.002	0.047	0	1
Mixed	Indicator for yearling that has mixed colour (brown or black/brown or bay)	0.105	0.306	0	1
Sire characteristics					
Sire age	Age of sire measured in years	11.637	3.737	7	27
Number of races won by sire	Number of races won by sire during its racing career	5.009	3.470	1	26
Champion sire	Whether sire awarded Horse of the Year or first three in Leading Sire	0.151	0.358	0	1
Dosage index (DI)	Dosage Index	2.554	1.682	0	11
Centre of distribution (CD)	Centre of Distribution	0.598	0.280	−0.09	2
Derby-eligible	Indicator for a yearling who is Derby-eligible (DI < 4 and CD < 1.25)	0.925	0.263	0	1
Sire's average race rank	Sire's average rank in races run	0.334	0.087	0.138	0.568
Stud fee					
Stud fee	Sire's sale-year stud fee	33,276	35,642	2,000	165,000
Dam characteristics					
Dam age	Age of dam measured in years	11.636	3.659	1	25
Races won by dam	Number of races won by dam (if raced) during its career	2.117	2.499	0	17
Champion dam	Whether dam awarded Horse of the Year	0	0	0	0
Dam raced but never won	Indicator for yearling whose dam has raced but did not win first place	0.212	0.409	0	1

Table 1 (*Continued*)

Variable	Description	Mean	SD	Min.	Max.
Dam's average race rank	Dam's average rank in races run	0.454	0.230	0	1
Buyer characteristics					
Foreign buyer	Indicator for yearling sold to a foreign buyer	0.160	0.366	0	1
Vendor characteristics					
Racer	Indicator for a seller involved in racing horses	0.707	0.455	0	1
Racing syndicate	Indicator for a seller who is a thoroughbred stud business with a racing syndicate in its name	0.687	0.464	0	1
Sibling characteristics on the dam side					
If a dam has winning son/daughter	Indicator for dam with a winning son/daughter	0.540	0.498	0	1
First foal	Indicator for a yearling that is the first foal of its mother	0.158	0.365	0	1
Within five foals	Indicator for a yearling that is one of the first five foals of its mother	0.730	0.444	0	1
Number of winning siblings by same mother	Number of winning siblings by same mother, regardless the number of wins	1.362	1.723	0	10
Sibling characteristics on the sire side					
Fraction of yearlings with same sire in same auction	Fraction of yearlings with same sire supplied within same auction sale, as a percentage of total yearlings in the same auction event	0.027	0.040	0	0.5
Sibling price on the dam side					
Average price of siblings from dam	Average price of siblings from dam from 2010 January to the auction date measured in thousand dollars	44.4	120.6	0	2,400
No sibling prices from dam	Indicator for yearling with no sibling prices recorded on mother's side	0.420	0.494	0	1
Sibling price on the sire side					
Average price of siblings from sire	Average price of siblings from sire from 2010 January to the auction date measured in thousand dollars	56.7	51.6	0	273.7
No sibling prices from sire	Indicator for yearling with no sibling prices recorded on father's side	0.032	0.176	0	1

Note: The sample size is 1,835. The variables, sale price, sire age, dam age and stud fee are logged in estimation. The variables, races won by sire, races won by dam and number of winning siblings are logged after adding one to each variable to avoid undefined ln(0). The variable, the fraction of yearlings with the same sire in same auction is logged after adding one to both its numerator and denominator to avoid ln(0).

The auctions conducted by Inglis are standard English auctions, typical of horse sales around the world. Lots are offered successively, all bids are public bids, and bidding proceeds in an ascending order. Subject to reaching the seller's reserve price, the buyer who registers the highest bid makes the purchase. The mean sale price for the yearlings in our main sample is $93,114. Table 2provides a list of the auction events and their shares in the sample. Aside from signature sales events such as the Easter Yearling Sale, for which many buyers and racing enthusiasts come from all over the world, Inglis also runs a variety of smaller sales events in which fewer horses are offered for sale and fewer buyers attend. As such, the minimum sale price observed in the sample is $400 and the maximum sale price is $2,200,000.

4.2. Empirical specification

Various functional forms in the estimation of hedonic price functions have been used in the literature, ranging from simple linear regression shown in Equation 2 to semi-log, log-linear, and quadratic models. The distribution of yearling prices in our sample has relatively high positive skewness. Taking the log of sale price not only allows for simpler interpretation of results but also makes the distribution of the dependent variable close to a normal

Table 2 List of auction events

Auction event	Share of sample (%)
2014 Classic Yearling Sale Summer Book*	12.37
2014 Melbourne Premier Yearling Sale*	15.75
2014 Autumn Thoroughbred Sale	0.27
2014 March Thoroughbred Sale	0.44
2014 Australian Easter Yearling Sale*	10.90
2014 Melbourne Victorian Owners and Breeders Incentive Scheme Gold Yearling Sale	7.52
2014 Scone Thoroughbred Sale	0.11
2014 Scone Select Yearling Sale	4.63
2014 Winter Thoroughbred Sale	0.22
2014 Classic Yearling Sale Winter Book	3.16
2014 Great Southern Sale	0.27
2014 Spring Thoroughbred Sale	0.22
2014 August Thoroughbred Sale	0.11
2014 The Star Ready2Race Sale	0.60
2014 Summer Thoroughbred Sale	0.11
2014 December Thoroughbred Sale	0.11
2015 Classic Yearling Sale Summer Book*	13.19
2015 Melbourne Premier Yearling Sale*	17.17
2015 Autumn Thoroughbred Sale	0.38
2015 March Thoroughbred Sale	0.11
2015 Australian Easter Yearling Sale*	12.37

Note: The star (*) marked events are 'premier' auction events. Auction events are listed in chronological order. The sample size is 1,835.

distribution. We therefore specify a model as follows. The dependent variable is the natural log of the sale price of a yearling. The explanatory variables include the characteristics of the yearling, the characteristics of the yearling's parents, the characteristics of the yearling's siblings, and other control variables such as seller and buyer characteristics and an auction event type indicator.

$$\ln Price = \alpha + Yearling'\beta + Father'\gamma + Mother'\delta + Sibling'\lambda + Control'\eta + \varepsilon. \tag{3}$$

Halvorsen and Pollakowski (1981) introduce a formal way of statistically testing for the validity of the choice of the functional form, while Rasmussen and Zuehlke (1990) find the quadratic semi-log model is a useful alternative to the linear specification. When two functional forms are non-nested with each other, Halvorsen and Pollakowski (1981) suggest the use of a non-nested testing procedure. Following Ng *et al*. (2013), we perform the *J*-test and Cox-Pesaran-Deaton test and find that using the natural log of the following quantitative explanatory variables is favourable: yearling age, sire age, number of races won by sire, stud fee, dam age, number of races won by dam, number of winning siblings by the same mother, and fraction of yearlings from the same sire in the same auction.[6]

Our models contain a set of new explanatory variables in addition to those tested in past studies in Australia: the log of sire's stud fee; sibling prices; and sire/dam race rank. We explain the various variables used in more detail in the next section. Using a number of specifications that vary in the explanatory variables included, we examine the influences of these factors on a yearling's sale price, as well as how these factors are interrelated in the pricing of yearlings.[7]

[6] When we put a semi-log model where all independent variables are not logged as a null hypothesis and the model where the above-mentioned independent variables are logged as an alternative, both the *J*-test and Cox-Pesaran-Deaton test show that the *P*-value is < 0.01. When we switch the null and alternative hypotheses, both tests show that the *P*-value is > 0.36. Therefore, using the logarithm of the selected variables is more favourable. In addition, this log-log model has the maximised likelihood value closer to that of the unrestricted Box-Cox model, compared to the level-level model (Halvorsen and Pollakowski 1981; Rasmussen and Zuehlke 1990).

[7] There are a total of 120 sires in our main sample. Approximately 20 per cent of the observations came from sires with no more than five yearlings in the sample. The stud fees of only seven sires change over time (from 2014 to 2015), and 289 yearlings (out of 1835) are from these sires. Given this large number of sires and the lack of variation in the key variables that we are interested in, we do not control for sire fixed effects in our preferred specifications. In unreported results from the analysis with the sire fixed effects, we find that the coefficient estimates of the other key variables (that vary within a sire) are similar to our main results.

4.3. Key variables

In this section, we describe the variables used and the expected relationship between sale price and each of the key explanatory variables.

4.3.1. Yearling characteristics

The yearling's individual characteristics: age; colour; and sex are taken from the sales results published by Inglis following the auction. A yearling's colour is specified as bay, brown, black, chestnut, grey, or mixed. The inclusion of colour dummies controls for any systematic preference of buyers towards colour. All of our models include the log of yearling's age. The age of a yearling, measured in the fraction of years from the date of birth to the auction date, is likely to influence its sale price. More mature yearlings can be expected to command a higher price at auction, given that they are closer to the age ready for training and racing, as compared to younger horses. The yearling's sex is expected to be a significant price determinant, as purses in races not restricted to gender are typically higher than purses in races for fillies only. On the other hand, female yearlings may have more significant residual breeding value than males, as males have to be top class performers to be stallion prospects. We do not include the yearling's conformation because there is no clear way to assess conformation and assessment of conformation is highly subjective.

4.3.2. Sire and dam characteristics

We use the Horse Search database owned by Australian Associated Press (AAP) Megaform, the racing division of AAP, to obtain data on the race results and age of a yearling's sire and dam in years at the time of sale.[8] We construct the sire and dam variables for average race rank, log of number of wins, and an indicator for whether a dam has raced but never won. Specifically, the average race rank is calculated in the following way. For each race, we divide the horse's rank position by the number of horses that competed in the race. We then average these ratios over all the races in which the horse competed.

Sire quality is also measured in the existing literature using an indicator variable for whether it is Derby-eligible (Chezum and Wimmer 1997; Ng *et al*. 2013). Derby eligibility is determined by two commonly used quantitative measures of performance – the dosage index (DI) and centre of distribution (CD) – which are calculated based on the horse's pedigree. These measures, created by Roman (1981), provide a horse's predicted ability to negotiate the various distances at which horse races are run. We obtain these measures from Pedigree Online Thoroughbred Database (www.pedigreequery.com). Low scores, specifically a DI below 4.00 and

[8] AAP Megaform Horse Search Database, Australian Associated Press (2015).

CD below 1.25, suggest that the horse is more suited to longer distances, typical of high stakes races, and thus would be Derby-eligible. We include a dummy variable that equals 1 if a yearling's sire is Derby-eligible according to these criteria for DI and CD. We note that being Derby-eligible does not imply that the horse was actually nominated for a Derby race. The usefulness of these three measures has been questioned throughout history as racehorses often defy the predictions that DI attempts to make; namely that a horse with a DI above 4.00 is highly unlikely to win the Kentucky Derby.

We also construct a dummy variable 'champion sire' to indicate whether a yearling's sire has been awarded the title of "Horse of the Year" or been named in the top three "Leading Sires". Having this variable ensures that the model is comparable to that in Ng *et al*. (2013). We construct an equivalent variable for dams to indicate whether a dam has been given the title of "Horse of the Year". As none of the dams in the sample have such a title, this variable has no bearing on the results.

4.3.3. Stud fees

We are particularly interested in the relative role of stud fees to various attributes of the yearlings in influencing their sale prices. Existing hedonic pricing studies for the Australian thoroughbred yearling market did not consider stud fees, while most of the US and UK studies include the stud fee as a measure of sire quality (Chezum and Wimmer 1997; Robbins and Kennedy 2001; Vickner and Koch 2001; Maynard *et al*. 2007). We collect the sale-year stud fee information from Racing NSW and www.stallions.com.au. In a few cases for which the sire's stud fee information is unavailable, we were able to ascertain any undisclosed fees from a bloodstock agent in the industry. We then include the log of sale-year stud fees in our hedonic pricing models.

The sire's sale-year stud fee reflects the current market valuation of a stallion's ability to produce successful racehorses and can serve as a useful proxy for sire quality. Stallions with a good track record are highly sought after for breeding and thus will command higher stud fees. Since not all quality measures of a sire are observed, the sire's stud fee is likely to contain information about its unobserved quality. We therefore expect stud fees to provide more information about a yearling's sale price than observable sire characteristics alone.

The quality of a sire's progeny is also likely to depend on the mare with which the sire is mated. Breeders are likely to selectively match a sire with various mares to produce foals. Given this selective breeding practice, we would expect the sire's stud fee, which captures the market valuation of its producing quality, to be correlated with its observable characteristics as well as the quality of its existing progeny (with various mares it was mated with in the past).[9]

4.3.4. Sibling characteristics

This study also includes the performance of yearlings' siblings as explanatory variables. The track record of siblings, in addition to that of parents, helps buyers to infer the potential of a yearling. Following Ng *et al.* (2013), we include characteristics of siblings on the dam side. These data are sourced from the sales catalogues published by Inglis. One of the variables is a dummy indicating whether a yearling is the first foal of its mother. We expect the average sale price of a first foal to be lower for two reasons. First, buyers face more uncertainty for a first foal as they can only infer the potential of the yearling based on the sire and dam's track record. Second, the first foal of a dam tends to be smaller (Elliott *et al.* 2009). We further include an additional dummy variable that indicates whether a yearling is within the first five foals of its mother because Inglis states on its website that statistically the best quality yearlings come from the first five foals of a dam.[10]

For those yearlings that have siblings by the same mother, our analysis includes the log of the number of winning siblings, regardless of the number of wins. Lastly, we include the log of the number of yearlings by the same father as a percentage of total yearlings in the same auction event. It is possible that yearlings may receive more publicity throughout the auction when there are more of them from a particular stallion and this greater exposure can lead to a higher price (Poerwanto and Stowe 2010; Ng *et al.* 2013). Alternatively, sale price may be diluted when more yearlings from a particular stallion are present in an auction event.[11]

4.3.5. Sibling prices

A novelty of this study is that we incorporate the average prices of a yearling's siblings on the dam and sire sides as additional measures in the hedonic price equation. The inclusion of the prices of siblings is an important addition to the hedonic pricing analysis but has been overlooked in the existing literature. Breeders often use sibling prices to encourage broodmare owners to breed to their stallions, or to promote stock bred from parents with high-priced progeny. As such, average sibling prices may have a high level of

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[9] The producing quality of a sire can also be captured by the ratio of the Average Earnings Index (AEI) to Comparable Index (CI) commonly reported in the United States. AEI measures the earning power of a sire's progeny by comparing the average earnings of the sire's progeny with all other runners of the same age, which raced in the same country during a given year. CI indicates the producing quality of the mares bred to a stallion, as it measures the average earnings of progeny produced from the annual book of mares bred to a sire, when those same dams were bred to other sires. A high AEI-to-CI ratio means that the sire's colts and fillies are outperforming their dams' other foals (half-siblings). We focus on stud fees as we do not have measures of AEI and CI.

[10] https://inglis.com.au/pedigrees-how-do-i-read-it/.

[11] We thank a referee for suggesting this point.

information about the quality of a yearling. Moreover, because the average sibling price commanded by a sire's progeny captures both the sire's quality and the quality of mares with which the sire was mated previously, it is likely to have a significant correlation with the sire's observable characteristics as well as the sire's stud fee. If a stallion's progeny have attracted relatively high prices in previous auctions and thus the stallion is shown to produce high quality foals, its stud fee may increase due to increased demand.

We also expect the average prices of siblings on the dam side to provide information about the sale price of a yearling. However, we do not expect the inclusion of the average price of siblings on the dam side to influence the estimated effect of stud fees on the sale price of a yearling, because these siblings capture the progeny of the yearling's dam from mating with mostly different sires.

The data related to sibling prices are constructed in the following ways. First, we use data from auction events by Inglis dated back to January 2010, excluding the current and future auction events. Note that auction events in different auction houses are excluded. Therefore, we consider all siblings sold at Inglis since 2010, but prior to the current auction event. These siblings may include siblings that were not yearlings when sold. We then calculate the average sale prices of siblings on the sire side and dam side, separately. For a few sires and dams in the sample where none of their progeny have been sold previously, a dummy variable is constructed to account for those yearlings with missing sibling prices. Because we use only the previous sale data from Inglis, we admit that the average sibling prices are measured with error. However, given that Inglis is the largest auction house in Australia and that we only consider domestic sires and dams, the concern about measurement error is minimised.

4.3.6. Buyer and seller characteristics

This study also incorporates the works of Chezum and Wimmer (1997) and Vickner and Koch (2001) who conduct a test for adverse selection by separating sellers into racers and breeders, although there is a deficiency in our data for the test. The listed vendors at auction events are sometimes an agent acting on behalf of the yearling's owner. This agent, generally a thoroughbred breeding business that deals with raising and preparing horses for sale, is employed by the owner to carry out such tasks and is listed as an agent acting on behalf of the owner.

In order to get an idea of the existence of adverse selection, we separate the listed vendors into racers and nonracing breeders, and account for the differences across racer types by constructing a variable indicating whether a racer is a stud farm that operates a racing syndicate in its name. A racing syndicate is made up of a group of people who own a percentage of a horse and share the costs and earnings involved in racing. For the vendors that are not studs, we ascertain whether they are involved in racing and create a dummy variable accordingly. We construct two variables, racer and racing syndicate, mainly by searching vendors or their agents from the race records in AAP Megaform, which lists the identity of owners of all horses raced and whether a particular owner is a racing syndicate. In a few cases where the vendors' racing status is ambiguous, we consulted bloodstock agents to ensure their status. Chezum and Wimmer (1997) construct a similar dummy variable to account for the intensity with which sellers who race are involved in racing in order to test whether those who are more heavily involved in racing command lower prices at auction. Vickner and Koch (2001) also include the adverse selection variable but do not find any statistically significant results. Although the racer variable we include is not as extensive as the one by Chezum and Wimmer (1997) or Vickner and Koch (2001), we take into consideration the subtle differences across racer types that previous studies have not discussed.

Lastly, we also include an indicator for whether the buyer is a foreigner or not, as foreign buyers may have different valuations. We construct the indicator using the purchaser location in the data. If a buyer of a yearling is not located in Australia, the variable takes a value of one and zero otherwise.

4.3.7. Auction events

In each year, Inglis runs the William Inglis Yearling Sale Series which consists of five auction events: Australian Easter Yearling Sales; Melbourne Premier Yearling Sales; Scone Select Yearling Sale; and Classic Yearling Sale Summer and Winter. These events are specific to yearlings. In addition, the Melbourne Victorian Owners & Breeders Incentive Scheme (VOBIS) Gold Yearling Sale is run annually by Inglis under the VOBIS which encourages investment in the Victorian breeding industry and rewards owners and breeders who invest in Victorian bloodstock. Only yearlings with high quality sires that were nominated to the VOBIS Sires program can be listed in the sale event. A total of nine auction events are in this category in our data. The other 12 auction events such as Winter Thoroughbred Sale are not restricted to yearlings, and hence, horses of all ages can be listed, except for the Star Ready2Race Sale which mostly focuses on horses between 2 and 3 years old. The relative fraction of yearlings among all horses listed in each of these auctions is low.

To control for the systematic differences between auctions, we include a dummy variable for 'premier' auction events. We classify six premier events: Classic Yearling Sale Summer Book; Melbourne Premier Yearling Sale; and Australian Easter Yearling Sale, in 2014 and 2015. Because we have 21 auctions from January 2014 to April 2015, we also include a dummy variable that takes a value of one if a yearling is sold in 2015 and zero otherwise. Given that we have 16 months of sales data, some annual events appear twice (once in 2014 and once in 2015). In Section 4.2, we restrict our sample to yearlings sold only in 2014 to examine the robustness of our analysis.

5. Results

We estimate a number of hedonic pricing models to obtain the hedonic prices of various yearling attributes and examine the relative role of the stud fee compared to that of sire characteristics in the price determination of a yearling. We also estimate specifications that include the average sale price of siblings on each side of the parents. These models allow us to examine whether the effect of stud fees on the price of a yearling is interrelated with sire characteristics as well as the quality of progeny of the sire. The analysis helps us identify whether the matching of sires and mares in the breeding market has consequential effects on the price of a yearling through the stud fee and prices of progeny. Table 3 reports the results.

The first column provides the results for the model in which yearling, sire, dam, buyer, and seller characteristics are included. Column (2) presents the results for the model that includes stud fees but not sire characteristics to see whether stud fees provide more information about sale price than sire characteristics. The model shown in the third column includes both stud fees and sire characteristics to examine whether the information provided by stud fees and sire characteristics fully overlap. Column (4) shows the results for the model that includes sibling characteristics but not average sibling prices on both the dam and sire sides. Columns (5) and (6) present the results for the models that include average prices of siblings on the dam side and sire side, respectively. The results in the last two columns show whether stud fees could capture some information related to the effect on yearling prices of how sires and dams are matched to produce quality yearlings. The premier auction and sale-year dummy variables are included in all six models.

5.1. Yearling characteristics

The regression results for all six models show that an older yearling, being one that is closer to 2 years old and therefore is nearer to racing age and associated with a higher sale price. A female yearling is estimated to command a lower price than its male counterpart. The result in column (1) reflects that brown yearlings might command lower prices than chestnut yearlings (the omitted colour category) on average, but generally it appears that colour does not significantly affect the price of a yearling (columns (2) to (6)). Since column (1) omits a large number of important variables and the estimates are sensitive to the inclusion of additional explanatory variables, the specification used for column (1) and other previous papers using such an approach are likely to produce biased and inconsistent estimates.

5.2. Sire characteristics and stud fees

Aside from yearling-specific characteristics, our results confirm that the price of a yearling is heavily influenced by its bloodline. In this section, we

Table 3 Regression of ln(Price) on selected explanatory variables

	(1)	(2)	(3)	(4)	(5)	(6)
Yearling characteristics						
Log of yearling age	4.374*** (0.324)	3.913*** (0.301)	3.830*** (0.302)	3.866*** (0.307)	3.738*** (0.308)	3.552*** (0.310)
Female	−0.271*** (0.044)	−0.297*** (0.042)	−0.305*** (0.042)	−0.307*** (0.041)	−0.304*** (0.041)	−0.310*** (0.041)
Bay in colour	−0.012 (0.058)	0.005 (0.055)	−0.015 (0.056)	0.001 (0.055)	−0.000 (0.055)	−0.022 (0.054)
Brown in colour	−0.210*** (0.082)	−0.106 (0.076)	−0.127 (0.077)	−0.113 (0.076)	−0.109 (0.076)	−0.122 (0.075)
Black in colour	−0.070 (0.212)	0.176 (0.152)	0.172 (0.164)	0.133 (0.178)	0.156 (0.196)	0.218 (0.220)
Grey in colour	−0.105 (0.171)	0.130 (0.153)	0.114 (0.150)	0.120 (0.154)	0.114 (0.153)	0.106 (0.153)
Mixed colour	−0.042 (0.088)	−0.011 (0.083)	−0.031 (0.084)	−0.013 (0.083)	−0.019 (0.083)	−0.037 (0.082)
Sire characteristics						
Log of sire age	−0.430*** (0.080)		−0.276*** (0.076)	−0.296*** (0.077)	−0.296*** (0.077)	−0.317*** (0.079)
Log of number of races won by sire	0.037 (0.062)		−0.146** (0.060)	−0.143** (0.059)	−0.144** (0.059)	−0.063 (0.060)
Champion sire	1.065*** (0.073)		0.276*** (0.087)	0.289*** (0.087)	0.258*** (0.087)	0.120 (0.094)
Dosage Index	0.044 (0.028)		0.041 (0.027)	0.049* (0.027)	0.048* (0.027)	0.050* (0.027)
Centre of Distribution	0.241 (0.148)		0.176 (0.139)	0.163 (0.138)	0.179 (0.137)	0.192 (0.138)
Derby-eligible	0.435*** (0.139)		0.087 (0.135)	0.123 (0.133)	0.124 (0.133)	0.166 (0.133)
Sire’s average race rank	−0.896*** (0.305)		0.036 (0.298)	0.091 (0.290)	0.118 (0.289)	0.391 (0.291)
Stud fee						
Log of stud fee		0.579*** (0.025)	0.567*** (0.036)	0.577*** (0.037)	0.570*** (0.037)	0.488*** (0.040)
Dam characteristics						
Log of dam age	0.165** (0.071)	0.224*** (0.066)	0.221*** (0.066)	−0.234* (0.119)	−0.233** (0.119)	−0.222* (0.118)
Log of number of races won by dam	0.030 (0.055)	0.000 (0.051)	−0.004 (0.051)	0.046 (0.052)	0.036 (0.052)	0.028 (0.052)
Dam raced but never won	−0.148* (0.084)	−0.156** (0.079)	−0.151* (0.079)	−0.116 (0.079)	−0.117 (0.079)	−0.122 (0.078)
Dam’s average race rank	−0.070 (0.098)	−0.031 (0.092)	−0.023 (0.092)	0.014 (0.091)	0.020 (0.091)	0.031 (0.090)
Buyer characteristics						
Foreign buyer	0.491*** (0.057)	0.459*** (0.054)	0.441*** (0.054)	0.430*** (0.053)	0.411*** (0.053)	0.402*** (0.053)
Vendor characteristics						
Racer	−0.107 (0.215)	0.042 (0.198)	0.005 (0.197)	0.005 (0.195)	0.007 (0.195)	0.017 (0.195)
Racing syndicate	0.288 (0.214)	0.114 (0.197)	0.154 (0.197)	0.147 (0.194)	0.133 (0.194)	0.111 (0.194)

Table 3 (*Continued*)

	(1)	(2)	(3)	(4)	(5)	(6)
Sibling characteristics on the dam side						
If a dam has a winning son/daughter				−0.006 (0.094)	0.005 (0.093)	0.010 (0.093)
First foal				−0.203*** (0.070)	−0.196*** (0.075)	−0.188** (0.075)
Within five foals				0.231*** (0.073)	0.221*** (0.073)	0.224*** (0.073)
Log of number of winning siblings by same mother				0.332*** (0.090)	0.310*** (0.089)	0.307*** (0.089)
Sibling characteristics on the sire side						
Log fraction of yearlings from same sire in same auction				−0.046* (0.026)	−0.053** (0.026)	−0.070*** (0.026)
Sibling price on the dam side						
Average price of siblings from dam (000's)					0.001*** (0.000)	0.001*** (0.000)
If no average sibling price recorded for dam					0.048 (0.051)	0.049 (0.051)
Sibling price on the sire side						
Average price of siblings from sire (000's)						0.003*** (0.001)
If no average sibling price recorded for sire						−0.113 (0.118)
Fixed effects						
Premier auction event	2.546*** (0.086)	2.241*** (0.086)	2.205*** (0.085)	2.152*** (0.086)	2.124*** (0.086)	2.104*** (0.086)
Auction is in year 2015	0.069 (0.046)	0.025 (0.043)	0.044 (0.043)	0.035 (0.043)	0.038 (0.043)	0.026 (0.043)
Constant	6.851*** (0.420)	0.936*** (0.311)	1.705*** (0.526)	2.109*** (0.579)	2.182*** (0.577)	2.658*** (0.579)
Observations	1,835	1,835	1,835	1,835	1,835	1,835
Adjusted R^2	0.598	0.642	0.647	0.656	0.660	0.664
Akaike information criterion	4,957.5	4,742.0	4,720.2	4,676.3	4,660.5	4,640.3

Note: $^{*}P < 0.10$; $^{**}P < 0.05$; $^{***}P < 0.01$. Robust standard errors in parentheses.

investigate the price effects of stud fees and sire characteristics and examine the amount of information that stud fees and sire characteristics have in explaining the price variation of yearlings.

Column (1) shows that the age of a sire is significant and negatively associated with the price of its yearling, indicating buyers prefer yearlings with a younger sire. The effect of the number of races won by a sire on the price of a yearling is not statistically different from zero. As expected, a yearling from a 'champion' sire – one that has carried the Horse of the Year title or been named in the first three of Leading Sires – commands a higher price at auction. The DI of sires has a positive and marginally significant effect on a yearling's sale price in columns (4)-(6), whereas the CD of sires has no significant effect on the sale price of a yearling. The positive effect of DI on a yearling's sale price is somewhat surprising given that low values of DI signify a horse's ability to perform well over long distances, which is most common for high stakes races. However, given that the average DI in the sample is 2.55, and over 90 per cent of sires lie within the desirable range of 0-4, the positive correlation between DI and price is not unreasonable. While it is desirable to have a DI below 4, a low figure indicates that the horse lacks speed. An additional explanation may be that while horses with a higher DI have less proclivity for the classic distance races, they may be speedier horses that can race sooner and hence yield a more timely return on investment for their owners. As expected, a yearling from a Derby-eligible sire commands a higher sale price on average, based on column (1). Similarly, a yearling from a sire with a lower average rank (i.e. better rank) commands a higher sale price on average.

Previous hedonic studies on the Australian thoroughbred yearling market have not included stud fees in the regression. Column (2) reports the model in which we include stud fees but exclude the sire characteristics. When we consider the model fit between the models in columns (1) and (2), we find that the model in column (2) has a higher explanatory power for the price of yearlings than the model in column (1). Stud fees seem to explain a significant portion of the variation in prices (Chezum and Wimmer 1997; Vickner and Koch 2001). The adjusted R^2 for the model in column (2) is 0.642, while the adjusted R^2 for the model in column (1) is only 0.598. The conclusion remains the same when we use the Akaike information criterion (AIC) as an alternative model selection criterion. This result indicates that the stud fee alone, compared to the observed sire characteristics, has more information about how sires' attributes are capitalised into the price of a yearling. The stud fee should reflect the market valuation of the quality of a sire in producing valuable foals. Some of this quality is captured by attributes unobserved by researchers but observed by participants in the market. As the sire's stud fee captures these unobserved attributes, it is reasonable to see that the stud fee alone has more information about the price of a yearling than the sire's attributes that we include in the model.

Next, we compare the models in columns (2) and (3), where the model in column (3) includes both the sire characteristics and stud fees. We use the *F*-test to examine whether all the sire characteristics are jointly significant after estimating the model in column (3). The calculated value of the *F*-statistic is 5.96 with the *P*-value <0.01. We therefore reject the null hypothesis that they are jointly insignificant. We also find that sire age, the number of races won by sire, champion sire, and DI are individually significant. These results indicate that the observed characteristics of a sire have additional information about a yearling's quality that buyers incorporated into their valuation.[12]

The results reported in columns (2)-(6) also show that stud fees are positively related to the sale price of a yearling. Using the results from the specification in column (6), we compute the marginal value of stud fees, which suggests that for a 10 per cent increase in stud fees, the sale price of a yearling increases by approximately 4.9 per cent, with a 95 per cent confidence interval of 4.1-5.7 per cent. In dollar terms, for an increase in stud fees of $3,327, the yearling's sale price is expected to increase by between $3,817 and $5,307 (or $4,562 on average). This result suggests that the marginal benefit of breeding foals out of expensive stallions is slightly higher than the marginal cost.

After controlling for stud fees, the number of races won by a sire is negative and significant in most specifications, for example, columns (3)-(5). This result is somewhat unexpected but is likely due to multicollinearity. Holding stud fees constant, we are essentially holding constant the proxy for the quality of sires in these regressions. Consider two sires with the same quality, yet one of them wins more races than the other. The one winning more must arguably be running lower quality (i.e. easier to win) races. The marginal value of the race won is lower and translates into a lower valuation in the price of yearlings. Otherwise, the yearlings from the winners of low quality races are overpriced. This point is strengthened by the observation that as we further control for correlates of the unobserved quality of sires (e.g. the sibling price from the same sire), the coefficient for the number of races won becomes more negative.

5.3. Dam characteristics

The age of a dam is significant and negatively associated with the price of a yearling after we control for sibling characteristics in columns (4)-(6). This result indicates that buyers prefer yearlings from younger dams. Older dams have a larger negative influence on price, which may be explained by the importance of good physical condition in mating and gestation. It may also be that older mares are less active and thus their foals do not get as much exercise when they are young, which is important for the development of

[12] These results do not change even if we control for additional variables such as buyer and vendor characteristics, as well as characteristics and prices of siblings.

strong bones. A dam's track record has no significant bearing on the price of its yearling, after we control for the yearling's sibling characteristics.

5.4. Sibling characteristics

We include the characteristics of siblings on the dam side in the models shown in columns (4)-(6). These sibling characteristics seem to be influential. Yearlings that are the first foal of their dam command lower prices, consistent with the idea that buyers face greater uncertainty about yearlings with no siblings, and that the first foal of a dam tends to be smaller. We also find that if a yearling is within the first five foals of its mother, the yearling's price increases significantly on average. This result is consistent with the claim by Finocchio (1986) and Barron (1995) that the best quality yearlings come from the first five foals of a dam.[13]

The number of winning siblings a yearling has from the dam's side is associated with a higher yearling price, as one would expect, given that buyers are better able to make inferences of that yearling's potential. Therefore, sibling performance turns out to be an important reference for buyers. We find that the fraction of yearlings in a particular sale with the same sire, measured as a percentage of total yearlings in the same auction event, has a negative effect on the price of a yearling, while Poerwanto and Stowe (2010) and Ng *et al*. (2013) find that prices of yearlings by sires with greater representation at the sales are higher.

5.5. Sibling price

We include previously untested variables related to the average price of a yearling's siblings on the dam side in column (5). The estimate shows that the average price of siblings on the dam side is positively correlated with the sale price of a yearling. The estimated price effect of stud fees (0.570) in column (5) is almost identical to the estimated price effect of stud fees (0.577) in column (4), meaning that there is no association between the sire's stud fees and the quality of the dam's progeny with other sires in terms of explaining yearling prices. This result indicates that stallion owners are unable to capitalise the quality of dam's progeny by charging higher stud fees. This result is not surprising because a sire's stud fee should only capture the quality of the sire and not the quality of the dam.

The estimated effect of the average sibling price on the sire side is three times the estimated effect of the average sibling price on the dam side. The estimated price effect of the sire's stud fees changes from 0.570 in column (5) to 0.488 in column (6). This result indicates that stud fees are highly correlated with the quality of a sire's progeny with other mares with which the sire previously mated and that sire owners capitalise this quality by

[13] We thank anonymous referees for making suggestions on the use of yearlings' birth order.

charging higher stud fees. This result is not surprising because a sire's progeny with other mares contains information about the quality of the sire in producing valuable foals, which is reflected in the stud fees charged. Thus, the stud fee that the owner of a sire charges captures not only the value directly generated by the sire's characteristics but also the value indirectly generated by the different dams with which the sire has been matched by breeders in the thoroughbred market.

5.6. Other variables

The results in all six columns indicate that foreign buyers pay a premium of over 40 per cent on yearlings at auction as compared to domestic buyers. The significant price difference possibly explains differences in the valuations of foreign buyers. This result is consistent with the Alchian-Allen theorem (Alchian and Allen 1964) that Eid *et al*. (2013) offer as an explanation. Eid *et al*. (2013) argue that any pricing estimation model would have unobservables observed by actual buyers. Foreign buyers have to incur export costs (e.g. shipping, quarantine and insurance costs) that are potentially not sensitive to the quality of a yearling. According to the Alchian-Allen theorem, the relative price of high quality to low quality horses is lower compared to the relative price faced by local buyers. Therefore, conditional on buying, foreign buyers tend to purchase better quality yearlings and the significant premium they pay captures the unobserved quality of yearlings.

The variable for whether a vendor is involved in racing is not statistically significant in the regression results. The insignificant result is similar to what Vickner and Koch (2001) have found.

Since our data consist of yearlings from different types of auction events in 2014 and 2015, we include premier auction and sale-year dummy variables to control for potential systematic differences across auction events.[14] We find that the premier auction events, such as Melbourne Premier Yearling Sale and Australian Easter Yearling Sale, exhibit a higher average sale price while regular sale events show a lower average sale price. There is no significant difference in sale prices between year 2014 and 2015.

5.7. Goodness of fit

Overall, our estimation results suggest that the addition of important variables significantly improves the model fit, as reflected in the increasing adjusted R^2 value. We include AIC in the results as an alternative measure of the relative quality of the models. While we use these two measures to focus on the goodnes of fit of the model, various other statistics such as the root mean square error can been employed for hedonic price forecasts (Fletcher

[14] We further implement robustness checks by restricting our sample to yearlings that were sold in a single year 2014 in Section 4.2.

et al. 2004; Limsombunchai 2004). Both the adjusted R^2 and AIC enable the identification of an optimal model from a set of competing models examined, taking into account their complexity (Bozdogan 1987). Both measures incorporate a trade-off between the goodness of fit of the model and model complexity, by penalising models that have been overfitted with variables. As expected, the AIC values successively decrease from model (1) to model (3) in which stud fees are included, and the AIC values further decrease from model (4) to model (6) in which sibling prices are included. Likewise, the adjusted R^2 increases as we include stud fees and average sibling prices.[15] These results confirm that the novel key variables that we introduce in this paper are important additions to the model. From these results, we argue that the model in column (6) provides the preferred specification.

6. Robustness checks

6.1. Including passed in yearlings

Our main sample excludes yearlings that were passed in during auction events. One may argue that the highest bid (which is lower than the seller's reserve price) actually reflects a yearling's price. During the sample period, a total of 378 yearlings were passed in, and we have information on the highest bids for 377 yearlings. We include these passed in yearlings in our sample and use the highest bid as the price to re-estimate the various specifications (total sample size is 2,122). Table 4 reports the estimates.

The results are almost identical to those in Table 3. In particular, the effect of stud fees on the price of a yearling is positive and significant. The results suggest that for a 10 per cent increase in stud fees, the sale price of a yearling increases by about 4.8 per cent. This estimate is similar to that reported in Table 3. The ways in which adjusted R^2, AIC and the estimated effect of an attribute on yearling prices change as we include and exclude various attributes of yearlings and stud fees are also similar to those reported in Table 3. Thus, our findings are robust to the exclusion of passed in yearlings.

In this analysis, we include an additional dummy variable that takes a value one if a yearling is passed in and zero otherwise. We find that the average passed in price is significantly lower than the average sale price.

6.2. Restricting the sample to 2014 data

Because our main sample includes 16 months of data, some events show up more than once in our sample. We examine whether our findings are sensitive to the over-representation of certain auction events by restricting the various specifications using only 2014 data. Table 5 reports the results.

[15] While the smaller AIC indicates the better fit, the higher adjusted R^2 means improvement in the model fit.

Table 4 Robustness checks including yearlings passed in

	(1)	(2)	(3)	(4)	(5)	(6)
Yearling characteristics						
Log of yearling age	4.476*** (0.297)	3.956*** (0.277)	3.871*** (0.277)	3.878*** (0.281)	3.721*** (0.281)	3.535*** (0.284)
Female	−0.253*** (0.040)	−0.265*** (0.038)	−0.279*** (0.037)	−0.282*** (0.037)	−0.280*** (0.037)	−0.282*** (0.036)
Bay in colour	0.006 (0.052)	0.016 (0.049)	0.002 (0.049)	0.012 (0.049)	0.009 (0.048)	−0.014 (0.048)
Brown in colour	−0.198*** (0.072)	−0.100 (0.068)	−0.115* (0.069)	−0.109 (0.068)	−0.104 (0.067)	−0.119* (0.067)
Black in colour	0.080 (0.223)	0.271* (0.162)	0.293 (0.182)	0.249 (0.191)	0.264 (0.201)	0.298 (0.210)
Grey in colour	−0.099 (0.155)	0.126 (0.139)	0.103 (0.136)	0.106 (0.139)	0.100 (0.139)	0.094 (0.139)
Mixed colour	−0.074 (0.079)	−0.030 (0.075)	−0.047 (0.075)	−0.029 (0.075)	−0.039 (0.074)	−0.055 (0.073)
Sire characteristics						
Log of sire age	−0.438*** (0.072)		−0.283*** (0.068)	−0.305*** (0.069)	−0.304*** (0.068)	−0.311*** (0.071)
Log of number of races won by sire	−0.004 (0.054)		−0.196*** (0.053)	−0.194*** (0.052)	−0.193*** (0.052)	−0.116** (0.053)
Champion sire	1.059*** (0.065)		0.291*** (0.077)	0.305*** (0.077)	0.268*** (0.077)	0.126 (0.082)
Dosage Index	0.039 (0.025)		0.032 (0.023)	0.039* (0.023)	0.039* (0.022)	0.041* (0.023)
Centre of distribution	0.188 (0.130)		0.159 (0.119)	0.150 (0.119)	0.164 (0.118)	0.167 (0.119)
Derby-eligible	0.364*** (0.123)		0.009 (0.118)	0.037 (0.116)	0.041 (0.115)	0.075 (0.116)
Sire's average race rank	−1.069*** (0.269)		−0.192 (0.269)	−0.140 (0.263)	−0.108 (0.261)	0.153 (0.264)
Stud fee						
Log of stud fee		0.571*** (0.023)	0.561*** (0.038)	0.574*** (0.038)	0.567*** (0.038)	0.484*** (0.038)
Dam characteristics						
Log of dam age	0.189*** (0.065)	0.228*** (0.060)	0.229*** (0.059)	−0.233** (0.111)	−0.232** (0.111)	−0.215* (0.110)
Log of number of races won by dam	0.056 (0.050)	0.034 (0.047)	0.030 (0.046)	0.076 (0.047)	0.064 (0.047)	0.055 (0.046)
Dam raced but never won	−0.112 (0.078)	−0.121* (0.073)	−0.109 (0.072)	−0.083 (0.072)	−0.085 (0.072)	−0.091 (0.071)
Dam's average race rank	−0.009 (0.089)	0.046 (0.084)	0.045 (0.083)	0.076 (0.082)	0.080 (0.082)	0.087 (0.081)
Buyer characteristics						
Foreign buyer	0.511*** (0.056)	0.481*** (0.053)	0.461*** (0.053)	0.451*** (0.053)	0.429*** (0.052)	0.421*** (0.052)
Vendor characteristics						
Racer	−0.259 (0.192)	−0.094 (0.180)	−0.142 (0.177)	−0.133 (0.174)	−0.129 (0.174)	−0.130 (0.175)
Racing syndicate	0.400** (0.191)	0.210 (0.179)	0.256 (0.177)	0.243 (0.173)	0.227 (0.173)	0.220 (0.175)

Table 4 (*Continued*)

	(1)	(2)	(3)	(4)	(5)	(6)
Sibling characteristics on the dam side						
If a dam has a winning son/daughter				−0.090 (0.087)	−0.077 (0.087)	−0.072 (0.086)
First foal				−0.201*** (0.064)	−0.194*** (0.068)	−0.183*** (0.067)
Within five foals				0.226*** (0.065)	0.215*** (0.065)	0.214*** (0.065)
Log of number of winning siblings by same mother				0.388*** (0.083)	0.362*** (0.082)	0.354*** (0.081)
Sibling characteristics on the sire side						
Log fraction of yearlings from same sire in same auction				−0.054** (0.024)	−0.060** (0.024)	−0.076*** (0.024)
Sibling price on the dam side						
Average price of siblings from dam (000's)					0.001*** (0.000)	0.001*** (0.000)
If no average sibling price for dam					0.056 (0.046)	0.053 (0.046)
Sibling price on the sire side						
Average price of siblings from sire (000's)						0.003*** (0.001)
If no average sibling price for sire						−0.056 (0.107)
Passed in						
If a yearling is passed in	−0.750*** (0.067)	−0.740*** (0.064)	−0.717*** (0.063)	−0.656*** (0.063)	−0.636*** (0.063)	−0.630*** (0.063)
Fixed effects						
Premier auction events	2.473*** (0.077)	2.173*** (0.078)	2.136*** (0.077)	2.073*** (0.077)	2.041*** (0.077)	2.020*** (0.077)
Auction is in year 2015	0.096** (0.040)	0.058 (0.038)	0.076** (0.038)	0.064* (0.038)	0.064* (0.038)	0.047 (0.038)
Constant	7.009*** (0.369)	0.965*** (0.281)	1.983*** (0.466)	2.406*** (0.524)	2.485*** (0.521)	2.959*** (0.522)
Observations	2,212	2,212	2,212	2,212	2,212	2,212
Adjusted R^2	0.595	0.637	0.644	0.653	0.658	0.662
Akaike information criterion	5,914.9	5,666.9	5,631.2	5,577.8	5,552.2	5,527.4

Note: $*P < 0.10$; $**P < 0.05$; $***P < 0.01$. Robust standard errors in parentheses.

In general, the results reported in Table 5 are similar to the results reported in Table 3. The sign, magnitude, and significance of all the coefficients are similar. The effect of stud fees on the price of a yearling becomes slightly lower. A 10 per cent increase in the stud fee leads to an increase in the sale price of a yearling by approximately 4.5 per cent, based on our preferred specification in column (6). Importantly, our conclusion regarding the role of stud fees, sire characteristics, and the average sibling price on the sire side remains unchanged.

6.3. Including yearlings with foreign parents

Our main sample excludes yearlings with foreign parents because some of the key variables are not available for these observations. We now expand the sample to include yearlings with foreign parents to assess the sensitivity of our findings.

First, we use the sample of yearlings with domestic parents to estimate a specification without sire's average race rank, dam's average race rank, average sibling price on the sire side, and average sibling price on the dam side. The estimates reported in column (1) of Table 6 are similar to those reported in column (5) of Table 3, despite the exclusion of sire's average race rank and dam's average race rank. Having established that the specification reported in column (1) of Table 6 is comparable to the specification reported in column (5) of Table 3, we now check whether our estimates are robust to the inclusion of yearlings with foreign parents. Adding these yearlings with foreign parents, we are able to expand the sample size to 3,156. The estimates reported in column (2) of Table 6 show that most of the estimates are similar to those reported in column (1) of Table 6. Most importantly, the adjusted R^2 and the effect of stud fees on prices of yearlings change marginally.

Second, we use the sample of yearlings with domestic parents to estimate a specification without stud fees, sire's average race rank, dam's average rank race, average sibling price on the sire side, and average sibling price on the dam side. We exclude stud fees from the specification because we can then compare the estimates based on this sample of yearlings with domestic parents with the estimates obtained from the same specification based on the expanded sample that includes all yearlings with foreign parents. We report the results in columns (3) and (4) of Table 6. The adjusted R^2 and most of the estimates in the two specifications are similar. Thus, the exclusion of yearlings with foreign parents does not affect our findings materially.

7. Concluding remarks

In this paper, we use various hedonic pricing models to estimate whether certain attributes of a yearling are associated with a premium or discount at auction. In particular, we investigate the role of stud fees in the price determination of yearlings. We find that a sire's stud fees explain a significant

Table 5 Robustness check using 2014 data only

	(1)	(2)	(3)	(4)	(5)	(6)
Yearling characteristics						
Log of yearling age	4.299*** (0.424)	3.857*** (0.395)	3.747*** (0.394)	3.723*** (0.401)	3.646*** (0.404)	3.485*** (0.403)
Female	−0.298*** (0.061)	−0.316*** (0.058)	−0.327*** (0.058)	−0.315*** (0.056)	−0.312*** (0.056)	−0.318*** (0.056)
Bay in colour	0.021 (0.084)	0.004 (0.082)	−0.004 (0.082)	0.003 (0.080)	0.001 (0.079)	−0.027 (0.078)
Brown in colour	−0.139 (0.112)	−0.086 (0.106)	−0.091 (0.108)	−0.091 (0.103)	−0.090 (0.103)	−0.101 (0.100)
Black in colour	−0.075 (0.227)	0.146 (0.172)	0.141 (0.190)	0.087 (0.222)	0.118 (0.249)	0.248 (0.295)
Grey in colour	−0.153 (0.216)	0.119 (0.196)	0.098 (0.190)	0.113 (0.195)	0.115 (0.197)	0.111 (0.200)
Mixed colour	0.096 (0.119)	0.025 (0.116)	0.027 (0.115)	0.035 (0.115)	0.034 (0.114)	0.010 (0.112)
Sire characteristics						
Log of sire age	−0.386*** (0.112)		−0.227** (0.104)	−0.312*** (0.105)	−0.312*** (0.104)	−0.301*** (0.105)
Log of number of races won by sire	−0.023 (0.080)		−0.212*** (0.078)	−0.206*** (0.075)	−0.205*** (0.075)	−0.099 (0.076)
Champion sire	1.064*** (0.106)		0.316** (0.124)	0.334*** (0.123)	0.298** (0.123)	0.011 (0.138)
Dosage Index	0.028 (0.036)		0.009 (0.034)	0.021 (0.033)	0.022 (0.033)	0.023 (0.033)
Centre of Distribution	0.263 (0.190)		0.332* (0.176)	0.308* (0.174)	0.329* (0.173)	0.386** (0.174)
Derby-eligible	0.299* (0.167)		0.030 (0.158)	0.066 (0.156)	0.076 (0.156)	0.143 (0.156)
Sire's average race rank	−0.778* (0.414)		−0.046 (0.399)	0.121 (0.379)	0.165 (0.378)	0.615 (0.382)
Stud fee						
Log of stud fee		0.559*** (0.036)	0.549*** (0.049)	0.589*** (0.050)	0.582*** (0.050)	0.452*** (0.056)
Dam characteristics						
Log of dam age	0.128 (0.098)	0.210** (0.091)	0.204** (0.091)	−0.354** (0.161)	−0.353** (0.161)	−0.332** (0.157)
Log of number of races won by dam	0.122 (0.078)	0.057 (0.072)	0.056 (0.072)	0.120 (0.074)	0.110 (0.074)	0.106 (0.073)
Dam raced but never won	−0.070 (0.121)	−0.119 (0.113)	−0.112 (0.113)	−0.054 (0.112)	−0.057 (0.112)	−0.053 (0.110)
Dam's average race rank	−0.117 (0.134)	−0.123 (0.128)	−0.099 (0.126)	−0.046 (0.122)	−0.043 (0.122)	−0.021 (0.121)
Buyer characteristics						
Foreign buyer	0.552*** (0.079)	0.528*** (0.075)	0.505*** (0.076)	0.486*** (0.075)	0.463*** (0.075)	0.457*** (0.075)
Vendor characteristics						
Racer	0.001 (0.310)	0.133 (0.282)	0.081 (0.286)	0.111 (0.275)	0.114 (0.275)	0.125 (0.273)
Racing syndicate	0.162 (0.309)	−0.002 (0.282)	0.050 (0.286)	0.022 (0.275)	0.012 (0.275)	−0.018 (0.272)

Table 5 (*Continued*)

	(1)	(2)	(3)	(4)	(5)	(6)
Sibling characteristics on the dam side						
If a dam has a winning son/daughter				0.062 (0.130)	0.058 (0.130)	0.075 (0.129)
First foal				−0.259*** (0.094)	−0.217** (0.103)	−0.197* (0.101)
Within five foals				0.247** (0.105)	0.241** (0.105)	0.231** (0.103)
Log of number of winning siblings by same mother				0.344*** (0.123)	0.325*** (0.123)	0.316*** (0.121)
Sibling characteristics on the sire side						
Log fraction of yearlings from same sire in same auction				−0.128*** (0.035)	−0.131*** (0.035)	−0.146*** (0.035)
Sibling price on the dam side						
Average price of siblings from dam (000's)					0.001*** (0.000)	0.001*** (0.000)
If no average sibling price for dam					−0.035 (0.071)	−0.031 (0.070)
Sibling price on the sire side						
Average price of siblings from sire (000's)						0.005*** (0.001)
If no average sibling price for sire						−0.089 (0.275)
Fixed effects						
Premier auction events	2.498*** (0.098)	2.220*** (0.100)	2.175*** (0.099)	2.082*** (0.099)	2.066*** (0.100)	2.052*** (0.099)
Constant	6.997*** (0.557)	1.193*** (0.431)	1.992*** (0.704)	2.116*** (0.781)	2.194*** (0.782)	2.793*** (0.782)
Observations	1,042	1,042	1,042	1,042	1,042	1,042
Adjusted R^2	0.620	0.658	0.664	0.680	0.682	0.689
Akaike information criterion	2,925.6	2,807.6	2,797.8	2,751.8	2,746.7	2,725.6

Note: $*P < 0.10$; $**P < 0.05$; $***P < 0.01$. Robust standard errors in parentheses.

Table 6 Robustness to sample size reduction

	Model with stud fees		Model without stud fees	
	(1) Domestic	(2) Domestic & foreign	(3) Domestic	(4) Domestic & foreign
Yearling characteristics				
Log of yearling age	3.917*** (0.308)	3.944*** (0.227)	4.505*** (0.330)	4.531*** (0.234)
Female	−0.303*** (0.041)	−0.263*** (0.032)	−0.275*** (0.044)	−0.239*** (0.032)
Bay in colour	−0.005 (0.054)	0.030 (0.043)	−0.025 (0.057)	0.045 (0.043)
Brown in colour	−0.114 (0.075)	0.017 (0.058)	−0.198** (0.080)	0.022 (0.060)
Black in colour	0.137 (0.187)	0.041 (0.198)	−0.101 (0.261)	−0.192 (0.243)
Grey in colour	0.096 (0.150)	0.096 (0.122)	−0.136 (0.172)	0.004 (0.121)
Mixed colour	−0.016 (0.083)	0.093 (0.062)	−0.043 (0.086)	0.125** (0.063)
Sire characteristics				
Log of sire age	−0.295*** (0.077)	−0.164*** (0.055)	−0.373*** (0.084)	−0.032 (0.057)
Log of number of races won by sire	−0.148*** (0.056)	−0.066* (0.039)	0.102* (0.056)	0.156*** (0.038)
Champion sire	0.299*** (0.087)	0.164*** (0.057)	1.023*** (0.078)	0.793*** (0.053)
Dosage Index	0.042 (0.026)	0.068*** (0.022)	0.021 (0.028)	0.049** (0.022)
Centre of Distribution	0.164 (0.136)	−0.067 (0.069)	0.333** (0.147)	−0.005 (0.071)
Derby-eligible	0.098 (0.131)	0.147 (0.107)	0.344** (0.138)	0.349*** (0.110)
Stud fee				
Log of stud fee	0.578*** (0.036)	0.563*** (0.026)		
Dam characteristics				
Log of dam age	−0.252** (0.119)	−0.242** (0.097)	−0.412*** (0.130)	−0.383*** (0.101)
Log of number of races won by dam	0.054 (0.052)	0.136*** (0.031)	0.095* (0.056)	0.191*** (0.032)
Dam raced but never won	−0.110 (0.078)	−0.038 (0.050)	−0.110 (0.083)	−0.036 (0.051)
Buyer characteristics				
Foreign buyer	0.438*** (0.053)	0.394*** (0.039)	0.483*** (0.057)	0.464*** (0.040)

Table 6 (*Continued*)

	Model with stud fees		Model without stud fees	
	(1) Domestic	(2) Domestic & foreign	(3) Domestic	(4) Domestic & foreign
Sibling characteristics on the dam side				
If a dam has a winning son/daughter	0.002 (0.094)	−0.055 (0.069)	0.033 (0.100)	0.027 (0.073)
First foal	−0.206*** (0.070)	−0.134** (0.054)	−0.226*** (0.075)	−0.144*** (0.055)
Within five foals	0.228*** (0.074)	0.246*** (0.057)	0.226*** (0.078)	0.193*** (0.058)
Log of number of winning siblings by same mother	0.331*** (0.089)	0.362*** (0.068)	0.358*** (0.095)	0.330*** (0.070)
Sibling characteristics on the sire side				
Log fraction of siblings from same sire in same auction	−0.043 (0.026)	−0.017 (0.020)	0.070** (0.028)	0.078*** (0.019)
Fixed effects				
Premier auction events	2.162*** (0.086)	2.200*** (0.066)	2.584*** (0.086)	2.679*** (0.061)
Auction is in year 2015	0.038 (0.043)	0.036 (0.032)	0.042 (0.045)	0.050 (0.032)
Constant	2.300*** (0.527)	1.934*** (0.391)	7.649*** (0.456)	6.618*** (0.341)
Observations	1,835	3,156	1,835	3,500
Adjusted R^2	0.655	0.651	0.606	0.604
Akaike information criterion	4,680.3	7,991.3	4,921.4	9,443.8

Note: *$P < 0.10$; **$P < 0.05$; ***$P < 0.01$. Robust standard errors in parentheses.

portion of its yearlings' auction price variation. A 10 per cent or around \$3,300 increase in the stud fee suggests an increase in the sale price of close to 4.9 per cent, or between \$3,817 and \$5,307. In addition, the stud fee alone has more information about the sale price of a yearling than sire characteristics, while their information about the sale price does not fully overlap. We also find that the average prices of a yearling's siblings on both the dam side and the sire side have positive and significant effects on the yearling's sale price at auction. The effect of stud fees on the price of a yearling changes after we include the average prices of siblings on the sire side, but not after we include the average prices of siblings on the dam side. Thus, we find evidence that stud fees capture not only the value directly generated by the sire's characteristics but also the value indirectly generated by the different dams with which the sire has been matched by breeders in the thoroughbred market. Lastly, we find that siblings' race performance influences yearling prices, but we do not find evidence that the addition of parents' average race rank variables and the variable indicating whether the seller is also involved in racing helps explain auction prices of yearlings.

The hedonic pricing models constructed in this analysis can help improve understanding of the viability of the thoroughbred industry. Specifically, the relative role of stud fees and sire and sibling characteristics in explaining the price of a yearling, uncovered in our analysis, indicates that stud fees capture the market valuation of the quality of sire's progeny. An interesting extension of this research could be to use the same type of hedonic pricing approach to examine the performance of yearlings after auction. This extension could alleviate some of the limitations involved in focusing only on sale prices, as buyers are also interested in how racehorses will perform in future.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Sample of catalogue entry from 2014 Inglis Easter Yearling Sale.