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EFFECTS OF MANAGEMENT ON REPRODUCTIVE EFFICIENCY IN THOROUGHBREDS

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THESIS

A thesis submitted in partial fulfillment of the requirements for a degree of Master of Science in the College of Agriculture at the University of Kentucky

By
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Lexington, Kentucky
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ABSTRACT OF THESIS

EFFECTS OF MANAGEMENT ON REPRODUCTIVE EFFICIENCY IN THOROUGHBREDS

Many factors influence the reproductive efficiency of thoroughbred mares. This thesis estimated two separate models for 13 farms in the 2004 breeding season. One model is estimated for pregnancy outcomes, the other is estimated for breeding intervals. Statistically significant variables include age of the mare, number of breedings, certain medications, farm size, last date of breeding for the first model. Statistically significant variables for the second model include age, status of mare, number of breedings, certain medication, and farm size. The model has implication to achieve an optimal breeding schedule and associated management decisions.

KEYWORDS: Equine, Kentucky, Reproductive management, Thoroughbred, Farm management

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CHAPTER I

INTRODUCTION

PROBLEM STATEMENT

In thoroughbred breeding, the main input for breeders is the mare. For breeders it is very important to have a high percentage of the mares foal each year, because of the high maintenance cost of the mares. The estimated economic cost of producing a foal through its sale as a yearling is $85,142 (Thalheimer and Lawrence, 2001). This high cost is partly the result of relatively low (50-70%) live foaling rates. Most thoroughbred breeders depend on the foals for financial health of the breeding operation. In some cases, breeders choose to sell the foals, or they choose to race them. In either case keeping a mare when she is not going to foal in that year is an economic loss. An improvement in reproductive efficiency could significantly lower the average economic cost per foal.

It is also very important that mares foal as early as possible in the year given the nature of age restricted thoroughbred racing. Every thoroughbred foal has an assigned birth date of January 1. At thoroughbred yearling sales buyers seek older yearlings, which had more time to develop, are more mature and are more likely to start their racing career as two year olds. Buyers prefer yearlings that were born before March 6 (Koch, 2002), and yearlings born after that day receive discounts in auctions prices.

The process of breeding begins with selection of mares, and choosing stallions to breed them. During this process, breeders assess the value of their breeding stock, and the potential value of future foals as well. After the mating decisions have been made, the next steps in the process include different management decisions. Based on the owner’s valuation of the future foal, the owner must decide how much they are willing to invest in the mare to ensure a pregnancy and an early foal. With a possibility of a high quality foal, owners might be willing to invest more to reduce the risk of pregnancy loss, and ensure an early foaling date. However, with lower quality mares and stallions, it might not be worth investing a significant amount of money to prevent pregnancy loss.

Faced with these decisions, breeders rely on veterinarians and past experiences. Reproductive efficiency of thoroughbred horses has been researched from a veterinary science standpoint. Research has identified a number of factors that influence reproductive efficiency in horses. These factors include the age and the breeding status of the mare, and stallion's booksize. Today the use of ultrasound as an aid for breeders is widespread, and many products are available on the market to correct reproductive health problems in mares. However, the overall live foal rates have not increased dramatically (Morris and Allen, 2002). The explanation for that could be that all thoroughbred mares have a unique combination of pedigree, racing success and reproductive success. Owners of high quality mares, even if the mare has health problems, might be willing to accept lower reproductive efficiency, if the potential foal can be bring a high price at the sales or potentially win important races.

The empirical objective of this thesis is to model management decisions that influence the outcomes of pregnancies, and breeding interval. McDowell *et al*. (1992) will be revisited to further study the effect of mare age, and stallion book size. Previous studies have reported different findings on the effect of mare status. Therefore I will revisit Morris and Allen, and Bruck *et al*. to reexamine the effect of mare's status. New to this study is the effect of farm size, management, and medication used on mares.

RELEVANCE

The importance of reproductive efficiency in thoroughbreds is evident. Reproductive efficiency is fundamental for the thoroughbred industry, considering the equine industry's economic significance for the United States and particularly for the state of Kentucky. The thoroughbred and equine industry play a significant role in the nation's economy and an even more central role in regional economy. The industry translates into economic value through its generated revenue, and the associated multiplier effects. The economic impact consists of sales revenue, purchase of inputs, employment of labor and taxes.

Quantity of horses in the United States

The United States total equine population was 5.32 million in 1999. The leader in number of horses was Texas with 600,000 head. California and Tennessee with 240,000 and 190,000 head, respectively, held second and third place. Florida, Oklahoma and

Pennsylvania tied for fourth place with 170,000 head each. Ohio was ranked seventh with 160,000 head. Kentucky, Minnesota, New York and Washington shared the eighth place with 155,000 head each. (Kentucky Agricultural Statistic Service, 1999).

Impact of equine industry in Kentucky

The state of Kentucky is a leader in many aspects of the equine industry. There are an estimated 200,000 head of horses in Kentucky. (Kentucky Equine Education Project, 2004). The state's equine population was 155,500 in 1999. That indicates that the equine population in Kentucky is growing, giving even more importance to the equine industry in the states economy.

Many of the industry leading breeding farms, racetracks and auction houses are located in Kentucky. Many prominent farms are located in Central Kentucky. The Keeneland Association and Fasig Tipton, both located in Lexington hold the equine industry most valuable public thoroughbred auctions. Five top racetracks (Keeneland, Churchill Downs, Turfway Park, The Red Mile and Ellis Park) provide year round horseracing schedule.

Kentucky's horse industry also plays a major role in the state's tourism. Tourist attractions such as the Kentucky Horse Park, The Kentucky Derby Museum and The American Saddlebred Museum, and many equine events such as The Kentucky Derby, The Rolex Three-Day Event, and The World Championship Horse Show provide tourist base to the region. The Jockey Club, American Horse Show association, American Association of Equine Practitioners, Association of Racing Commissioners International, Inc., Breeders' Cup Limited, Thoroughbred Owners and Breeders Association, and National Thoroughbred Racing Association each have headquarters or offices in Kentucky (CBER, 1991).

Quantity of Thoroughbreds

Kentucky leads all states by all measures of quantity of thoroughbreds except for number of stallions. In 2003, Kentucky's 8,238 registered thoroughbred foals represented 26.2 percent of the nation's registered thoroughbred foals (The Jockey Club, 2005). Florida and California were second and third with 13.3 and 11.4 percent, respectively, of the nation's 33,820 registered thoroughbred foals in 2003 (The Jockey Club, 2005). In 2004, Kentucky was second in number of active stallions with 354. Only California surpassed Kentucky with 385 stallions. Kentucky led the nation in number of mares bred and average book sizes as well. The importance of Kentucky's thoroughbred breeding can be clearly seen from the number of mares bred. Kentucky is home to 10.8 percent of thoroughbred stallions that bred 34.7 percent of the mares in 2004. Table 1.1 illustrates the top ten states by number of mares bred.

Table 1.1 Top ten states by number of mares bred

State	Number of mares bred	Number of stallions	Average stallion book size
Kentucky	20,046	354	56.6
Florida	6,810	231	29.5
California	5,695	385	14.8
Louisiana	3,149	240	13.1
Texas	2,915	332	8.8
New York	2,621	149	17.6
Maryland	1,587	69	23.0
New Mexico	1,566	156	10.0
Oklahoma	1,519	180	8.4
Washington	1,168	96	12.2

Economic impact of the equine industry

In 1995, the American Horse Council undertook a major study of horse industry in the United States. The study not only established the size of the industry but also established its impact on the national economy. The total impact of the horse industry on US gross domestic product was $112.1 billion, including direct, indirect and induced effects. The direct value of horse-related goods and services was $25.3 billion. The following table shows the horse industry's gross domestic product contribution compared with other industries.

Table 1.2 Gross Domestic product contribution

Apparel and other textile products manufacturing	27.8 billion
Horse production and entertainment services	25.3 billion
Motion picture services	24.8 billion
Furniture and fixtures manufacturing	19.0 billion

The horse industry also generates 1,404,400 full-time equivalent jobs, and there are over 7 million people participate in some activity related to horses. The participants of the horse industry paid a total of $1.9 billion in taxes in 1995. (National Economic Impact Study, 1996) The equine industry is especially important in Kentucky's agricultural economy. In 2001 and 2002, Kentucky's number one agricultural cash crop was the equine industry with over $1 billion in sales, and the economic impact in Kentucky was over $3 billion in 1996. The export of horses generated $127 million in 2002. Only a portion of the horse industry in Kentucky is subject to the 6% sales tax,but stallion fees alone generated $16 million in sales tax in 2001.(Kentucky Equine Education Project, 2005)

The following two tables demonstrate the quantity and value of Thoroughbred horses sold in 2004 in the United States and Keeneland. It is clear from the tables that the Keeneland auction house is the major place for thoroughbred sales. It is also important to note that the quality of horses at Kentucky auctions is higher than other auctions. While 37.5% of all thoroughbred sold in 2004 were sold at Keeneland, they represented almost 65% of the value of all thoroughbreds sold.

Table 1.3 2004 Sales results for Thoroughbred horses in the United States

Type of horse	Number Sold	Gross Sales	Average Price	Percent Change 1994-2004
Weanlings	1,952	$71,730,989	$36,747	+68.5
Yearlings	9,412	$497,153,983	$52,821	+93.5
2-Year-Olds	3,012	$175,347,558	$58,216	+124.3
Broodmares	4,813	$264,990,875	$55,057	+116.6
Horses of Racing Age & Broodmare Prospects	1,015	$44,610,404		
Stallions & Stallion Shares or Seasons	86	$1,298,410		
Total	20,290	$1,055,132,219		

(Jockey Club Fact Book, 2005)

Table 1.4 2004 Sales results for Keeneland auction house

Type of horse	Number sold	Gross Sales	Average Price
Weanlings	1,127	$59,211,900	$52,539
Yearlings	3,787	$336,770,300	$88,928
2-Year-Olds	108	$24,037,000	$222,565
Broodmares	2,503	$256,029,700	$102,289
Horses of Racing Age & Broodmare Prospects	84	$1,927,500	$22,946
Total	7,609	$677,876,400	

(Keeneland web site, 2005)

As can be seen from the tables, over the past ten years the average prices greatly increased at thoroughbred auctions. The Keeneland auction house not only sold over third of thoroughbred horses offered at public auctions in 2004, but also surpassed some of its own previous records. The highest price ever paid for a yearling at the Keeneland September Yearling Sale was $8,000,000, which happened in 2004. In addition, the Keeneland September Yearling Sale exceeded its previous gross record, with a gross of

$324,904,300. The gross sale results clearly show the significance of the thoroughbred industry in both Kentucky and in the United States.

OBJECTIVES AND PROCEDURES

The objective of this thesis is to develop a model to explain what management decisions influence pregnancy outcomes and breeding intervals. The following procedures will be used to accomplish that goal.

(1) Draw a representative sample of mares in the Central Kentucky area.

(2) Accumulate characteristics of the sample and expand the data with stallion characteristics.

(3) Summarize and blend relevant economic and veterinary literature on thoroughbred sale prices and reproductive efficiency.

(4) Estimate empirical model using proper econometric methods.

(5) Summarize results and test hypothesis concerning reproductive efficiency in thoroughbreds.

(6) Portray conclusions from research about the management decisions made by owners.

OUTLINE OF THESIS

Chapter II will review and summarize the relevant literature on economic research as well as applicable veterinary literature. Chapter III will outline the model, and provide a detailed description of the data. Chapter IV will show the empirical results, and finally Chapter V will provide conclusions.

CHAPTER II
LITERATURE REVIEW

This chapter reviews the literature and summarizes research with implications for the thoroughbred industry and reproductive efficiency in equines. The relevant literature fits into two categories, economic research on the horse industry, and veterinary research on equine reproduction. The economic literature reviewed here is concerned with price discovery in equine markets. The veterinary research reviewed here is concerned with reproductive efficiency in thoroughbreds.

ECONOMIC LITERATURE

Price discovery in livestock markets

The first research in price discovery, related to animal husbandry was done on beef cattle auction prices. In the following section there will be a brief review some of that literature.

Faminow and Gum (1986) developed a model to identify Arizona cattle auction prices in 1984 and 1985 based on gender, breed, and weight and lot size. Their research contributed to the literature as it identified optimal market weight for cattle. The results also identified the optimal lot size in order to maximize auction price.

Schroder et al. (1988) developed a model to analyze price differentials in cattle prices at Kansas auctions. Their research used more independent variables. This research found health, horns, condition, fill, muscling, and frame size to be significant in addition to weight and lot size.

Price discovery in equine markets

Price discovery in equine markets is not as extensive as in other livestock markets. Given the subjective nature of many phenotypical variables, it is very difficult to estimate thoroughbred hammer prices at public auction. The conformation of each thoroughbred is extremely important in determining the price, but it can not be measured objectively. The evaluation of conformation depends on the buyer’s experience, and what he/she thinks is a serious fault. Therefore most researchers did not include variables regarding conformation in their research.

Hastings (1987) used data from five Australian auctions in 1984 to examine the price variation in thoroughbred yearlings. His research included ten yearling-specific variables to understand what determines yearling prices. That research was unique because it included phenotypic characteristics, such as height, weight and conformation of individuals. Other studies since then excluded phenotypic variables, because the data are not recorded at auctions, and there is much subjectivity in the evaluation of these variables. Hastings' results showed that yearling price was affected by the racing performance of the dam and sire.

Commer (1991) examined the relationship between yearling prices and yearling-specific variables at the Fasig-Tipton Mid-Atlantic region sales between 1987 and 1989. The model revealed that the sex of the yearling, month foaled, racing earnings of the dam, number of Black Type[1] horses by the sire, the dam and the maternal grand dam, nomination to the Maryland Millions and/or Breeder's Cup, whether the yearling was Maryland bred had a significant influence on sale prices.

Karungu et al. (1993) developed a model to test the effect of macroeconomic variables on yearling prices. The model included the consumer price index to represent inflation, three-month yield on treasury bills to represent interest rate, and the exchange rate. This research did not include any yearling-specific variables. The results indicated that the tax law change, inflation, and exchange rate influenced yearling prices and through the prices the thoroughbred industry as a whole.

Buzby and Jessup (1994) presented a study, which examined the effects of both macroeconomic factors and yearling-specific variables. The results showed that yearling-specific variables have more impact on auction prices than macroeconomic factors. The study indicated that from yearling-specific variables stud fee, month foaled, Black Type dam were significant, and from macroeconomic variables tax change, interest rate and the dollars of gross foreign purchase were significant. Black Type dam and stud fee were positively correlated with price, while month foaled was negatively correlated with price as it was expected prior to the study.

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[1] Black Type refers to bold face type used in sales catalogs to distinguish horse that have won or placed in a stakes race.

Neibergs (2001) conducted a hedonic price analysis of broodmare characteristics. The data were collected from the 1996 Keeneland November Sale. The object of the study was to identify the characteristics that influence broodmare prices and calculate their marginal value. Every broodmare represents a unique combination of breeding racing and genetic characteristics. Breeders need to make careful decisions when investing in broodmares, because there is a considerable financial risk associated with overvaluing a mare. The long generation interval, large capital investment and biotechnology restrictions highlight the emphasis on broodmare management decisions. For purposes of the study the mare characteristics were divided into three groups; breeding, racing and genetic characteristics. Breeding characteristics reveal the mare's ability to produce foals. This category included variables representing the mare's status, stud fee of covering sire, age, average earnings per foal of racing age, and binary variables for being Black Type producer and graded stakes[2] producer. Racing characteristics refer to the mares racing career. This group included the mare's earnings at the racetrack, and binary variables whether she was a black type winner or graded stakes winner. Genetic characteristics refer to the quality of the mare's pedigree. This group contained an index for the mare's sire quality, binary variables for black type dam and sibling, and graded stakes winner sibling. The results show all of the above-mentioned variables to be significant.

For this thesis' purposes, I will highlight the variables that are more closely related to reproductive efficiency and management decisions. The age of mare, as expected, negatively effects sale price. A mare that is a year younger receives $3,051 more at auction, ceteris paribus. The implication of that for management decisions is if one wishes to sell the mare, when to sell her. In addition, an older mare with exceptional pedigree can be relatively inexpensive, if one is willing to take the risks associated with older mares. Barren mares received $15,010 less compared to pregnant mares, which is probably due to the cost associated with keeping the mare for one extra year without producing a foal, and potential reproductive problems. One aspect of breeding characteristics that was not significant is the index of percent of years the mare was not

[2] Graded stakes are the most prestigious races. Only few horses from each crop are able to compete at that level.

pregnant relative to her age. This could be explained by the creation of that variable. Mares of the same age can have different reasons to get the same percentage. One of them possibly never raced, and therefore could have produced more foals, while another could have raced for 3 years, giving her fewer chances to produce foals relative to her age. Unfortunately, this study did not include the last covering date for the mares.

Thalheimer and Lawrence (2001) prepared a study on Mare Reproductive Loss Syndrome (MRLS). The study evaluated the economic losses associated with MRLS. In the research, they also provided an estimation on cost of producing a sale yearling. The costs associated with producing a sale yearling are broodmare maintenance and replacement expenditure, stud fee, weanling and yearling maintenance expenditures and finally yearling sales preparation fee. In thoroughbred breeding, the stud fee paid most commonly is with a live foal guarantee. That means if the foal does not stand and nurse the mare’s owner does not have to pay the stud fee. The stud fee might be due in advance, or when the foal stands and nurses. If the stud fee is paid in advance and the foal fails to stand and nurse, the stud fee is refunded. Therefore, for the purposes of this study the stud fee does not affect the cost of keeping mares that fail to produce a foal. Broodmare expenditures include the board bill that covers farm labor, feed, tack and supplies, utilities, repairs and other expenditures. This does not include cost of veterinary services or medications.

The study cites that the live foal rate for Kentucky thoroughbred broodmares was 69% in 2000. The authors offer two interpretations for this figure. One way to view the figure is that a mare will have a foal approximately two out of every three years. Another interpretation is that it takes 1.5 mares to produce a foal. This latter view was used through the analysis. The annual maintenance of one broodmare was $9,293, but it rises to $13,940 if one calculates the maintenance cost for 1.5 mares, which is the expenditure per foal. Based on that, breeders can reduce per foal expenditures with better reproductive efficiency. The study calculated annualized broodmare replacement costs. The value of mares was given by average sales price of Kentucky Auction Sales in 2000, and the useful life of mares was 5 years. The annualized replacement for one mare was $20,091 and $30,137 for 1.5 mares. The maintenance and replacement cost for 1.5 mares adds up to $44,077 compared to $29,384 for one mare. From these results, it is clear that breeders have an incentive to improve live foal rates. Even though a 100% live foal rate is not a realistic target, other livestock have live birth rates over 90%. Thoroughbred breeders could substantially lower their costs per foal with higher live foal rates.

REPRODUCTIVE EFFICIENCY IN HORSES

The thoroughbred horse is considered to have relatively poor reproductive efficiency compared with sheep and beef cattle, which are selected for fertility. Sheep and beef cattle can have live birth rates exceeding 90% (Engelken 1999; Menzies 1999). Previous studies of thoroughbreds, standardbreds, and quarter horses have revealed cumulative end of season pregnancy rates of 70-80% (Laing and Leech 1975; Sullivan *et al*. 1975; von Lepel 1975; Bruck *et al*. 1993), and foaling rates of 50-70% (Laing and Leech 1975; Osborne 1975; Merkt et al. 1979; Jeffcott *et al*. 1982; Bruck *et al*. 1993; Morley and Townsend 1997). Analysis of Weatherby's Stud Book records of 12,386 mares revealed that 80.5% of mares were pregnant at the end of season, but only 71.4% foaled. This suggests that pregnancy loss contributes to the relatively low reproductive efficiency of thoroughbreds.

Thoroughbred mares and stallions are not selected on fertility, but entirely on a combination of pedigree and performance on the racetrack; therefore, physiological factors may contribute to the failure of mares to produce live foals. The long pregnancy, seasonality and strict uniparity can also play a role in the low reproductive efficiency. Various factors concerning the mare, such as age (Hutton and Meacham 1968; Laing and Leech 1975; Jeffcott *et al*. 1982; Sanderson and Allen 1987; Held and Rohrbach 1991; Waelchi 1990; Ricketts and Alonso 1991), status of the mare (Sanderson and Allen 1987; Woods *et al*. 1987; Ricketts and Alonso 1991) also influence the chances of producing a live foal.

Morris and Allen (2002) have conducted a research on reproductive efficiency on thoroughbred mares in Newmarket. The study compared 1393 mares from the 1998 breeding season to a similar study done in 1983. This study focused on the effects of mare age and status, stallion, month of mating, uterine treatments, rates of singleton and twin pregnancies, and pregnancy losses. The mares in the study were grouped into four age groups (3-8 years, 9-13 years, 14-18 years, and more then 18 years old). The results show that mares in the first two groups had significantly lower number of matings per a positive day 15 pregnancy (1.78 and 1.86 versus 2.22 respectively). The overall pregnancy loss was significantly lower for mares in the 3-8 years old group, 11.8, compared to the other groups. The other groups had 20.8, 27.8, and 31.4 percent of pregnancy losses respectively. The percentage of mares that produced live foal was significantly higher for the mares aged 3-8 years (86.6 percent) compared to 73.1 percent for mares aged 14-18 years. To examine the mare's status the study categorized the mares as maiden (never mated), barren (mated without a pregnancy at the end of season in 1997), foaling, aborted (pregnant at the end of the season in 1997 but lost it before the start of 1998 season), rested (not mated during 1997 season).The results show no significant difference in number of matings for the different groups. The pregnancy loss was significantly higher (33.3 percent) for mares who aborted, than for barren mares (11.7 percent). The study found no significant differences in the percentage of mares that produced live foals between the five groups. Among the other things the study examined, neither the stud farm nor the attending veterinarian had an effect on pregnancy rates. There was no overall effect of the month of mating on per cycle pregnancy rates, but the per cycle pregnancy rate in May was higher (62.7%) then that for June and July (52.6%). They explain this phenomenon with the high fertility of maiden mares that are mated early in the season, and mares that foal early had no problem becoming pregnant in the previous year. However, mares that are mated late in the season probably represent mares that had taken longer in the previous year to conceive. When the authors compare these results to the earlier study, they note that there was an increase in the percentage of mares that produced live foals (74.7 in 1983 and 82.8 in 1998). Their explanation for the increase is the improvement in the management of estrous, the timing of matings, and implementation of uterine therapy.

Bruck *et al*. (1993) analyzed the records of 1630 mare years from six thoroughbred farms in Australia from 1981 to 1986. The overall pregnancy rate was 83.9% and the foaling rate was 69.3%. They found foaling rates to be higher for mares under the age of 10(73.6%) compared to 59.3% for mares aged 11 years or older. The foaling rate was significantly higher in mares served one estrous cycle (77.8%) compared with mares served two estrous cycles (65.4%), and mares served more than two estrous cycle (42.9%). The study found that of the diagnosed pregnancies 19.5% were lost. Pregnancy loss was lower in maiden mares (12.4%) then in barren (19.7%) or foaling (20.9%) mares.

McDowell *et al*. (1992) conducted a study on the entire population of thoroughbred horses in the United States, Canada and Puerto Rico registered with the Jockey Club of America. The goal of the study was examine the effect of stallion booksize, age of mare and stallion on live foal percentage. The data consisted of records of the 1987 and 1988 breeding seasons. During that time there were 17,260 stallions bred to 179,009 mares, with the overall live foal rate of 58.1%. The book size in the data ranged from one to 75 mares, with the average book size of 10.4. 15.8% of stallions had a book size of one, and only 11.7% of them bred more then 25 mares, 5.8% bred more then 40 mares, and 1.3% bred more then 60 mares. The results show that live foal percentage increased as booksize increased. The authors note that this could be because stallions with the larger booksize are well known, are on larger farms, and possibly represent greater stud fees as well. Therefore, these stallions and the mares bred to them are likely to be subjected to greater management intensity. The age of mares ranged from one to 28 years. Results show that live foal percentage decreased as age of mare increased. The age of the stallion had no effect on live foal percentage.

CHAPTER III
MODEL DEVELOPMENT AND DATA DESCRIPTION

The objective of this thesis is to test which management factors influence breeding efficiency in thoroughbreds. There are two models developed in the thesis. The first model examines the interval to get the mare in foal. Earlier foals are more desirable both at the sales and the race track given the nature of racing in age groups. The second model has the outcome of the pregnancy check as the dependent variable. This model evaluates variables that influence the outcomes of pregnancy in the mares. The variables used in both models can be categorized as follows: mare characteristics, stallion characteristics, medications, farm characteristics, and management.

STYLIZED MODEL DEVELOPEMENT

The stylized model used to test the hypotheses set forth in Chapter I is given by the following equations. These equations include all variables that were used in the model. The first equation has the interval as the dependent variable.

$$\begin{aligned}
Interval = {} & \beta_0+\beta_1*Status_1+\beta_2*Status_2+\beta_3*Age+\beta_4*Fee+\beta_5*Booksize \\
& +\beta_6*St_Loc+\beta_7*BR_1+\beta_8*BR_2+\beta_9*BR_3+\beta_{10}*BR_4+\beta_{11}*BR_5 \\
& +\beta_{12}*Interval_2+\beta_{13}*LDB+\beta_{14}*Oxy+\beta_{15}*Prostin+\beta_{16}*PE+\beta_{17}*HCG \\
& +\beta_{18}*Ovuplant+\beta_{19}*GNRH+\beta_{20}*Domper+\beta_{21}*Thyroid_supp \\
& +\beta_{22}*Progest_preg+\beta_{23}*Regumate_foal+\beta_{24}*Regumate_breed \\
& +\beta_{25}*Regumate_preg+\beta_{26}*Prostin_P+\beta_{27}*PE_P+\beta_{28}*Ovuplant_P \\
& +\beta_{29}*HCG_P+\beta_{30}*GNRH_P+\beta_{31}*Deslor_P+\beta_{32}*Thyroid_suppP+\beta_{33}*Regumate_breedP \\
& +\beta_{34}*Regumate_pregP+\beta_{35}*Prostin_P+\beta_{36}*PE_P \\
& +\beta_{37}*Ovuplant_P+\beta_{38}*HCG_P+\beta_{39}*GNRH_P+\beta_{40}*Deslor_P \\
& +\beta_{41}*Thyroid_suppP+\beta_{42}*Regumate_breedP+\beta_{43}*Regumate_pregP \\
& +\beta_{44}*Big+\beta_{45}*Clients+\beta_{46}*Ultrasound+\beta_{47}*Pregnancy_check \\
& +\beta_{48}*Deworm+\beta_{49}*Culling+error
\end{aligned}$$

The second equation was used to estimate the probability of the mare becoming pregnant.

$$D40\_out=\beta_0+\beta_1*Status\_1+\beta_2*Status\_2+\beta_3*Age+\beta_4*Fee+\beta_5*Booksize$$
$$+\beta_6*St\_Loc+\beta_7*BR\_1+\beta_8*BR\_2+\beta_9*BR\_3+\beta_{10}*BR\_4+\beta_{11}*BR\_5$$
$$+\beta_{12}*Interval\_2+\beta_{13}*LDB+\beta_{14}*Oxy+\beta_{15}*Prostin+\beta_{16}*PE+\beta_{17}*HCG$$
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$$+\beta_{25}*Regumate\_preg+\beta_{26}*Big+\beta_{27}*Clients+\beta_{28}*Ultrasound$$
$$+\beta_{29}*Pregnancy\_check+\beta_{30}*Deworm+\beta_{31}*Culling+error$$

Definitions for each variable in the model can be found in Table 3.1.

Table 3.1 Definition of Empirical Analysis Variables

Variable	Definition
Status_1	Status of mare = 1 if foaling in 2004
Status_2	Status of mare = 1 if barren at the beginning of 2004
Status_3	Status of mare = 1 if maiden in 2004[3]
Age	Age of mare in years
Fee	Advertised stud fee for stallions in 2004, divided by 10000
Booksize	Number of mare bred by stallion in 2004
St_loc	Location of covering stallion =1 if same farm as mare
BR_1	Number of breedings for mare =1 if one
BR_2	Number of breedings for mare =1 if two
BR_3	Number of breedings for mare =1 if three
BR_4	Number of breedings for mare =1 if four
BR_5	Number of breedings for mare =1 if five
D40_out	Outcome of pregnancy check on day 40
D15_out	Outcome of pregnancy check on day 15
Interval	Length of time in days for mare to get pregnant

[3] Given the exclusive nature of mare status, Status_3 was included in the intercept term

Interval_2	Length of time in days from first possible day of breeding to first breeding
LDB	Last date of breeding[4]
Oxy	Oxytocin =1 if drug used on mare
Prostin	Prostaglandin =1 if drug was used on mare
PE	Estradiol with progesterone =1 if drug were used on mare
HCG	Human Chorionic Gonadotropin =1 if drug was used on mare
Ovuplant	Ovuplant =1 if drug was used on mare
GnRH	GnRH =1 if drug was used on mare
Domper	Domperidone =1 if drug was used on mare
Thyroid_supp	Thyroid Supplement =1 if drug was used on mare
Progest_preg	Progesterone =1 if drug was used on mare during 2004 pregnancy
Regumate_foal	Regumate =1 if drug was used on mare before foaling in 2004
Regumate_breed	Regumate =1 if drug was used on mare before pregnancy was confirmed
Regumate_preg	Regumate =1 if drug was used on mare after pregnancy was confirmed
Big	1 if farm has more than 100 mares
Clients	1 if farm has owners boarding mares
Ultrasound	1 if farm uses ultrasound to monitor heat cycle
Pregnancy_check	1 if farm uses ultrasound to monitor pregnancies
Deworm	1 if farm has deworming program
Culling	1 if farm has culling program

DATA DESCRIPTION

The data were collected in a detailed study by Karin Bosh, PhD candidate in veterinary sciences at the University of Kentucky, from 13 thoroughbred farms in Central Kentucky. These 13 farms have boarded 1091 mares which were bred to 170 stallions in the 2004

[4] Days of the year were counted such as 1=Jan 1, 2=Jan 2 etc.

breeding season. Five of the farms stood stallions in 2004. The number of mares per farm ranged from 28 to 169. The data contained all available breeding data on each mare for the 2004 breeding season, such as mare's age and status, foaling date, all breeding dates, medications used on each mare, outcomes of pregnancy tests.

Mare characteristics

Following Morris and Allen (2002), Bruck, Anderson and Hyland (1993), and McDowell, Powell and Baker (1992) this study tests the effects of mare age and status at the beginning of foaling season. The status of a mare entering breeding season was categorized as foaling barren or maiden. Foaling mares will foal in that year, barren mares are not in foal at the beginning of the breeding season due to various reasons, and maiden mares have never been mated.

Table 3.2 summarizes the status of mares in the whole data set, while Table 3.3 describes the mares' status by farm.

Table 3.2 Status of Mares

Status of mare	Number of mares	Percentage of mares
Foaling	771	70.67%
Barren	157	14.39%
Maiden	163	14.94%
Total	1091	100.00%

Table 3.3 Status of mares by farm

Farm	Foaling	Barren	Maiden
1	58.88%	25.23%	15.89%
2	68.29%	12.20%	19.51%
3	55.71%	10.00%	34.29%
4	75.00%	21.43%	3.57%
5	85.53%	9.21%	5.26%
6	94.00%	4.00%	2.00%
7	70.21%	14.89%	14.89%
8	56.41%	23.08%	20.51%
9	78.38%	16.22%	5.41%
10	74.81%	15.27%	9.92%
11	66.86%	13.02%	20.12%
12	66.97%	10.09%	22.94%
13	72.57%	14.16%	13.27%

Because the data were collected in the summer of 2004 the foaling data were not available, therefore the day 40 pregnancy results were used in the calculations. The overall day 40 pregnancy rates ranged 64.3% to 97.6%. The percentage of foaling mares in 2004 ranged approximately from 70% to 95.9%. These values are approximate because the number of mares on each farms through the 2003 breeding season were not available, therefore the values were calculated using the barren and foaling mares that were bred in 2004.

The age of mares in the data ranged from two to 24 years old. The average age was 9.64 years, while the median age was 8 years. The mares in this data set were relatively young 56.74% were under 10 years old, and only 54 were 20 years or older. The mare’s age is expected to have a negative effect on both pregnancy outcome and length of interval. A detailed description on the age of mares is in Table 3.4

Table 3.4 Age of mares

Age range	Number of mares
Younger then 5 years	112
5-9 years old	507
10-14 years old	265
15-19 years old	128
20 years or older	54

The number of times the mare was bred can indicate reproductive problems. In an ideal case, each mare would have to be bred only one time; however, many times the mare fails to become pregnant after the first cover. This can be because of poor reproductive health of the mare, or poor management. The number of breedings was between one and six. 61.8% of the mares were bred once, 25.5% of the mares were bred twice, 7.8% of the mares were bred three times, 2.8% of the mares were bred four times, 1.5% of the mares were bred five times, and only 0.2% of the mares were bred six times. A priori expectation concerning number of breeding is that the fewer times a mare has to be bred the more likely she becomes pregnant. The larger number of breedings obviously will lengthen the interval, but is not clear by how many days.

Stallion characteristics

This study tests the null hypothesis of no effect of stallion's book size and stud fee. New in this study is a variable for the location of the stallion. The hypothesis is that if the stallion stands on the same farm where the mare is boarded, it might be easier to get the mare bred at the optimum point in her cycle. Therefore I expect the stallion location to positively influence pregnancy outcomes, and shorten the interval. The stallions to which these mares were bred stood on 38 different farms. The stud fee range was from $1,000 to $500,000, with the average of $59,684. Because pedigree or sales results information were not available about the mares the stud fee could serve as a proxy for the mare's value. It can be used because the best quality mares are likely to be bred to the highest quality stallions, with higher service fee, while the lower quality mares will be bred to lesser quality stallions with lower stud fee. (For scaling purposes the stud fees were divided by 10,000 in the analysis.) Table 3.5 summarizes the average and median stud fees paid by farms.

Table 3.5 Average and median stud fees

Farm	Average Stud Fee	Median Stud Fee
Farm 1	$19000	$10000
Farm 2	$38537	$30000
Farm 3	$70893	$35000
Farm 4	$12393	$10000
Farm 5	$46127	$40000
Farm 6	$21080	$25000
Farm 7	$22245	$10000
Farm 8	$30513	$17500
Farm 9	$102004	$30000
Farm 10	$51279	$40000
Farm 11	$41704	$30000
Farm 12	$111124	$50000
Farm 13	$109370	$35000

The booksize for these stallions ranged from 5 to 199, with the average of 97. Table 3.6 shows the number of stallions in each booksize group.

Table 3.6 Booksize of stallions

Booksize	Number of stallions	Percentage of stallions
0-24	7	4.21
25-49	14	8.43
50-74	29	17.46
75-99	30	18.07
100-124	45	27.10
125-149	26	15.66
150-	15	9.03

Farm Characteristics

In this data set farm characteristics included farm size, whether the farm stands stallions, uses ultrasound to monitor follicles before breeding, and pregnancies, whether the farm has boarding clients, a deworming program, and a culling program. Mares that were boarded on farms that had more then 100 mares were given a value of one for the dummy variable "big". Based on the available data there were no other differences identified between farms. The following table summarizes the farms' performance on positive pregnancy outcomes on day 15 and day 40[5] both on first breeding and at the end of season. The outcome of first breeding is shown because thoroughbred races are for specific age groups, such as races for two year olds, therefore it is important to get a mare in foal as early in the breeding season as possible. Buyers at public auction are willing to pay a premium for older yearlings, and on the racetrack older horses from the same age group have more time to develop and mature.

The farms performance varied on the outcome of positive pregnancies from 91.3% to 108.3 % on day 15 at the end of season. (Percentages higher than 100.0% indicate that

[5] In thoroughbred breeding pregnancy check is performed for the first time on around day 15 after breeding. It is very important to check the mares at this time to make sure the cover was successful, check for twin pregnancies. Even if the mare is not pregnant at this point, the veterinary exam can also determine problems. The results of the day 40 pregnancy checks were used in this study to determine the end of season pregnancy rates.

some of the mares were found in foal at day 15, but lost the pregnancy later, and were bred and found in foal at day 15 again. Therefore the end of season pregnancy outcomes on day 15 can be higher than 100%).

Table 3.7 Measures of reproductive efficiency by farm

Farm	Day 15 outcome on first breeding	Day 40 outcome on first breeding	Day 15 outcome at end of season	Day 40 outcome at end of season
1	54.6	47.2	97.2	75.0
2	75.6	68.3	104.9	97.6
3	64.3	58.6	98.6	91.4
4	67.9	42.9	103.6	64.3
5	51.3	47.4	96.1	84.2
6	64.0	62.0	92.0	84.0
7	65.2	45.7	91.3	67.4
8	71.8	64.1	100.0	84.6
9	71.2	65.8	100.9	92.8
10	58.9	46.5	99.2	70.5
11	65.1	59.8	97.0	85.2
12	69.7	61.5	108.3	92.7
13	68.8	61.6	103.6	92.9

The age of a thoroughbred yearling at the sales, and later on at the racetrack are important factors in its valuation. In thoroughbred racing the horses race in age groups. According to Jockey Club rules, all thoroughbreds born in the same calendar year, regardless of actual birth date, are assigned a common birthday of January 1. With this method all animals in a crop are the same age at the sale and on the racetrack. However, actual January born foals can have an advantage over later born foals; usually the earlier foals are more mature then late foals. The last date of breeding can be used to estimate the foaling date for the next year. A mare will foal approximately 11 months after breeding that means that a mare whose last date of breeding is February 14, will foal around January 14. In the data the earliest last date of breeding was February 11, and the latest last date of breeding was July 7. The average last date of breeding was April 16. It is the decision of owners and managers whether to breed a mare late in the breeding season (June and July) or rest her, and start early in the next year. Table 3.8 shows the number of mares that were last bred in each month.

Table 3.8 Month of last breeding

Month	Number of mares
February	155
March	254
April	257
May	283
June	134
July	8

The management of a farm can do little to move the first date of breeding to an earlier point in the breeding season. A mare can move in from a different farm or be brought from the sales with a late covering date. Unfortunately data were not available whether the mare was new to the farm or not. The management however can shorten the interval for breeding by: assessing and treating reproductive problems early in the breeding season, lighting programs, and proper breeding management. Therefore I chose to examine the interval between the first possible date of breeding and the final date of cover. The interval was defined slightly differently for barren and maiden mares than for pregnant mares. For barren and maiden mares the interval was calculated by subtracting February 14 (the official start of breeding season) from the last date of breeding. Using this method a barren mare whose last date of breeding was February 20, would have an interval of 6 days. For foaling mares the interval was calculated by subtracting the date 30 days after foaling from the last date of breeding. Using this method a mare that foaled on March 1st, and was bred for the last time on April 1st would have an interval of one day. (for mares that foaled so early in the year, that the calculation method would put their first breeding before February 14 had February 14 assigned as the start of their interval) I chose this method because around 30 days after foaling is the general timing of first breeding. The management however can make a decision to breed a mare on foal heat which occurs about a week after foaling. This practice can be used to have the mare foal earlier next year. The other option to move the foaling to an earlier date the following year is to short cycle the mare after foal heat. That means the use of hormones to bring the mare back into heat in a week, instead of the natural three weeks. If the management chooses to breed on foal heat, or short cycle and it is successful, that would reflect in a negative interval.

Treatments used in equine reproduction

There is often a conflict between horse breeders and Mother Nature. Breeders usually wish to breed horses early in the year, but horses are seasonal breeders. The physiological breeding season extends from April through October, while the breeding season for thoroughbreds is from the middle of February through early July in the northern hemisphere. Light has a major influence on the mare's estrous cycle. Mares respond to increasing periods of light in the spring by slowly beginning to cycle, and to decreasing periods of light in the winter by slowly terminating ovarian activity. (Book of Horses, 1996) It is recognized that light treatment can be used to hasten the onset of breeding season. Mares are commonly kept under lights during winter months to initiate cycling early in the year. Cycling commences 8-10 weeks after the lighting program has begun. Therefore, if one aims to have horses cycling in February, lighting must be initiated in November. Ideal photoperiod is about 16 hours of light. (Drug use in equine reproduction, 2004) Horse breeders can also use hormones in addition to the light program to hasten the onset of breeding season.

In the next section, I will focus on hormones that were used on the mares in the data. The veterinarian can subscribe altrenogest to suppress transitional estrous and to hasten onset of ovulation in transitional mares. The oral progestogen altrenogest (Regumate) can be used for this purpose. Administration of Regumate effectively suppresses estrous. To hasten ovulation, the recommended course of 10-15 days is effective, and the following withdrawal drives ovulation. Progesterone products can be used to maintain pregnancy as well. Progesterone supplementation to mares suffering an endotoxic insult is a good measure to prevent pregnancy loss. Regumate can be used for that purpose (Drug use in equine reproduction, 2004). To separate the different uses of Regumate in the data, Regumate_breed represents if the product was used to onset ovulation, Regumate_preg represents if the product was used for pregnancy maintenance in the 2004 breeding season, while Regumate_foal if it was used starting in the 2003 breeding season through foaling. Regumate is an oral supplement therefore; it is convenient, but expensive source of progesterone for pregnancy maintenance. Alternative options for pregnancy maintenance is repositol progesterone (Progesterone) injection, or use estradiol combined with progesterone (P&E) injection.

Another important hormone used in equine reproduction is prostaglandin. Injection of prostaglandin will shorten the length of diestrus, therefore shortens the waiting period following missed ovulations. It is widely used in managing brood mares. Some medical conditions, such as persistent corpus luteum, also require the use of prostaglandin. Prostaglandin can be used to terminate unwanted pregnancies. One reason to terminate pregnancy in thoroughbreds can be the presence of twins, when the option to manually compress one of then cannot be achieved.

Uterine defenses require that intrauterine fluid be removed, and that the walls of the uterus be brought into close apposition. Oxytocin injection is used for that purpose without invading the uterus. (Drug use in equine reproduction, 2004)

The timing of breeding with respect to the time of ovulation is crucial to achieve pregnancy. Because the Jockey Club does not allow artificial insemination for thoroughbreds, it is extremely important to breed the mare at the optimal point in her estrous cycle. The stallion has to cover the mares naturally, and therefore the number of mares that can be bred on a day is very limited, as opposed to horse breeds where artificial insemination is allowed. Ovulation inducing drugs are widely used on thoroughbred brood mares to ensure that she will ovulate within 48 hours of breeding. There are many drugs available on the market for that purpose. Human chorionic gonagotrophin (HCG), Ovuplant, Deslorelin, and GnRH are commonly used to induce ovulation.

Other hormones included in the data were thyroid supplement, and domperidone. Thyroid supplement is used on horses when the horse suffers from hypothyroidism. Thyroid hormones control protein synthesis. They are responsible for the overall metabolism of the horse and have bearing on the animal's energy level. Hypothyroidism is due either to insufficient levels of thyroid hormones or inappropriate release of hormones from the thyroid gland. Signs of hypothyroidism include lethargy, muscular weakness, decreased exercise tolerance and goiter. Obesity, cresty neck, frequent bouts of laminitis, poor hair coat, mare infertility and foal tendon problems have all been reported to be associated with hypothyroidism. Domperidone is primarily marketed to prevent fescue toxicosis, but can be used on pregnant mares when the mare fails to develop the udder prior to foaling. The following table shows the use of each medication in the data set.

3.9 Medication used on mares

Medication	Number of mares
Prostin	428
P&E	87
HCG	286
Ovuplant	397
GnRH	11
Deslorelin	23
Oxytocin	108
Domperidone	94
Thyroid supplement	41
Regumate_foal	128
Regumate_breed	115
Regumate_preg	288
Progest_preg	58

The following table will summarize the cost of medications, and the typical length of usage. (The costs are approximate only because with most medications the cost depends on the manufacturer, quantity bought)

Table 3.10 Cost of medications

Medication	Cost per dose	Length of use
Prostin	$1.6	One time
P&E	$3	Through pregnancy
HCG	$8	One time
Ovuplant	$40	One time
Deslorelin	$58	One time
Oxytocin	$0.12	Variable
Thyroid supplement	$20	Year round
Regumate	$3	From 10 days up to through pregnancy

Interaction variables were created combining the mare's status and different medications, for all medication that was used on mares in different status.(For example Domperidone was only used on foaling mares, therefore there was no need to create interaction variables.) The reason for that was to be able to separate the effect. Using interaction dummy variables provides greater detail to the analysis. The definition of these variables was as follows:

Prostin_P=Prostin*Status_1, where Prostin_P is 1 if Prostin was used on foaling mare.

Prostin_B=Prostin*Status_2, where Prostin_B is 1 if Prostin was used on barren mare.

Results of pregnancy checks on day 15 and day 40 after breeding are part of the data set. Usually the first examination for pregnancy happens around 15 days after breeding. At that time, the veterinarian examines the mares for the presence of pregnancy and for twin pregnancies as well. In horses it is essential to terminate one of the twins, or if this is not possible then both, because mares abort most of twin pregnancies and even if she carries it to full term it is very likely that one or both of them will die. At day 15, the veterinarian can also check for potential problems, which can cause abortion later, and recommend preventative treatment. The pregnancy check on day 40 is also very important to make sure the mare is still pregnant, especially because of hormonal changes, it is extremely difficult to get mares pregnant again if they lose the pregnancy after 40 days.

Summary statistics of the empirical analysis variables is given in tables 3.10 and 3.11.

Table 3.11 Mean and Standard Deviation of Empirical Variables

Variable	Mean	Standard Deviation
Status_1	0.691	0.462
Status_2	0.144	0.351
Status_3	0.164	0.370
Age	9.118	4.425
Fee	6.226	10.125
Booksize	112.923	37.483
St_loc	0.794	0.404
BR_1	0.671	0.469
BR_2	0.242	0.428
BR_3	0.062	0.242
BR_4	0.016	0.127
BR_5	0.006	0.081
D15_out_1	0.924	0.266
D40_out_1	0.890	0.313
Interval	33.791	23.114
Interval_2	41.854	30.279
LDB	98.809	33.403
Oxy	0.103	0.305
Prostin	0.392	0.488
P&E	0.092	0.290
HCG	0.272	0.445
Ovuplant	0.387	0.487
GnRH	0.008	0.093
Domper	0.087	0.282
Thyroid_supp	0.030	0.173
Progest_preg	0.042	0.202
Regumate_foal	0.115	0.320
Regumate_breed	0.083	0.277
Regumate_preg	0.275	0.447
Prostin_P	0.242	0.429
PE_P	0.003	0.057
Ovuplant_P	0.283	0.451
Hcg_P	0.179	0.384
GnRH_P	0.003	0.057
Deslor_P	0.015	0.123
Thyroid_suppP	0.015	0.123
Regumate_breedP	0.061	0.240

Reguate_pregP	0.185	0.388
Progest_pregP	0.029	0.170
Prostin_B	0.077	0.267
PE_B	0.054	0.226
Ovuplant_B	0.056	0.230
HCG_B	0.035	0.184
GnRH_B	0.001	0.033
Thyroid_suppB	0.008	0.093
Regumate_breedB	0.012	0.109
Regumate_pregB	0.052	0.224
Progest_pregB	0.009	0.099
Big	0.685	0.464
Clients	0.470	0.499
Ultrasound	0.513	0.500
Pregnancy_check	0.110	0.313
Deworm	0.169	0.375
Culling	0.364	0.481

Table 3.12 Minimum, maximum and Sum of Empirical Variables

Variable	Minimum	Maximum	Sum
Status_1	0	1	771
Status_2	0	1	157
Status_3	0	1	163
Age	2	23	10324
Fee	0.10	50.00	6511.50
Booksize	5	199	122559
St_loc	0	1	874
BR_1	0	1	675
BR_2	0	1	279
BR_3	0	1	86
BR_4	0	1	31
BR_5	0	1	17
D15_out_1	0	1	908
D40_out_1	0	1	1003
Interval	-4[6]	129	41688
Interval_2	-4	178	50900
LDB	42	178	117056
Oxy	0	1	108
Prostin	0	1	428
PE	0	1	95
HCG	0	1	294
Ovuplant	0	1	405

[6] The negative number indicates that some mares were bred before the official start of the breeding season.

GnRH	0	1	11
Domper	0	1	94
Thyroid_supp	0	1	41
Progest_preg	0	1	58
Regumate_foal	0	1	128
Regumate_breed	0	1	115288
Regumate_preg	0	1	281
Prostin_P	0	1	4
PE_P	0	1	294
Ovuplant_P	0	1	194
HCG_P	0	1	4
GnRH_P	0	1	20
Deslor_P	0	1	22
Thyroid_suppP	0	1	89
Regumate_breedP	0	1	189
Regumate_pregP	0	1	41
Progest_pregP	0	1	77
Prostin_B	0	1	58
PE_B	0	1	64
Ovuplant_B	0	1	42
HCG_B	0	1	3
GnRH_B	0	1	2
Thyroid_suppB	0	1	12
Regumate_breedB	0	1	15
Reguate_pregB	0	1	54
Progest_pregB	0	1	14
Big	0	1	740
Clients	0	1	558
Ultrasound	0	1	532
Pregnancy_check	0	1	11
Deworm	0	1	204
Culling	0	1	370

CHAPTER IV
EMPIRICAL RESULTS

MODEL DIAGNOSTICS

In the first model 18 of the variables were significant. The significant variables were found among the mare and farm characteristics, and medication variables, while none of the stallion characteristics variables were significant. The R^2 for the model was 0.6857. I found no multicollinearity among the independent variables. There are no variance inflation factors greater then 10. The factor pattern analysis revealed no grouping behavior either. The model was checked for autocorrelation, using standard first-differencing for first order autocorrelation, and the test revealed that autocorrelation was not a problem.

The model was examined for problems of heteroskedasticity, and the test indicated that the problem of heteroskedasticity existed in the model. I used Whites' Two-step correction procedure for multiplicative heteroskedasticity to correct the problem.

Using F test I eliminated many of the insignificant variables. Therefore the final model did not include all variables set forth in the equations in Chapter III.

The results of the regression for interval, such as parameter estimates and standard errors are shown is Table 4.1. The dependent variable in the regression was the interval measured in days.

Table 4.1 Interval regression Parameter Estimates and Standard Errors

Variable	Parameter Estimate	Standard Error
Intercept	94.81397***	3.66201
Int_2	0.32148***	0.01859
Age	-0.51145***	0.12787
Status_1	-15.83917***	1.78256
Status_2	4.84889**	2.38122
Fee	-0.08609	0.05464
St_loc	-0.85958	1.39214
BR_1	-69.28964***	2.82593
BR_2	-45.16699***	2.85123
BR_3	-17.16532***	3.11713
Booksize	0.00129	0.01271
Oxy	-1.12932	1.85293
Prostin	11.70242***	1.80976
PE	-23.45754***	5.38026
HCG	-1.38290	1.41367
Ovuplant	-2.22783	1.38336
GnRH	10.12003**	4.62540
Deslor	-3.66182	16.81033
Domper	-0.01732	1.96515
Thyroid_supp	3.30323	2.47892
Progest_preg	-9.68727	7.63471
Regumate_foal	-9.36335***	1.79190
Regumate_preg	-2.87186	1.87084
Regumate_breed	-1.15425	1.74989
Big	3.07569**	1.32714
Clients	-1.21676	1.37241
Prostin_P	-9.96391***	2.25519
PE_P	17.20059	33.59809
GnRH_P	4.60201	8.82174
Regumate_pregP	7.38211***	2.32463
Progest_pregP	17.60862**	8.15895
Ovuplant_B	-11.32208***	3.20193
HCG_B	-10.10787***	3.21502
Progest_pregB	15.44643*	8.36300

Note: * Statistical significance at .10 level(10%),

** Statistical significance at.05 level (5%),

*** Statistical significance at .01 level (1%)

Mare Characteristics

The status of the mares entering the breeding season was found to be significant. If a mare was foaling in 2004, on the average the interval was 15.83 days shorter. However, if the mare was barren entering the 2004 breeding season, the interval was 4.84 days longer. This seems sensible, because the barren mares have had some problems in the past, which resulted in not having a foal in 2004. The result for pregnant mares is slightly surprising. Generally, maiden mares, which were included in the intercept term, are believed to be in the best reproductive health. Based on this results however, the interval for foaling mares was shorter. Even though the studies cited in the literature review did not analyze the length of interval, Morris and Allen (2002) found that mares between the ages of 3-8 (possibly many of them maiden) required the lowest number of matings (1.78) to achieve a positive day 15 pregnancy. This indirectly suggests a shorter interval (the more times a mare has to be bred the longer the interval). One explanation for that is the possibility that the maiden mares just came from the racetrack before the breeding season starts, and might need some time to adjust to the new environment.

The age of the mare was significant as well. The results show that a one year increase in the mare's age shortens the interval by 0.51 day. This result was contrary to a priori expectations. However, the effect of age even though is significant, it is not great.

The Int_2, which was defined as the number of days from first possible date of breeding to the actual first date of breeding, is significant. The interpretation of this result is, if the first breeding is delayed by one day the interval becomes 0.32 day longer.

The number of breedings, as expected, is negatively correlated with the interval. For mares that were bred one time only the interval was 69.28 days shorter, the mares that were bred two or three times the interval was 45.16 and 17.16 days shorter respectively. These results show that having to breed a mare more then one time is usually not simply to just having to breed her on the next estrous cycle. A horse's estrous cycle is typically 21 days. One can see from the results that the second breeding lengthens the interval by 24 days, and a third breeding further lengthens it with 28 days. This suggests that if the mare does not become pregnant on the first cover, the management might have to correct some existing problems, before she can be bred again.

Another reason for these results could be that some mares have a positive pregnancy check on day 15, but lose the pregnancy later; therefore the next breeding is delayed.

Stallion Characteristics

From the variables relating to the stallion, none of them were significant. A priori expectations were that the higher fee would have a negative effect on the interval, because the higher priced stallions usually get mares that are in excellent reproductive health. If the stallion is located on the same farm as the mare the effect on the interval was expected to be negative. The reason for that was that it is possibly easier to schedule the breedings when the mare and the stallion are on the same farm. Booksize was expected to lengthen the interval, because a stallion can only cover a limited number of mares a day, and mares have only a short period of time when they can become pregnant in each cycle. Therefore in case of stallions with large books I expected more scheduling conflicts and possible delays in breedings. But none of the stallion characteristics had a significant impact on the interval.

Medications

A priori all medications were expected to have a negative correlation with the interval. All of the treatments are marketed with the intention of helping breeders to get the mares in foal, and/or shorten the interval. Therefore, if the results show that a given medication lengthens the interval it is more likely that it can be the result of the mare's reproductive health problems, rather than the drug itself. Since it was not a controlled study, one cannot assume that mares treated with any medication are as healthy as the ones not treated. Hormonal treatments such as progesterone and Regumate are prescribed during pregnancy to prevent pregnancy loss. It is likely that these products would be used mostly on mares with high risk of losing the pregnancy.

The results indicate that use of Prostin lengthened the interval by 11.7 days. The explanation for that is that the use of Prostin can be to terminate unwanted pregnancies, which clearly makes the interval longer. Other possibilities include that the use of Prostin to shorten diestrus implies a missed ovulation, in which case the use of Prostin lengthens the interval by less when compared to waiting for the next estrus cycle. If breeders recognize a missed ovulation and use Prostin, a mare can be bred again in a week, while without it the breeders have to wait for the next natural cycle which occurs in approximately 21 days.

The use of PE shortened the interval by 23.45 days. PE, as I mentioned earlier, is used to prevent pregnancy loss. Therefore it indirectly shortens the interval. By preventing pregnancy loss, the breeders can avoid breeding the mare again after a loss of pregnancy.

From ovulation inducing drugs only GNRH was significant. The use of GHRH lengthened the interval by 10.12 days. This is contrary to a priori expectations. However, I must note that this particular drug was used only on a few mares. This result may indicate that those mares were in relatively poor reproductive health.

Regumate used on foaling mares reduced the interval by 9.36 days. This result suggest that foaling mares on Regumate can start cycling after foaling earlier compared to the ones not on Regumate.

The size of the farm also had an effect on the interval. Farms with more then a hundred mares had on the average 3.07 days longer interval. In previous studies the effect of farm size has not been tested. A priori the expected effect of this variable was undetermined. One argument could be made for smaller farms having more time for individual mares, and the manager being able to oversee the whole operation better, or the bigger farms have probably more invested, and can afford state of the art techniques. The results suggest that on big farms the management may not pay as close attention to individual mares as managers of smaller farms.

From the interaction variables created for the analysis Prostin_P, Regumate_pregP, Progest_pregP, Ovuplant_B, and HCG_B were significant. It is worth to note that, except for the drug Prostin, none of the other medications were significant when not combined with the status of the mare. Prostin_P shortened the interval by 9.96 days. This is different from the effect of Prostin, which lengthened the interval. The reason for that can be that on foaling mares prostin might be used to shorten the waiting period after foaling, and this use clearly can shorten the interval. However, on barren and maiden mares, with the right management, and no reproductive problems, the mare should be ready for breeding at the beginning of the breeding season. Therefore, it is likely that on barren and maiden mares use of Prostin indicate some kind of health issue, while on foaling mares it is possibly used to shorten the waiting period.

Both Regumate_pregP and Progest_pregP lengthened the interval, by 7.38, and 17.60 days, respectively. Since these drugs, when used on pregnant mares help to prevent pregnancy loss, one can infer that the mares were more likely to lose the pregnancy than the ones where these preventative measures were not in place. The possible explanation for the results that these mares had trouble getting in foal and/or have a history of losing the pregnancy. Again, note that this was not a controlled study, therefore the medication alone can not be cited as the only reason for longer intervals.

From the ovulation inducing drugs combined with mare status, Ovuplant and HCG use on barren mares were significant. Ovuplant_B and HCG_B both lowered the interval, by 11.32 and 10.10 days respectively. These results are reasonable, given that these drugs are used to make the mares ovulate at the right time, and avoid the need for further breedings.

MODELING THE PROBABILITY OF PREGNANCY IN MARES

A second model estimated the probability of mares becoming pregnant. The model had a pseudo R^2 of 50.42. Table 4.2 summarizes the accuracy of the model. The table shows that the model correctly predicted the outcomes for 90.59% of the observations.

Table 4.2 Predicted and actual outcomes of pregnancies

	Predicted outcome		Total
Actual outcome	0	1	
0	64	33	97
1	53	764	817
Total	117	797	914

The marginal effect of the significant variables was estimated. In this process the marginal effect of the variables was calculated at each variable's mean. For the dichotomous variables the marginal effect was calculated for each of these variables where they were set to zero and one. Table 4.3 shows the marginal effect of the variables.

Table 4.3 Marginal effect of variables

Variable	Marginal effect at mean values	Marginal effect when D=0	Marginal effect when D=1
Intercept	0	0	0
Age	-9.158E-7	0	0
GnRH	-0.00001	-0.00001	-0.000067
Thyroid_supp	-0.000011	-9.988E-6	-0.000063
Regumate_preg	6.7884E-6	0.0000143	1.0303E-6
Regumate_breed	-9.394E-6	-8.009E-6	-0.000035
LDB	-0.002151	0	0
Big	2.4602E-6	4.6808E-6	1.9792E-6

The results show that the effect of each variable, even though statistically significant, is very small. That indicates that there is no one single factor determining the chances of positive pregnancy outcomes, but it is a result of many different things.

Furthermore the effect of each significant variable was estimated while the other variables were set to an adjusted minimum and maximum as well. The adjusted minimum was calculated setting all variables to one third of the range, while for the adjusted maximum, variables were set to two third of the range. The results are shown in Table 4.4. ME_M is the marginal effect of the variables when all variables are set to their mean. ME_MIN and ME_MAX are the marginal effects of the variables when all other variables are set to their adjusted minimum and maximum respectively.

Table 4.4 Marginal effect of variables when other variables are set to different levels

Variable	ME_MIN	ME_M	ME_MAX
Intercept	0.20119	0.22537	1.07374
Age	-0.00131	-0.00146	-0.00699
GnRH	-0.03113	-0.03487	-0.16616
Thyroid_supp	-0.03048	-0.03414	-0.16269
Regumate_preg	0.04366	0.04891	0.23303
Regumate_breed	-0.02444	-0.02738	-0.13044
LDB	-0.00134	-0.00150	-0.00715
Big	0.01428	0.01600	0.07624

The results from Table 4.4 indicate that the marginal effect of the variables increases as the other variables move from their adjusted minimum to their adjusted maximum. In this case the age of the mare lowers the chances of becoming pregnant by only 0.1% when all other variables are at their adjusted minimum. But when all other variables are at their adjusted maximum, one year increase in the age of the mare lowers the chance of becoming pregnant by 0.6%. The last day of breeding has similar marginal values. Breeding he mare one day later lowers her chances of becoming pregnant by 0.1% when all other variables are at their adjusted minimum. However, breeding the mare a day later when all other variables are at their adjusted maximum lowers her chances of becoming pregnant by 0.7%. This finding is especially important if one thinks about mares that are bred very late in the season (June). The last date of breeding for these mares can be months over the ideal time of breeding. It is likely that mares that are bred that late in the season have various reproductive problems.

From the medication used on the mares only four were significant: GNRH, Thyroid_Supp, Regumate_Preg and Regumate_Breed. Only Regumate_Preg had a positive effect on pregnancy outcomes. Regumate_preg increased the probability of becoming pregnant by 4% when all other variables were set to their adjusted minimum or their mean, but increased the probability of becoming pregnant by 23% when the other variables were set to their adjusted maximum. While Regumate_preg increased the probability in an indirect way, (by the definition of the variable, it is used when the mare is confirmed in foal) it had the largest effect. Typically veterinarians suggest the use of Regumate on pregnant mares at the first pregnancy check, on day 15. Therefore the use of this drug prevents the pregnancy loss in the future, so the mares are more likely to be still pregnant on day 40. The other drugs that were significant had a negative effect on the probability of having a positive day 40 pregnancy check. I would contribute these results to the notion that these drugs were probably used on mares with more reproductive problems. Thyroid_supp is used on mares which do not produce enough thyroid hormones, which is reported to cause infertility, so it is likely that those mares had smaller chance to become pregnant. Regumate_Breed implies that the use of the drug started before the confirmation of pregnancy, so it is possible that it was used on only mares that had a history of reproductive problems.

While the marginal effects are small, it is not surprising if one considers all the different things that determine the outcome of a pregnancy. When one analyzes the change from ME_MIN to ME_MAX, some of the results indicate a greater effect.

CHAPTER V
SUMMARY AND CONCLUSIONS

SUMMARY

The foremost objective of this thesis was to identify mare and stallion characteristics, and management variables that influence the pregnancy outcomes and breeding intervals. The secondary objective was to revisit the effect of mare's age and status, and stallion's book size on reproductive efficiency. The thesis began with a review of related literature from both economics and veterinary science. Next, I identified a hypothesis to be tested, and accumulated a data set. Following that, I performed the analysis and reviewed the empirical results.

CONCLUSIONS

Most importantly, the analysis identified the independent variables that have an effect on pregnancy outcomes and interval length. The results showed that mare characteristics and medications have a significant impact on interval length. The model for the probability of a mare becoming pregnant predicted the actual outcome 90.5% of the time.

With respect to the results, brood mare managers and owners alike, can plan ahead to achieve their goals in reproductive efficiency. The manager can use the results to optimally program the mares, so they can be successfully bred early in the breeding season. The results show that using certain hormonal treatments on brood mares, can help the mares become and remain pregnant, and/or become pregnant earlier in the season. Managers can also see from the results that with mares that may have more health issues, the treatments available cannot guarantee success. Owners can also use this analysis to manage their buying and selling decisions. The age and status of mare have significant impact on both aspects of reproductive efficiency examined in detail here.

Stallion owners and stallion managers can also use the results to identify mares which are less likely to become pregnant and/or take more breedings. In order to maximize profits for stallion owners it is crucial that the mares produce live foals, given that most breeding contracts are with live foal guarantee. The regulations of the Jockey

Club prohibit artificial insemination, therefore for stallion owners it is important that mares become pregnant on the first cover, so the stallion can breed other mares.

Future research of reproductive efficiency in thoroughbreds can be directed to examine live foal rates in more detail, and possibly combine those with sales results. The data should be extended to include the outcomes of foaling as well as more details about management practices on farms. There is a need for identifying the differences on the farm level, so breeding efficiency can be examined to a much greater detail. The end goal for many breeders is to sell yearlings. While a good pedigree and excellent conformation are crucial factors in determining sale prices, the first step is to breed the mare. This thesis' purpose was to aid decision makers to achieve high pregnancy rates. There are many more aspects of the thoroughbred industry worth further research. This way broodmare managers, and owners can make decisions that are more informed.

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