Selection for prolificacy and the economic impact of sow retention in the breeding herd

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Selection for prolificacy and the economic impact of sow retention in the breeding herd

by

Tasha Renae Gruhot

A thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Animal Breeding and Genetics

Program of Study Committee:
Tom Baas, Major Professor
Kenneth Stalder
Kenneth Koehler

Iowa State University
Ames, Iowa

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TABLE OF CONTENTS

LIST OF FIGURES ........................................................................................................ iv
LIST OF TABLES ........................................................................................................... v
ACKNOWLEDGMENTS ................................................................................................. vi
ABSTRACT .................................................................................................................. viii

CHAPTER 1 GENERAL INTRODUCTION ................................................................... 1

CHAPTER 2 LITERATURE REVIEW ............................................................................ 5

I. Optimal parity distribution ..................................................................................... 5
   a. Definition ........................................................................................................... 5
   b. Replacement gilts ............................................................................................. 5
      i. Sow herd dynamics ..................................................................................... 5
      ii. Genetic merit of replacement gilts .............................................................. 6
      iii. Cause of replacement .............................................................................. 7
   c. Culling rates ..................................................................................................... 7
      i. Gilt culling .................................................................................................. 9
   d. Health benefits of older sows ...................................................................... 10
   e. What has been recommended? ..................................................................... 11
      i. How cull sow, gilt, and weaned pig prices impact OPD ......................... 13
   f. Industry averages .......................................................................................... 13

II. How does the industry improve sow longevity? ................................................ 14
   a. Selecting for increased longevity .................................................................. 15

III. Economic analysis of the breeding herd ............................................................ 16
   a. Profitability and productivity ....................................................................... 16
   b. Inputs and outputs ......................................................................................... 17
   c. Systems breakeven point .............................................................................. 17
   d. Costs associated with the sow farm ............................................................. 18
   e. Full value pigs ............................................................................................... 19
   f. Economic benefit of later parity sows .......................................................... 20
      i. Weaned pigs ............................................................................................ 20
      ii. Effect of culling/replacement rate ........................................................... 21
      iii. Non-productive days ............................................................................. 22
   g. Net present value ......................................................................................... 22
IV. Early parity performance impact on later parity performance .......................... 24
  a. Objective of early parity selection tools .................................................. 24
  b. Classification of early parity performance ............................................. 25
  c. Predictability of early parity information ............................................. 26
     i. Correlation/repeatability ..................................................................... 26
     ii. Effect of culling .............................................................................. 26
     iii. Number born alive and pigs weaned .............................................. 27
     iv. Total litter size and effect of first and second parity interaction ....... 27

CHAPTER 3 USING FIRST AND SECOND PARITY NUMBER BORN ALIVE INFORMATION TO ESTIMATE LATER REPRODUCTIVE PERFORMANCE IN SOWS ........................................................................ 29
Abstract .................................................................................................. 29
Keywords ................................................................................................. 30
3.1 Introduction .......................................................................................... 31
3.2 Materials and Methods ......................................................................... 32
  3.2.1 Performance data and data exclusion criteria .................................. 32
  3.2.2 Categorization according to NBA in parity 1 and parity 2 ............. 33
  3.2.3 Statistical analysis .......................................................................... 33
3.3 Results and Discussion ......................................................................... 35
3.4 Summary and implications .................................................................. 41
Literature Cited ......................................................................................... 43

CHAPTER 4 AN ECONOMIC ANALYSIS OF SOW RETENTION IN A U.S. BREED-TO-WEAN SYSTEM ..................................................................................... 51
Abstract .................................................................................................. 51
Keywords ................................................................................................. 52
4.1 Introduction .......................................................................................... 52
4.2 Materials and Methods ......................................................................... 54
  4.2.1 Production data and data exclusion criteria .................................. 54
  4.2.2 Estimation of number born alive and pre-weaning mortality from the production data ........................................................................ 55
  4.2.3 Value of animals .............................................................................. 56
  4.2.4 Model operation .............................................................................. 56
  4.2.5 Variable costs ................................................................................. 57
  4.2.6 Fixed costs ...................................................................................... 58
  4.2.7 Sensitivity analysis .......................................................................... 59
4.3 Results and Discussion ......................................................................... 59
4.4 Conclusions ........................................................................................ 65
Literature Cited ......................................................................................... 66

CHAPTER 5 GENERAL CONCLUSIONS ................................................................. 80

CHAPTER 6 LITERATURE CITED ....................................................................... 82
LIST OF FIGURES

Figure 3.1 Number born alive (NBA; least squares means ± SE) in parities 3 through 10 based on parity 1 number of piglets born alive classification subdivided by parity 2 classification ........................................ 49

Figure 3.2 The effect of the interaction of first and second parity performance (by parity classification) used to predict removal parity from 105,719 sow records from farms the Mid-West United States. ........................................ 50

Figure 4.1 Pigs born alive per litter and pre-weaning mortality, (Least squares means ± SE) estimates by parity, for parities 1 through 8 from 105,719 sows... 77

Figure 4.2 Number born alive per litter estimates by parity groups and year groups (Least squares means ± SE), from 105,719 sows. ............................... 78

Figure 4.3 Pigs born alive per litter and pre-weaning mortality (least squares means ± SE) estimates by parity, for parities 1 through 8 . ......................... 79
LIST OF TABLES

Table 3.1 Number and the percentage of sows that changed in NBA classification according to the number of piglets born alive (NBA) in parity 1 and parity 2 from a Mid-West U.S. integrated commercial swine operation ................................................................. 45

Table 3.2 First or second parity performance (by number of piglets born alive -NBA- parity classification) used to predict LSM estimates ± SE for parities 3 through 10 for NBA and the difference between the high and low NBA groups within first and second parity classifications from 105,719 sows from farms in the Mid-West United States ................. 46

Table 3.3 First and second parity performance (by number of piglets born alive -NBA- parity classification) used to predict lifetime number born alive LSM estimates ± SE for parities 4 through 8 from 105,719 sow records from farms the Mid-West U.S. .......................................................... 47

Table 4.1 Market prices, production values, investment costs, and miscellaneous expenses used in the economic analysis of sow retention for a 5,000 sow breed-to-wean operation (all prices, costs, and expenses in $U.S.) ... 69

Table 4.2 Production values, inputs and outputs used in the economic analysis of sow retention of a 5,000 sow breed-to-wean operation .............................................. 71

Table 4.3 Budget analysis of sow retention in a 5,000 sow breed-to-wean operation on a per weaned pig basis (all prices, costs, and expenses in $U.S.) ................................................................. 72

Table 4.4 Returns over total costs on a per weaned pig basis and net return on investment for a 5,000 sow breed-to-wean operation (all prices in $U.S) 74

Table 4.5 Production values, inputs and outputs used in the economic analysis of sow retention of a 5,000 sow breed-to-wean operation ..................... 75

Table 4.6 Feed and total expense inputs in the sensitivity economic analysis of sow retention 5000 head breed-to-wean operation on a per weaned pig basis (all prices, costs, and expenses in $U.S.) ........................................ 76
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ABSTRACT

The objectives of this thesis were i) to compare lifetime sow performance and number of piglets born alive (NBA) across parities, according to 3 NBA classifications in first and second parity and ii) to determine the number of parities a sow should be retained in a breeding to wean system to maximize returns over total costs per weaned pig and net return on investment. Sensitivity of returns over total costs per weaned pig to feed price and number born alive (NBA) was also analyzed. For both objectives the production data used were collected between the years 2001 to 2014 at 17 farms owned by the same Mid-West U.S. company. A total of 502,491 records accounting for the lifetime performance of 105,719 sows were used in this analysis. Data included both purebred and crossbred sow information. For the first objective sows were classified into 3 NBA categories (i.e., low, medium, and high) according to the 25th percentiles of NBA in parity 1 and parity 2. Mixed model analyses were applied to the data. Sows in low first and second parity NBA classification had an average of 1 to 1.8 NBA less per parity in parities 3 through 7 when compared with sows in the medium and high NBA classification, respectively ($P < 0.05$). Conversely, sows classified as high NBA in parity 1 and parity 2 had greater NBA in all subsequent parities as well as total lifetime NBA when compared with sows classified as low or medium NBA ($P < 0.05$). The results indicated that with the inclusion of second parity classification, sows classified as low NBA in parity 1 had a greater level of variation between later parity estimates than sows that were classified as high NBA in parity 1 ($P < 0.05$). Thus, the effect that parity 2 classification had on estimated later parity performance was found to be dependent on parity 1 classification ($P$-interaction $< 0.05$). The interaction between classes was seen
when predicting total lifetime performance on a number born alive basis as well. As parity 1 classification increased, the difference between estimates by high and low NBA parity 2 classification became smaller. It was shown that parity 1 and 2 classification only had a small effect on the parity of removal. In conclusion, it was demonstrated that the use of first and second parity performance (based on number born alive) can be used effectively to predict subsequent parity and lifetime performance which can be used to aid in selection and culling decision early in the sows’ life. For the second objective, projected budgets were used to compare returns for various parity distributions. A “steady-state” model was used to demonstrate returns based on an existing farm versus a system that is just entering production. The returns over total cost per weaned pig were calculated using both variable and fixed costs associated with a 5,000 head sow farm based on the proportion of sows by parity in the distribution. Estimates for NBA and pre-wean mortality were shown to be statistically different between parities ($P < 0.05$). The parity distribution where sows are culled after parity 6 produced weaned pigs at lowest costs with the highest returns. Keeping sows until later parities, such as parity 7 through 9, had greater returns over total costs versus culling sows after parities 1 through 4. Net return on investment was maximized in the parity distribution that culled after parity 6, and parity distributions culling after parities 5 through 8 all showed approximately a 15% return on investment. Sensitivity analysis results indicate that as sows increased in NBA, culling after parities 5 through 9 saw higher returns. When feed prices were low the parity distributions culling after parities 6 through 9 resulted in the greatest returns and when feed prices were high, all parity distribution’s costs exceed returns per weaned pig, but culling after parities 5 and 6 were the parity distributions that were closest to break-
even. Results from this body of work demonstrate the economic benefits associated with increased sow longevity as well as a means to select superior dams early in their life. Both production strategies have the potential to be implemented into breeding herds to increase the profit realized by the system.
CHAPTER 1
GENERAL INTRODUCTION

The primary purpose of the breeding herd is to produce a source of pigs to feed through market weight or to directly market weaned pigs. Breeding herd efficiency is measured in terms of profitability or productivity (i.e., piglets produced per sow per year, kg of meat produced per sow) (Stevermer, 1991). Herd productivity is influenced by the parity distribution of the breeding herd and it has been shown that herds with parity distributions retaining older sows are more productive and profitable than herds that are comprised of primarily lower parity sows (Dhuyvetter, 2000b).

In the USA, sows are, on average, removed after 3.1 to 3.7 parities (Stalder et al., 2000; Lucia et al., 1999); however, benefits of allowing sows to remain in the breeding herd longer have been observed in productivity as well as economic gains. For instance, sows that remain longer in the herd (i.e., sows with increased longevity) have a greater number of litters produced and the number of pigs weaned per sow per year increases (Lucia et al., 1999). This gives the sow a greater opportunity to cover her costs and be profitable for the producer (Stalder et al. 2003).

However, sow longevity is difficult to define and it is commonly measured in the context of the traits that are being studied. Studies focusing on nutrition or genetics may be interested in defining longevity by length of life, productive life, or removal parity. On the other hand, a study focusing on economics may be more interested in defining longevity based on lifetime productivity measurements or at which parity a positive net present value is attained (Stalder et al. 2004; Stalder et al. 2003). Though there have been several definitions of sow longevity proposed, most studies have concluded that sows are
currently not being retained in the breeding herd as long as they should be based on their reproductive capabilities as well as the beneficial economic impacts older sows may bring to the herd (Dhuyvetter, 2000b; Stalder et al. 2000; Stalder et al., 2003).

Sows are removed for either voluntary (i.e., set parity cull) or involuntary reasons (i.e., failure to conceive and locomotion problems) (D’Allaire et al., 1987) and it has been estimated that approximately 50 to 60% of sows are removed annually (including both removals and deaths) in the USA (Stein et al., 1990; Mabry, 2015; Loula et al., 2010). Reducing the voluntary and involuntary culling rate in the sow population is essential to increase the longevity of the herd (Rodriguez-Zas et al., 2006). One way to reduce culling rates is to identify superior sows early in life. If superior animals can be selected within their first several parities, culling on poor performance is reduced as it has been reported that sow retention in the breeding herd can be increased by selecting for highly prolific sows (Serenius, 2004). Using first and second parity performance has been previously used as an efficient method to identify superior sows based on several traits including litter size and number born alive (Iida and Koketsu, 2015). The early indicator trait of number of piglets born alive within each parity was specifically shown to be useful when predicting sow longevity (Engblom et al., 2015).

The value of sow longevity has been observed from an economic perspective. Older sows wean heavier pigs and produce more pigs per year than females in lower parities (Lucia et al., 1999; Carney-Hinkle et al., 2013; Dhuyvetter, 2000a). Dhuyvetter (2000b) reported that maximum returns per weaned pig are realized by allowing sows to remain in the breeding herd until their 8th or 9th parity and Stevermer (1991) reported that sows as old as parity 8 through 10 outperform sows in their first parity. A sow reaches a
positive value for lifetime net income at her $3^{rd}$ parity (Sasaki et al., 2004; Stalder et al., 2003); however, with the U.S. average culling parity between 3.1 and 3.7 (Stalder et al., 2003) a sow barely covers her replacement cost at the time of removal. This represents a loss in profit potential by not retaining that sow until later parities. If the cost of a replacement gilt can be spread over a greater number of pigs produced, such as the case when sows are retained longer, the cost to produce a market hog decreases (Abell et al., 2010).
Thesis organization

The general introduction in Chapter I is followed by Chapter II, a comprehensive literature review about related topics to the overall thesis subject. Chapters III and IV are submitted journal articles that have been modified for the purpose of this thesis. Chapter III is “Using first and second parity number born alive information to estimate later reproductive performance in sows” and Chapter IV “An economic analysis of sow retention in a U.S. breed-to-wean system”. Chapter V consists of an overall conclusion to the work in this thesis. Chapter VI contains the literature cited for the literature review of Chapter II.
CHAPTER 2
LITERATURE REVIEW

I. Optimal parity distribution

a. Definition

Optimal parity distribution (OPD) is examined to determine the most cost effective and optimally profitable herd based on the distribution of sows across the given number of parities within the breeding herd. Factors including the cost of replacement gilts, the cost of feed, conception rate, and average pigs weaned per litter by parity contribute in developing the OPD (Dhuyvetter, 2000a).

b. Replacement gilts

i. Sow herd dynamics

The combination of mortality, culling, changes in herd inventory, size of the herd, breed, lactation length, and the desired genetic improvement play a dynamic role in influencing gilt replacement rates (Irwin and Deen, 2000). High replacement rate levels seen in the past, especially in the nucleus and multiplication levels of production, are largely due to the desire to make genetic progress quickly through the replacement of an older sow with a younger, genetically superior female. Generation interval, or the age of parents when their offspring are selected to replace them, directly influences how quickly this genetic gain is made. Thus by increasing replacement rate, the generation interval is shortened, increasing the amount of genetic gain (Falconer and Mackay, 1996). This rapid genetic gain is desirable in nucleus herds as the main purpose of a nucleus herd is to rapidly increase gain and produce a genetically superior new generation. Nucleus herds
account for the smallest percent of sows in production, with the largest percent of sows being bred to produce market animals. However, the animals in the nucleus are used to produce the future generations of pigs that are used in populating the multiplication herd, or the sows used to produce the breeding animals for commercial production. The multiplication level is where genetic improvement made in the nucleus is disseminated throughout the production system, approximately 10-15% sows (Sellers, 1994). The greatest proportion of sows exists in the commercial segment, where commercial animals are bred to produce market animals for consumption. The commercial animals are the end result of all genetic decisions made throughout the nucleus and multiplier farms that then influence commercial sow performance as well as the performance of their offspring to increase profitability (Abell et al., 2010).

ii. Genetic merit of replacement gilts

Unnecessary high replacement levels are seen if too much emphasis is put on reducing generation interval in the commercial tier of production, which can lead to reduced profitability. Relatively little genetic progress is made if a sow is replaced in her early parties due to the slow genetic change made at the commercial level. It is likely that the replacement gilts and culled sows are of similar genetic merit (Abell et al., 2010). Abell et al. (2010) studied the difference between the genetic value of a sow versus the genetic value of a replacement gilt. The authors reported that voluntarily replacing a sow before the average value of the genetic loss exceeds the purchase and development price of replacement gilts is detrimental to making a profit from that herd. Abell et al. (2010) recommended that sows stay in the herd as long as they are still producing at a
satisfactory level based on that herds requirements (Abell et al., 2010). Once a replacement gilt is introduced into the breeding herd to replace an older sow, the genetic improvement will be recognized immediately regardless of how many parities the sow was retained in the herd, but by allowing the sow to produce in the herd longer the profit level per animal is increased (Abell et al., 2010).

iii. Causes of replacement

Annual sow replacement rates have been reported at approximately 50% (Stalder et al., 2011). Farms with high replacement rates have low sow retention and thus have a higher number of litters produced from young sows compared to system that have a lower replacement rate (Joaquin Spörke, 2009; Stevermer, 1991). Gilts have been selected for performance and carcass traits, which are unfavorably related to sow productive lifetime (Joaquin Spörke, 2009). The majority of sow productivity traits have been found to be lowly heritable, but carcass and production traits have higher heritability values (See, 2008). A shorter productive life of the sow has also been reported as producers have bred for increased leanness (Stalder et al., 2008). Part of this poor gilt performance may also be due to the lack of effective gilt puberty management programs (Stalder et al., 2003; Mabry, 2015).

c. Culling rates

Reported sow culling rates vary from 40-50% annually (Stein et al., 1990; Mabry, 2015; Loula et al., 2010) with an average sow mortality rate of 8% (Loula et al., 2010). It has been reported that when the genetic improvement seen in a gilt outweighs the
development cost of that gilt, the optimal culling parity is reached (Abell et al., 2010). Culling rate within a herd is influenced by past and expected performance, physical characteristics of the sow such as locomotion problems, the expected performance of potential replacement stock, reproductive failure, as well as market trends at that time of culling decisions (Irwin and Deen, 2000; Stevermer, 1991).

Time of year or climatic season can directly influence culling rate. The greatest proportion of annual culling is reported to occur in late autumn/early winter with the lowest proportion culled during the summer months, which is the season shown to have the highest sow mortality (Irwin and Deen, 2000). The main reasons reported for high culling rates include reproductive failure, such as anestrus and failure to conceive, locomotion issues, and old age (Irwin and Deen, 2000; Sasaki and Koketsu, 2008; Stalder et al., 2004; Sehested, 1996). Poor litter performance has also been reported to be a common reason to remove sows from the herd, as it has been reported that 50% of sows classified as low producers early in life were culled before parity 6 (Sasaki and Koketsu, 2008). Each extra piglet above the average per litter has been shown to decrease culling rates at that parity by 2% and an 8% increase in culling rate was correlated with 1 or more stillbirths in the preceding litter (Irwin and Deen, 2000).

Fifteen to 20% of sows produce only 1 litter before time of removal (Lucia et al., 2000) with approximately 30% or more removed before their third parity in commercial herds (Engblom et al., 2007). Studies have indicated that sow culling from parity 1 through 4 remains fairly consistent. After parity 4, the proportion of sows culled by parity steadily increases until parity 6 where an even more drastic increase in culling can be seen after parity 7 (Irwin and Deen, 2000). Average removal parities of 3.1 to 3.7 as those
reported by Stalder et al. (2000), are indicative of a large percentage of culls taking place in young animals, which supports the findings that culls most commonly occur for reproductive failure. However, it has been reported that once a sow reaches her third parity the more common reasons for removal are old age, poor reproductive performance, and in some cases, death. High culling rates have a direct negative influence on herd productivity, especially when a large portion of young sows are culled prior to reaching their peak productive parities (Stalder et al., 2004).

Typically the purchase price of a replacement gilt exceeds the market price of the sow being replaced or of traditional market hogs. Sows become heavier with increasing parities up to at least parity 4. If a sow can stay in the herd for additional parities and increase weight and condition this will increase her cull sow value. This cull sow value needs to be used to help determine when to replace the sow (Abell et al., 2010).

i. Gilt culling

It is estimated that 30-50% of gilts do not show estrus or do not conceive and are removed prior to entering the breeding herd (Loula et al., 2010). Costs associated with replacement gilts are purchase price or rearing costs, feed, vaccinations, the space required for housing, and semen costs if they were bred but did not conceive. The cost associated with developing gilts that do not breed and are culled have to be recovered by the gilts that enter the breeding herd. The greater number of parities a sow remains in the breeding herd, the more litters or weaned pigs she then has to spread gilt development costs over which will in turn reduce the cost of producing each market hog (Loula et al., 2010; Dhuyvetter, 2000b).
d. Health benefit of older sows

Distinct differences in progeny proficiency can be seen between a gilt and sow. Generally it is accepted that these differences seen between the progeny of first parity dams versus mature sows are due to reduced health status of the primiparous females (Burkey et al., 2008; Carney-Hinkle et al., 2013; Mahan, 1998). It was reported that older sows have higher immunoglobulin concentrations 24 hours pre-farrowing when compared to gilts and it was suggested that gilts have a greater stress level, as measured by cortisol concentrations, near the time of parturition when compared to older females. It was also shown that progeny from older sows have a greater concentration of immunoglobulin starting at day 0 post-farrowing until day 37 post-farrowing when compared to parity 1 offspring. These greater immunoglobulin concentrations produced from older sows and their progeny may lead to the improved health status of these animals. This allows for better immune protection against pathogens allowing for the observed increased weaning weights, increased nursery and finishing average daily gain, as well as decreased mortality in the nursery and finishing phases of the sows offspring in comparison to the offspring of gilts (Burkey et al., 2008). Parity of the dam has been reported to affect other production traits. For instance, pigs born from primiparous dams have progeny with a lower birth weight as well as lower litter weight when compared to older sows. This weight difference carried over to weaning, as offspring from first parity dams had a lower average weaning weight due to lower average daily gain compared to offspring produced by older sows (Carney-Hinkle et al., 2013; Mahan, 1998). This trend of healthier offspring by older sows was also shown into the finishing phases as it was
reported that market hogs from mature sows were significantly more profitable than market hogs from first parity sows (Mabry, 2015).

From a breeding herd perspective there is an increased health risk when incorporating new gilts into the breeding herd. When gilts are introduced into the breeding herd there is a risk that the gilt may introduce diseases that are not already present in the mature sow population. The more frequent gilts need to be introduced into the breeding herd, the greater the replacement rate, and the risk of disease outbreak is exacerbated (Stalder et al., 2004; Stalder et al., 2008).

e. What has been recommended?

First and second parity sows wean fewer pigs per litter, and they tend to be lighter at weaning, when compared to offspring produced by older mature sows (Carney-Hinkle et al., 2013; Dhuyvetter, 2000b), for this reason it is recommended that producers keep culling levels low to reduce the number of dams in first or second parity within the breeding herd (Stevermer, 1991). Sow retention rate drives OPD, due to the producers want to retain the highest producing females at the greatest percentages. As a result, the more productive parities will compose a higher proportion of sows throughout the parity distribution (Morrison et al., 2002). A 52% target of a systems’ farrowing being comprised of sows in their third to sixth parity has been set due to these litters being considered peak performance in the sows lifetime (Joaquin Spörke, 2007, Stalder et al., 2000). Other studies have shown the greatest productivity occurring in even later parities, up to parity 10 (Dhuyvetter, 2000b; Stevermer, 1991). A sow should not be replaced until the productivity of the higher parity sow is less than that of a potential replacement gilt.
However, by replacing the older sow with a gilt, the cost of production per unit of weaned pig may increase depending on current prices (Stevermer, 1991).

It has previously been reported that a breeding herd is optimal when comprised of 19 to 20% gilts (Dhuyvetter, 2000a; Loula et al., 2010; Morrison et al., 2002) representing a 40-60% replacement rate depending on the farm (Loula et al., 2010; Morrison et al., 2002). This allows for maximum pigs weaned/sow/year by keeping sows through their 8th parity. By keeping the sows until parity 7 through 9 the cost of producing a weaned pig is minimized, and when a sow is retained for 7 to 10 parities the return per sow can be doubled when compared to culling after parity 4 (Abell et al., 2010; Dhuyvetter, 2000b).

Other optimal parity distributions have been suggested, limiting the early parity sow percentages even more to 15% first parity sows, 14% second parity sows, and 13% third parity sows (Muirhead and Alexander, 1997). Mean parity of the breeding herd for these recommended OPDs was between 2.8 and 3.85. This value varied due to the percentage of older sows at each parity throughout each distribution, though the percentage of first parity animals had similar recommendations (Stalder et al., 2000; Dhuyvetter, 2000a; Morrison et al., 2002).

If the cost of a replacement gilt can be spread over a greater number of pigs produced, such as the case when sows are retained longer, the cost to produce a market hog decreases (Abell et al., 2010). All presented studies that recommend an optimal parity distribution, though they vary slightly, highlighted the importance of including older sows in the distribution at a higher percentage than first or second parity dams.
i. How cull sow, gilt, and weaned pig prices impact OPD

Gilt replacement cost and sow salvage value (cull sow value) have the greatest impact on OPD followed closely by weaned pig price (Rodriguez-Zas et al., 2003). Gilt replacement cost is the amount a producer has invested into a gilt the day she enters the breeding herd and replaces an older sow. These costs include her value or purchase price, as well as costs associated with acclimation, feed, transportation, vaccines and medication (Morrison et al., 2002). It was observed that in situations where gilt prices are high but cull sow value and weaned pig value were low, the optimal parity of removal was between parity 6 and 10. However, when gilt prices were low, but cull values and weaned pig prices were high the optimal parity of removal could be as low as parity 2 (Rodriguez-Zas et al., 2003). When just the cost of a replacement gilt is assessed, if the cost of replacement gilts was decreased slightly ($200 to $150), optimal parity of cull did not change from parity 8, whereas when the price increased ($200 to $250), it was shown that the sow must be kept longer, to parity 9. These values were based on a per weaned pig basis (Dhuyvetter, 2000b).

f. Industry averages

It is important to know the present industry conditions in order to assess how much progress has already been made as well as where opportunities exist to improve sow herd efficiency. In 2014, average litters per sow per year was reported at 2.26 with an average number of piglets born alive of 12.3 (Productivity, 2014). Average number of weaned piglets was reported at 9.7, which is lower than previous years, 10.2 in 2013, and
10.3 in 2012. This lower number weaned can be explained, at least partially, by the Porcine Epidemic Diarrhea Virus (PEDV) breakout that occurred at that time in the USA. The PEDV outbreak can also explain the increase in pre-weaning mortality which was 20.5% in 2014 (Productivity, 2014). In the U.S., sows culled for inadequate performance are reported as having an average parity cull of 5.11 parities, while sows culled for reproductive failure had an average parity cull of 2.37 (D’Allaire et al., 1987; Stalder et al., 2004). An overall breeding herd average parity cull was reported between 3.1 to 3.7 (Stalder et al., 2000) and the average parity of females in inventory was reported at 2.55 (Anil et al., 2003). In Japan, a higher average cull parity has been reported than in U.S. at 4.6 parities (Koketsu, 2007). An even lower average parity of removal of 2.7 was reported in 2015, however, this average included all gilts entering the breeding herd regardless if they produced a litter or not (Engblom et al., 2015).

II. How does the industry improve sow retention?

Lifetime piglets produced has been suggested as a measure of longevity, specifically for economic analysis (Engblom et al., 2015). The 2 major components contributing to lifetime productivity are sow attrition control as well as reproductive performance and efficiency in gilts and sows. Reproductive efficiency is measured several ways including conception rate, farrowing rate, pigs born alive, pigs weaned per litter, litters weaned per sow per year, and pigs weaned per sow per year (Stevermer, 1991). Advancements have been seen in sow productivity as sows are weaning more pigs per year than in the past, as long as disease is not a factor (Joaquin Spörke, 2009). Pigs per mated sow per year has increased, total born has increased, as well as improvements
in feed conversion have all been observed (Pork Checkoff, 2014). The implementation of more effective gilt management programs are necessary to improve gilt breeding performance by managing body condition, implementing proper feeding programs, and increasing boar exposure, as well as utilizing employees who are well trained to detect heat and breed (Joaquin Spörke, 2009; English et al., 1977).

a. Selecting for increased longevity

It has been reported that length of productive life and lifetime prolificacy have heritabilities of 0.23 and 0.25, respectively (Guo et al., 2001). These moderate heritabilities indicated that through selection in an efficient breeding program improvement should be realized in these traits overtime (Guo et al., 2001; Engblom et al., 2015). There have been several indicator traits reported that impact the length of productive life and lifetime prolificacy that may be used to indirectly select for these longevity traits. For example, gilt backfat has been shown to be an indicator for sow longevity. It was reported that leaner sows had fewer lifetime total pigs born alive when compared to sows that had more backfat as gilts. It was also observed that the fattest gilts had the highest lifetime total pigs born as well as the averaged a greater parity of removal when compared to leaner sows (Stalder et al., 2005). Structural soundness is also associated with sow longevity. Sows that were weak or soft in their front leg pasterns remained in the breeding herd longer than sows that were too straight in their pasterns (Stalder et al., 2008). Other considerations such as dam age should be examined when selecting for sow herd longevity. Sows that were born from dams in their third, fourth, and fifth parities tended to be retained in the breeding herd longer than sows that were
born from dams in other parities. It was observed that the older a gilt is at first farrowing is negatively associated with longevity, or the younger the age at first farrowing, the lower the risk of the sow being culled early (Serenius and Stalder, 2007). Sow retention in the breeding herd can also be increased by selecting for highly prolific sows (Serenius, 2004). The early indicator trait of number of piglets born alive within each parity was specifically shown to be useful when predicting sow longevity (Engblom et al., 2015).

As molecular genetics tools become less expensive and more reliable it is likely that producers will also invest in technologies such as genotyping to enhance their selection decisions for sow longevity. Twenty-two genes have been reported to be associated with leg and body conformation traits, which in turn affect the health and productivity of the pigs (Onteru et al., 2008). Additionally, there are 3 genes that have been identified that have significant effects on longevity (Mote et al., 2005). The effects of these genes varied from a 0.2 to over a 2 parity increase between different homozygotes. It was shown that 2 of these genes influence other production traits. It has been suggested that by selecting for these longevity genes improvements in other traits may be realized as well (Mote et al., 2005).

III. Economic analysis of the breeding herd

a. Profitability and productivity

The efficiency of the breeding herd is measured in terms of profitability or productivity. The difference between the cost of production and product value is referred to as profitability. Profitability is related to productivity but is often more of a reflection of production costs and market price (Stevermer, 1991).
b. Inputs and outputs

Profit of the sow herd is calculated as output values subtracted from input values. The output value, or weaned pig sold value, is dependent on weight and quality of the weaned pigs as well as the total number sold from the farm. Input values, or costs can be categorized as fixed or variable costs (English et al., 1977). Fixed or overhead costs include costs associated investment in facilities and the equipment needed to produce weaned pigs (Stevermer, 1991). Fixed costs include taxes, insurance, interest, labor, machinery, stock replacement, and building depreciation. Costs that are considered fixed tend to stay constant regardless of the level of farm output and the level of production has little influence on total annual dollars of fixed costs (Stevermer, 1991; English et al., 1977). Of the total cost of production, variable costs account for the largest proportion of cost inputs and are highly correlated with production level (Stevermer, 1991). Variable costs include items such as feed, heating, and veterinary cost. These costs will increase or decrease with the output level (English et al., 1977). The opportunity to spread both fixed and some variable costs over more pigs is enhanced as reproductive efficiency improves in the breeding herd (Stevermer, 1991).

c. A systems breakeven point

A breakeven point is described as an economic loss occurring below this point with an increase in profit margin occurring the farther above this point that a system reaches. The output required to meet a breakeven point is dependent on current values of pigmeat as well as input costs for that system. When pigmeat prices are low, a much
greater weaned pig output is needed to reach the breakeven point than when pigmeat prices are high (English et al., 1977).

d. Costs associated with the sow farm

The highest cost for a system producing weaned pigs is feed costs for sows, at approximately 70% of total costs (English et al., 1977). It has been reported that when feed costs decrease and feed conversion ratio increases sows lifetime profitability also increase (Sasaki and Koketsu, 2008). It has also been observed that when feed costs are high it takes the sow longer to pay for herself and reach a positive net present value (Stalder et al., 2000).

As feed is the most expensive cost to the system, producers have been selecting sows for feed efficiency. Sows have been successfully selected and produced that are more feed efficient than previous generations while still improving reproductive output. It has been reported that as sows that wean more pigs per year, they have more efficient feed conversion ratios (total food per kg of weaned pig) than sows that wean fewer pigs (English et al., 1977).

This comparison in sow efficiency of weaned pigs per year has been studied in an economic analysis which reported that the size of the sow herd required to achieve the same total margin over feed costs when comparing the most efficient sows (i.e., 24 weaned pigs per year) to less efficient sows (i.e., 16 weaned pigs per year) would require doubling the size of the sow herd when using the less efficient sows. By selecting a more efficient sow a decrease in feed cost per weaned pig can be realized (English et al., 1977).
Improving efficiency for overhead costs, like that of housing, are more difficult to make improvements on. It has been reported that the most effective means to reduce building costs is to make the most efficient use of available space that still meets the requirements for comfort of the stock and proper welfare (English et al., 1977). Other means to reduce cost per animal can be in utility costs by improved insulation, and providing microenvironments for young pigs rather than heating the whole room to a high temperature. As a building ages it is important to clean, repair and or replace fans, heaters, curtains, or any other equipment that show significant signs of wear, as they will not run or work as efficiently as new or well maintained equipment. Larger sow herds are more efficient in the use of building capital and labor compared to smaller herds, this is referred to as economies of scale (English et al., 1977).

e. Full value pigs

In order to maximize input values, or the value of weaned pigs sold, producers must try to produce a high level of full-value pigs. Full-value pigs are referred to as the weaned or finished pigs that fall under the standards set when selling them. The producer receives a premium for pigs in the desired weight and carcass characteristic range, while receiving discounts for pigs that do not fall in this range. A goal of 94 to 95% of all pigs weaned falling into the desired range and receiving full-value for them is a common standard set by producers. Part of achieving this goal is selecting the correct pigs for every load based on weight and just age (Loula et al., 2010). Proper handling of pigs during loading and transportation is crucial to minimize death loss and reduce the incidence of poor carcass characteristics due to stress (Loula et al., 2010).
f. Economic benefit of later parity sows

The economic benefit of increased sow longevity has been well described. It has been shown that a sow reaches a positive value of lifetime net income at her third parity (Sasaki et al. 2012; Stalder et al. 2003). The average parity of cull is reported at 3.1-3.7 (Stalder et al. 2003), thus, a sow barely pays for herself and then is removed from the breeding herd. This represents a loss in profit potential by not retaining that sow until later parities as her cost would be spread among a greater number of pigs sold. The net income of a sow from each litter was shown to increased from $145.80 to $390.20 as parity increased from first to fifth and lifetime net income of the sow increased from $-272.8 in her first litter to $1,944.90 as parity increased to parity 8. By increasing sow retention or longevity of the commercial breeding herd, lifetime net income per sow also increases (Sasaki et al. 2012).

i. Weaned pigs

Weaned pigs per litter is a measurement used to assess reproductive efficiency of the breeding herd as it can be used to allocate all expenses shared and distributed among the number of pigs weaned. It has been shown that $1000 per sow is commonly invested just in facilities and equipment, she also has her own initial cost as a replacement and several other variable costs associated with producing pigs (Stevermer, 1991). If small litters are produced or farrowing crates are sitting idle, the fixed cost per weaned pig is higher than when all farrowing crates are being utilized, as well as when litter sizes are larger. The cost of production and net profit for the breeding herd is greatly influenced by a difference in 1 or 2 pigs weaned per litter. This is due to the additional profit seen as
weaned pigs increase as well as the ability to share costs over more pigs (Stevermer, 1991).

In a study conducted by Kroes and Van Male (1979) it was observed that the greatest cost associated with producing a weaned pig was for first parity sows. The cost per weaned pig then decreased over the next 2 litters before slowly rising again, but never to the level of pigs produced by a first parity sow. It was shown that the cumulative costs were lowest in the sow’s seventh parity (Kroes and Van Male, 1979). Similarly, in a study conducted by Dhuyvetter (2000b), the greatest cost associated with producing a weaned pig was when the herd was made up of all parity 1 sows. As later parities are included in the parity distribution, the returns over total cost increases until sows are retained through parity 9 with only a slight decrease in returns observed by incorporating parity 10 sows.

ii. Effect of culling/replacement rate

Annual sow replacement rates have been reported at approximately 50% (Stalder et al., 2011). Herds that cull at a high rate see an increased price associated per weaned pig sold. This is because as the cull rate increases the replacement rate. This increase in replacement rate and the cost associated with it is the main driver for the higher cost associated with the weaned pigs in these types of systems versus a system that has a lower culling and replacement rate (Kroes and Van Male, 1979). When replacement rate is low, a greater optimal parity was observed as well as more favorable economic conditions seen in net present value, internal rate of return, modified internal rate of
return, and annuity equivalent when compared to systems with a higher replacement rate (Rodriguez-Zas et al., 2006).

iii. Non-productive days

Non-productive days (NPD) are days, typically reported per year, are days that a sow is not gestating or lactating. Non-productive days represent the time spent in breeding where the sow is taking space and eating, which both have a cost associated with them, as she is not actively partaking in profit producing activities. If estrus is not detected after weaning or the sow does not conceive after weaning NPD are increased. The goal of a producer is to maximize pigs produced per sow per year (PSY) at the least cost of production. NPD, lactation length, number of stillborns per litter, as well as pre-weaning mortality all influence PSY, with NPD having the strongest influence (Polson et al., 1993). A study by Lucia et al., (1999) showed that 20.7% of a sows herd life was spent in NPD. It was reported that as the removal parity increased the proportion of herd-life spend in NPD decreased (Lucia et al., 1999).

g. Net present value (NPV)

The optimal time to cull a sow will be directly influenced by the cost of replacement gilts for that herd (Dhuyvetter, 2000a). Purchasing gilts increase the capital investment required for a system. There are the costs of acclimation and development that need to be considered. An even larger capital investment is needed with high replacement rates and or high gilt prices. A way to assess the time in which the initial gilt investment is profitable is by using net present value (NPV) analysis. A positive NPV determines
how many parities are necessary for that sow to stay in the breeding herd until this breakeven point is reached, otherwise defined as the difference observed in the present value of income and costs including depreciation (Stalder et al., 2003; Rodriguez-Zas et al., 2006). The earlier a sow reaches a positive NPV the more profit she produces for that system. Due to the greater production seen with sows and the cost associated with replacement gilts (facilities, feed, breeding, purchase price, etc.) it is profitable for a producer to have as many sows as possible reach the parity where they have attained a positive NPV and paid for their initial costs (Abell et al., 2010). In the USA, this positive net present value has been reported to be realized once a sow is through her third parity (Stalder et al., 2003). Number of pigs born alive, pigs sold per litter and weaned pig price all effect NPV. If a dam is a low producer, such as low number born alive, it will take her longer to reach the breakeven point. This greater breakeven point is noted when gilt prices are higher as it will take more parities before a positive NPV can be observed. Perhaps the most volatile effect on NPV is weaned pig price, as this price changes so will the parity at which a positive NPV can be realized (Stalder et al., 2003).

When a sow reaches this break-even point has been shown to be directly influenced by feed cost, number of pigs born alive, as well as market hog price. As average number born alive increases, sows reach a positive NPV earlier in life than when pigs born alive is less. As market hog price increases it is also shown that sows reach a positive NPV earlier in their lifetime versus when market prices are low. It has been observed that when feed prices are high a sow reaches a positive NPV later in life than when feed prices are low (Stalder et al., 2000).
NPV of a sow has been assessed from a market hog sold perspective as well. It was shown that a sow reaches a positive NPV at her third parity (Stalder et al., 2000). Number born alive, market hog price, and feed cost per market hog were used in a sensitivity analysis was conducted Stalder et al., (2000) using these inputs and a positive NPV was found between parity 2 and parity 4. A higher purchase price of replacement gilts increased when a positive NPV is realized by one parity, to parity 4. NPV is also affected by equity. It was shown that as equity decreased from 50% to 30% a positive NPV is realized in parity 4 instead of third parity (Stalder et al., 2000).

IV. Early parity performance impact on later parity performance

a. Objective of early parity selection tools

The ability for producers to make decisions about keeping or culling sows at an early age has the ability to increase herd productivity by identifying high producing sows (Iida and Koketsu, 2015). Studies conducted in Europe and Japan have shown that sows with a high number of piglets born alive in parity 1 have subsequent litters with a higher than average number of piglets born alive (Iida and Koketsu, 2015; Sasaki and Koketsu, 2008; Hoving et al., 2011). This increased production can directly be tied to sow longevity and retention in the herd as high lifetime performance is associated with sow longevity (Sasaki and Koketsu, 2008; Hoving et al., 2011; Engblom et al., 2015; Serenius, 2004).
b. Classification of early parity performance

Studies conducted in Japan and Europe have shown that classifying young sows into low, medium, and high producing groups is a reliable way of identifying high producing sows early in their life (Iida and Koketsu, 2015; Hoving et al., 2011). This classification has been conducted several ways for different reproductive traits such as number of piglets born alive as well as total number born. (Iida and Koketsu, 2015; Iida et al., 2015).

In a Netherlands study that assessed litter size (total number born), the classification system used for sows included first and second parity as explanatory variables broke into groups of low, medium, and high based on the average litter size of first and second parity (11.4 ± 0.01) and (12.0 ± 0.02), respectively (Hoving et al., 2011). A similar study in Japan assessed the relationship between sow retention in the herd with reproductive lifetime measurements with the objective of testing the correlation between these factors. Sows were classified as high, medium, or low producers based on annualized lifetime pigs born alive. If culled before parity 6, the sow was considered a low longevity sow, and if after parity 6, a high longevity sow. The classes were set based on the upper and lower 25th percentiles for annualized lifetime pigs born alive (Sasaki and Koketsu, 2008). Studies in Spain and Japan have specifically looked at number born alive in parity 1 in relation to lifetime and reproductive performance. Another study classified sows into parity 1 reproductive group by the lower and upper 25th percentiles of pigs born alive and farms were classified as high or low producing herds based on the 50th percentile of pigs weaned per mated female per year (Iida and Koketsu, 2015). While
a similar study classified sows into groups by the 10th, 50th, and 90th percentiles for nba in parity 1 (Iida et al., 2015).

c. Predictability of early parity information
   i. Correlation/repeatability

   The repeatability between any 2 adjacent parities within a sow for number of piglets born alive is 0.15 (Dube et al., 2012; Iida et al., 2015). Iida et al. (2015) reported that the intraclass correlation between a sows parity records for number of piglets born alive is 17.6%. A greater proportion of high longevity high reproductive efficiency sows in the herd was correlated with more pigs weaned per mated female per year as well a more litters per mated female per year (Sasaki and Koketsu, 2008). Annualized lifetime pigs born alive was shown to be highly correlated with sows longevity in the herd, parity at culling, and nonproductive days per parity, with correlations of 0.68, 0.76, -0.46 respectively (Sasaki and Koketsu, 2008).

   ii. Effect on culling

   The effect of parity 1 and parity 2 classification on parity of culling indicated that sows with a low parity 2 classification for litter size in second parity were culled earlier than sows with a high or medium classification (Hoving et al., 2011). A lower percentage of high classified parity 1 females for number of piglets born alive were culled early in relation to low or medium classified females. This indicated that high parity 1 performance sows have reduced risk of premature culling and have increased survival and longevity in the breeding herd (Iida and Koketsu, 2015).
iii. **Number born alive and pigs weaned**

Sows that were retained the longest and had the highest reproductive efficiency had the most lifetime pigs born alive and the shortest non-productive days (Sasaki and Koketsu, 2008). Sows that had 15 or more piglets born alive in parity 1 had 0.5 to 1.8 more pigs born alive in all subsequent parities, which was greater and significantly different than sows in lower parity 1 groups. The high parity 1 group showed to have 0.2 to 1.5 more pigs weaned with a farrowing rate of 2.8 to 5.4% higher than those in the low parity 1 group in parities 1 through 3. Sows in the high parity 1 group had 2.9 to 11.7 more annualized lifetime number of piglets born alive than sows in the medium or low parity 1 sow groups (Iida et al., 2015). Pigs born alive in parity 1 seem to explain about 30% of the unexplained variance of lifetime average pigs born alive. The difference seen in lifetime pigs weaned as predicted by parity 1 classification was larger between sows groups in low performing herds than in sow groups of high performing herds (Iida and Koketsu, 2015).

iv. **Total litter size and effect of first and second parity interaction**

Litter size in parity 3 and up was shown to decrease with decreasing parity 1 and parity 2 litter size classification. This decrease between classifications was not independent. Sows second parity effects were greater when sows had a low first parity classification than when sows had a high first parity classification. When second parity was high however, there was little difference between parity 1 low and medium sows in later parities. The results indicated that sows that were high litter size in both parity 1 and 2 had the greatest litter sizes in all subsequent parities. From the model sum of litter size
in parity 3 through 5, it was shown that sows with a high litter size in parity 2 produced more piglets from parity 3 through 5 regardless of what the first parity classification was. However, the effect of parity 1 was still seen as low parity 1 sows had the greatest effect seen by parity 2 classification (Hoving et al., 2011).

All studies using parity 1 and or parity 2 classification concluded that the use of early parity performance is useful to predict highly prolific sows at an early age.
CHAPTER 3

USING FIRST AND SECOND PARITY NUMBER BORN ALIVE INFORMATION TO ESTIMATE LATER REPRODUCTIVE PERFORMANCE IN SOWS

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Abstract

The study objectives were to compare the lifetime performance of sows and number of piglets born alive (NBA) across parities, according to 3 NBA classifications in first and second parity. The data used for this study were collected from 2001 to 2014 at 17 farms owned by the same company. Farms were located in the Mid-West region of the United States. A total of 502,491 records accounting for the lifetime performance of 105,719 sows were used in this analysis. Data included both purebred and crossbred sow information. Sows were classified into 3 NBA categories (i.e., low, medium, and high) according to the 25th percentiles of NBA parity 1 and parity 2. Mixed model analyses were applied to the data. Sows in the low first and second parity NBA classification had an average of 1 to 1.8 less NBA per parity in parities 3 through 7, when compared with sows in the medium and high NBA classifications, respectively ($P < 0.05$). Conversely,
sows classified as high NBA in parity 1 and parity 2 had greater NBA in all subsequent parities as well as total lifetime NBA when compared with sows classified as low or medium NBA \((P < 0.05)\). With the inclusion of parity 2 classification in the model, the variation observed in the estimates of NBA by parity was greater in sows that were classified as low in first parity versus sows that were classified as high in parity 1 \((P < 0.05)\). This indicates that the effect that parity 2 classification has on estimated later parity performance is dependent on parity 1 classification \((P\text{-interaction} < 0.05)\). The interaction between classes was also seen when predicting total lifetime performance on a number born alive basis. As parity 1 classification increased, the difference between estimates of high versus low parity 2 NBA classification sows became smaller. It was shown that parity 1 and 2 classification only had a small effect on the parity of removal. Overall, it was demonstrated that the use of first and second parity performance, based on number born alive, can be used effectively to predict subsequent parity and lifetime performance which can be used to aid in selection and culling decisions early in the sow’s life.

**Keywords:** Number born alive, subsequent reproductive performance, early parity classification, first parity, second parity, repeated measures, lifetime performance, swine, parity of removal
3.1 Introduction

The ability to assess sow performance at first and second parity is necessary when making selection and culling decisions for the breeding herd, as early performance of the sow has been shown to be indicative of later lifetime performance (Iida and Koketsu, 2015; Sasaki and Koketsu, 2008; Hoving et al., 2011). The classification of parity 1 and parity 2 dams as low, medium, or high for reproductive traits can give producers a consistent means to predict later parity performance for sows (Iida and Koketsu, 2015; Sasaki and Koketsu, 2008; Hoving et al., 2011). The repeatability of number of piglets born alive (NBA) is considered to be low (Dube et al., 2012) and there are additional factors that may influence first parity performance beyond the sow’s genetic potential that are not as prevalent in later parities, such as an increased sensitivity to seasonal effects (Tummaruk et al., 2010). Adding additional performance records, such as parity 2 records, improves the accuracy of the prediction for future parities (Mrode, 2014). Generally, even if a sow’s performance is less than desirable in her first parity, she is generally retained until second parity to assess if her performance improves.

Studies conducted in Europe and Japan have shown that sows with a high number born alive in parity 1 have subsequent litters with a higher than average number born alive as well (Iida and Koketsu, 2015; Sasaki and Koketsu, 2008). This can be directly tied to sow longevity and retention in the herd as it has been shown that high lifetime performance is associated with superior sow longevity (Sasaki and Koketsu, 2008). It has also been demonstrated that sow retention in the breeding herd can be increased by selecting for highly prolific sows (Serenius, 2004), and the early indicator trait of number
born alive within each parity was specifically shown to be useful when predicting sow longevity (Engblom et al., 2015).

Therefore, the objectives of this study were to compare the lifetime performance of sows and number of piglets born alive across parities, according to 3 NBA classifications in parity 1 and 2.

3.2 Methods and Materials

Animal Care and Use Committee approval was not obtained for this study because the data used for this analysis were obtained from a private company’s existing database.

3.2.1 Performance data and data exclusion criteria

Data editing and categorization was conducted in R (R, 2015). Data were collected over a 13-year span (2001 to 2014) at 17 farms located in the Mid-West region in the United States. Both purebred and crossbred sow lines were included in the dataset. Data editing was performed to ensure data were within normal physiological ranges and free from recording errors. Outlier records were removed and any sow that did not have complete lifetime performance records was not included in the analysis. Individual records were considered outliers and removed from the data set if they were ±3 standard deviations from the mean for the following traits at each parity: number of piglets born alive, number of piglets weaned, total piglets born, number of stillborn piglets, wean to first service interval, and weaning age. Records greater than parity 10 were removed due to the small number of records in those high parities. The Shapiro test was used on the
model residual information as well as the examination of the normal plot to evaluate the dataset for normal distribution. The final data set included 502,491 records accounting for lifetime performance of 105,719 sows.

3.2.2 Categorization according to NBA in parity 1 and parity 2

Sows were classified into low, medium, and high NBA categories according to the NBA in parity 1 and parity 2. Sows were classified in these groups based on the lower and upper NBA 25th percentiles (Sasaki and Koketsu, 2008; Iida and Koketsu, 2015). For parity 1, the low NBA group was classified as less than 10 piglets born alive, medium NBA was classified as 10 through 12 piglets born alive, and high NBA was classified as greater than 12 piglets born alive. The subsequent percentage of sows per group was 23.7%, 43.6%, and 32.6% respectively. The same criteria were used to classify sows in parity 2 according to NBA. The low NBA group was classified as less than 11 piglets born alive, the medium NBA group equated to 11 through 13 piglets born alive, and the high NBA group, greater than 13 piglets born alive. The respective percentages of sows in these groups were as follows, 29.9%, 42.8%, and 27.2%.

3.2.3 Statistical analysis

Statistical analyses were conducted using ASReml software. Three separate models were used.

Model 1: Model 1 was used to estimate number of piglets born alive by parity, for parities 3 through 10. Parity 1 high (P1H), medium (P1M), and low (P1L) classifications were used as the fixed effect called P1HML, and parity 2 high (P2H), medium (P2M) and
low (P2L) classifications were used as the fixed effect called P2HML. Other fixed effects included year, parity, breed, wean to first service interval, and farm. All fixed effects were found to be significant sources of variation in the model \((P < 0.05)\). Random effects included in the model were contemporary group (farm by year by season) as well as sow to account for the repeated records per sow. The random effects were removed from the model temporarily in order to calculate the adjusted model \(R^2\) value as a means to show if the effect of parity classification improved the model more than what would be expected by chance.

**Model 2:** Model 2 was the model for total number born alive throughout a sows productive lifetime with ending parities of 3 through 10. This model was used to estimate lifetime total born alive at different cull parties as a means to show the difference between low and high producing sows in both parity 1 and 2. The fixed effects of breed, P1HML, P2HML, farm, and year of first parity were used. All fixed effects were significant sources of variation in the model \((P < 0.05)\). Number of piglets born alive was summed across each sows lifetime to her end parity (3 through 10) and was used as the response variable in the model. Each sow only appeared in the analysis once as the response variable of total number born alive was a lifetime measurement.

**Model 3:** Model 3 was used to model the effect of P1HML and P2HML on the parity a sow was removed from the herd. The response variable was the removal parity and the fixed effects used in the model included breed, farm, year of first parity, and the interaction of P1HML and P2HML. All effects were significant sources of variation in the model \((P < 0.05)\).
3.3 Results and Discussion

The threshold system used in this study has successfully been used in European herds to estimate later reproductive performance (Iida et al., 2015). The classifications used in this analysis estimated least squares means by parity as well as lifetime average NBA and the values presented are specific to this systems sow herd.

For the base model used to evaluate NBA, fixed effects included parity, year, breed, farm, and wean to first service interval. The adjusted R-squared value was 0.04. By including P1HML into the model the adjusted R-squared increased to 0.16. By adding both P1HML and P2HML the adjusted R-squared value further increased to 0.22. With the addition of both P1HML and P2HML a difference of 0.18 can be realized in the adjusted R-squared value for the model used to predict number born alive in parities 3 through 10.

Table 3.1 shows the percentage of sows that changed or remained in the same NBA classification between first and second parity. The percentage of sows that shared the same classification in first and second parity was approximately 40%, meaning approximately 60% of sows did not share the same classification between parity 1 and parity 2. This lack of consistency seen between parity 1 and parity 2 classification by sow was not unexpected, as repeatability of number born alive is relatively low (Dube et al., 2012), especially when parity 1 is considered. By adding parity 2 classifications to the model it made the model a more reliable means of predicting later performance as seen by the increase in the adjusted R-squared value for the model. However, it is important to note that sow classifications are herd specific as they are based around the 25th percentiles for first and second parity of this specific herd. It is expected that these
percentages would vary slightly if data were obtained from another sow herd. For example, it was shown that 50% of sows decreased in classification in a study that also classified sows based on first and second parity NBA in Japanese herds (Sasaki and Koketsu 2008). Environmental factors play a large role in sow production and this environmental impact can be seen at an even larger scale in gilts (Tummaruk et al., 2010). Differences in management, climate, feed, and housing could all play a role in the difference of production by farm (English et al., 1977) and thus classification groups by farm system.

Model 1: Table 3.2 shows the estimates of later parity performance (parities 3 through 10) by using P1HML or P2HML as a predictor variable. The difference between the least squares means estimates of the high versus the low group by both P1HML and P2HML classifications is also presented in Table 3.2. By using P1HML, a minimum difference of 0.6 pigs born alive was observed per subsequent parity between the sows classified as high NBA versus the sows classified as low NBA in parity 1 ($P < 0.05$). By using P2HML, a minimum difference of 0.7 pigs born alive was observed per subsequent parity between the high and low NBA classification groups of parity 2 ($P < 0.05$). At all later parities the sows that were classified as high NBA in either parity 1 or 2 outperformed the sows classified as low NBA ($P < 0.05$). There was a greater difference between the P2H and P2L sows than the P1H and P1L sows ($P < 0.05$). The average difference between the high and low NBA classified groups in parity 1 was 0.6 pigs born alive, while the average difference between the high and low NBA classified groups in second parity was 1 pig born alive. This demonstrates how second parity information may be useful in identifying superior and inferior sows for making culling/selection
decisions as the sows identified as high in parity 2 outperformed the sows identified as low in parity 2 to a greater extent than what was seen in the parity 1 sow group classifications.

The estimates form the interaction of P1HML and P2HML is represented as NBA least squares means (LSM) by parities 3 through 10 (Figure 3.1). Number born alive was shown to increase with both increasing parity 1 and parity 2 classification. The exception to this was seen in parity 10 estimates. However, the parity 10 estimates were found to not be statistically different between the sow NBA classification groups. Estimated later parity performance was greatest with the P2H sows observed throughout the sow’s entire lifetime across all parity 1 groups, with differences of up to 1 piglet born alive per parity compared to P2L sows. Though the P2H sows outperformed sows in the low and medium second parity NBA classifications, this was observed to be dependent on the sows first parity NBA group as an interaction was identified between P1HML and P2HML (P< 0.05).

The average difference of LSM estimates for parities 3 through 10 of P1L sows subdivided by their P2H and P2L classifications (figure 3.1a) was 0.73 pigs born alive. The average difference in P1H sows between parity two classification interaction (P2H and P2L) (figure 3.1c) was 0.35 pigs born alive. These results indicate that parity 2 classifications had a greater influence on subsequent parities in the P1L sows than the P1H sows as the effects observed in the P1H sows had less variation between the sow classifications. Though it is important to note that sows that were P1H and P2H had the greatest overall estimated NBA for parities 3 through parity 9 and sows that were P1L and P2L had the lowest estimated NBA per subsequent parity.
The dependency of parity 2 classification on parity 1 classification was found in a previous study by Hoving et al. (2011) who used the classification system of parity 1 and parity 2 for litter size. In that study, second parity litter size classification had a greater effect on low first parity litter size classification sows versus sows that were classified as high for litter size in parity 1. Additionally, sows that were classified as high for litter size in parity 1 and parity 2 had greater litter sizes in their subsequent parities (Hoving et al., 2011).

Identifying high producing sows in parity 1 and parity 2 could have many benefits for pig producers, such as the sow could recover her initial cost more quickly and become a source of revenue for the producer faster than a lower producing sow. The animals classified as high in parity 1 and parity 2 had the highest subsequent performance by parity as well as total NBA produced over their lifetime which likely indicates that these animals were the ones with the highest genetic potential for number of piglets born alive.

**Model 2**: Model 2 was used to estimate lifetime number born alive using first and second parity classification. All classification estimates were shown to be statistically different from each other within each end parity ($P < 0.05$). All sows that were classified as high in parity 2 had greater lifetime piglets born alive within their relative P1 classification (high, medium or low) regardless of their parity of removal (Table 3.3). As parity 1 classification increased from low to high, a decrease in the difference of estimated lifetime NBA, as subdivide by P2H and P2L, was observed with differences more pronounced at later parities of removal. For example, the difference between a P1LP2H and P1LP2L sow at with a removal parity of 7 was 10.3 lifetime NBA while the difference between P1HP2H and P1HP2L sows was 8.6 lifetime NBA. This indicates that
sows classified as high in parity 1 have more uniformity in their lifetime performance regardless of parity 2 classification in comparison to sows classified as low in parity 1. This is important to realize when making early selection or culling decisions. For example, if a sow was classified as high in her first parity, she will likely be a more predictable producer than selecting a low classified sow after parity 1. If a producer allows the low producing sow to remain in the herd until second parity and her performance improves, this sow would be preferable to select over a sow who remained a low performer in parity 2 based on lifetime NBA estimates as shown in Table 3.3.

It is important to observe the large difference in lifetime performance between the highest producing sows (P1HP2H) and the lowest producing sows (P1LP2L). The average difference across all parities of removal (3 through 10) was 21 pigs born alive in the sow’s lifetime. This demonstrates that using the effect of parity 1 and parity 2 NBA classification can aide to identify the over and under performing sows in the herd for lifetime productivity.

The number of piglets born alive by keeping a sow past parity 6 is noteworthy. If culled after parity 5, a P1HP2H sow has an estimated lifetime NBA of 66 pigs but by keeping that sows for an additional 2 or 3 parities an additional 25 to 39 pigs born alive may be realized from that sow. The importance of retaining sows in the herd longer has been observed with both enhanced productivity as well as in economic benefits to older sows (Dhuyvetter, 2000). By improving sow retention or longevity of the commercial breeding herd, lifetime net income per sow has been shown to increase (Sasaki et al., 2012). It has been demonstrated that as parity of removal increases, the number of litters weaned per year as well as number of pigs weaned per year also increases (Lucia et al.,
This allows the sow a greater opportunity to cover her initial costs as well as produce at a profit for the farm (Stalder et al., 2003; Dhuyvetter, 2000). If the highest producing sows can be identified and retained, such as the P1HP2H sows, this above average production will allow these sows to pay themselves off faster and produce at a higher profit for the farm.

Model 3: Only a small difference in parity at time of culling was observed based on first and second parity classification (Figure 3.2). The largest difference observed between the classifications was a 0.25 difference in parity of removal, which was observed between the groups of LL and HM (P1LP2L and P1HP2M). The highest producing sows (P1HP2H presented as HH) were not estimated to be the last of all classifications culled, as initially hypothesized based on greatest productivity estimates. The classification with the latest parity of removal showed to be P1HP2M instead.

Pairwise comparisons between the parity classification groups revealed that all classes presented in Figure 3.2 are statistically different from each other ($P < 0.05$) except P1MP2H and P1HP2M, shown as MH and HM, as well as P1HP2M and P1HP2H, shown as MH and HH ($P = 0.1$). The groups that did not show a statistical difference between them were classified as high in either first, second, or both parities. Though these classification groups were not significantly different from each other they were significantly different from all groups containing a sow classified as low. These groups also make-up the sows that remained in the herd longest over all other groups with the addition of the MM (P1MP2M) classification. The conclusion can be drawn that if a sow is classified as low in either parity 1 or 2 she is removed slightly before sows that are classified as high or medium in parity 1 or 2 (Figure 3.2).
A study conducted in Japan, observed that sows classified as low for annualized NBA in parity 1 comprised 50% of the sows that were culled prior to parity 6 in their system (Sasaki and Koketsu, 2008). From the observed data in the present study, it was shown that the percentage of sows classified as low NBA in either parity 1 or 2 and culled prior to parity 6 was equal to 79.2%. The percentage of sows that were classified as high NBA in either parity 1 or 2 and culled prior to parity 6 was equal to 76.5%. This indicates that of sows that were high producers in either first or second parity, approximately 3% of them were retained in the herd longer than a sow that had poor performance in her first or second parity. This coincides with the parity of removal estimates by classification (Figure 3.2).

The lack of difference between the estimated removal parity between NBA classifications suggest that sows from this system were culled for reasons other than reproductive performance, as it has been shown that high NBA sows produced greater numbers of pigs born alive compared with the low NBA sows across all parities as well as over their lifetime. There are several reasons to cull a sow, including performance, structural issues, health issues, fertility issues, market trends or a set parity cull (Irwin and Deen, 2000; Stevermer, 1991). It was reported in a previous study that producers tended to cull sows for fertility reasons more than reasons related to litter traits (Sasaki and Koketsu, 2008), which could explain the trend shown in this analysis.

3.4 Summary and implications

The ability to select superior sows for prolificacy has the potential to increase herd longevity and productivity (Serenius, 2004), and thus increase the profit margin
produced by the farm (Dhuyvetter, 2000). The combination of first and second parity information for number of piglets born alive can be used to effectively predict later parity performance and identify superior and inferior performing sows to make culling and selection decisions early in the sow’s life. It was shown that sows classified as high in parity 1 and parity 2 out-preformed all other classification groups while sows that were low in both parity 1 and 2 produced the least amount of pigs per litter as well as less pigs over their lifetime in comparison to all other classifications ($P < 0.05$). The effect parity 2 has on predicting later parity performance is not independent of parity 1 performance for number of piglets born alive ($P$-interaction $< 0.05$). This effect is magnified in sows classified as low NBA in their first parity as the estimates produced from first and second parity classification interaction showed greater variation in later parity estimates than sows classified as high in parity 1 ($P < 0.05$).

The cut-offs used to assign classifications for first and second parity would need to be re-assigned based on a system’s specific average for NBA if this study were to be repeated on a different group of sows. This study was conducted using commercial farm data and thus some limitations apply. Nutrition, herd health, boar fertility and service sire effect as well as sow genotype was not available and not taken into account in this analysis. However, this research is representative of a U.S. commercial herd and valuable information on the use of parity 1 and parity 2 number born alive information as an indicator of future performance as been demonstrated.
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Table 3.1 Number and the percentage of sows that changed in NBA classification according to the number of piglets born alive (NBA) in parity 1 and parity 2 from a Mid-West U.S. integrated commercial swine operation

<table>
<thead>
<tr>
<th>NBA Classifications¹</th>
<th>Percentage of Total Sows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low P1 &amp; P2</td>
<td>9.6%</td>
</tr>
<tr>
<td>Low to Medium</td>
<td>10.1%</td>
</tr>
<tr>
<td>Low to High</td>
<td>4.7%</td>
</tr>
<tr>
<td>Medium P1 &amp; P2</td>
<td>19.2%</td>
</tr>
<tr>
<td>Medium to Low</td>
<td>13.9%</td>
</tr>
<tr>
<td>Medium to High</td>
<td>10.5%</td>
</tr>
<tr>
<td>High P1 &amp; P2</td>
<td>11.1%</td>
</tr>
<tr>
<td>High to Low</td>
<td>8.0%</td>
</tr>
<tr>
<td>High to Medium</td>
<td>12.9%</td>
</tr>
<tr>
<td>Total Decrease in Classification</td>
<td>34.8%</td>
</tr>
<tr>
<td>Total Increase in Classification</td>
<td>25.3%</td>
</tr>
<tr>
<td>Total No Change in Classification</td>
<td>39.9%</td>
</tr>
</tbody>
</table>

¹ Sow classification was determined by using the 25th percentiles for NBA in both first and second parity.
² An increase in classification was considered as a sow that was of medium NBA classification in parity 1 changing to a high NBA classification in parity 2, or a low NBA parity 1 sow changing to a medium or high NBA classified sow in parity 2. A decrease in classification was considered as a sow that was of high NBA classification in parity 1 changing to a medium or low NBA classification in parity 2, or a sow that was classified as medium NBA in parity 1 classified as low NBA in parity 2. No change in classification is considered sows that did not change their classification level between parity 1 and 2.
Table 3.2 First or second parity performance (by number of piglets born alive –NBA- parity classification\(^1\)) used to predict LSM estimates ± SE for parities 3 through 10 for and the difference between the high and low NBA groups within first and second parity classifications NBA from 105,719 sows from farms in the Mid-West United States

<table>
<thead>
<tr>
<th>Parity</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1H(^2) estimate</td>
<td>12.3 ± 0.1</td>
<td>12.1 ± 0.1</td>
<td>11.9 ± 0.1</td>
<td>11.5 ± 0.1</td>
<td>11.3 ± 0.1</td>
<td>11.1 ± 0.1</td>
<td>10.6 ± 0.2</td>
<td>10 ± 0.3</td>
</tr>
<tr>
<td>P1L(^3) estimate</td>
<td>11.5 ± 0.1</td>
<td>11.4 ± 0.1</td>
<td>11.2 ± 0.1</td>
<td>10.9 ± 0.1</td>
<td>10.6 ± 0.1</td>
<td>10.4 ± 0.1</td>
<td>10.1 ± 0.9</td>
<td>9.7 ± 0.4</td>
</tr>
<tr>
<td>P1H-P1L(^4)</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
<td>0.6</td>
<td>0.7</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>P2H(^5) estimate</td>
<td>12.5 ± 0.1</td>
<td>12.4 ± 0.1</td>
<td>12.1 ± 0.1</td>
<td>11.7 ± 0.1</td>
<td>11.4 ± 0.1</td>
<td>11.2 ± 0.1</td>
<td>10.7 ± 0.2</td>
<td>10.6 ± 0.4</td>
</tr>
<tr>
<td>P2L(^6) estimate</td>
<td>11.2 ± 0.1</td>
<td>11.1 ± 0.1</td>
<td>11 ± 0.1</td>
<td>10.7 ± 0.1</td>
<td>10.5 ± 0.1</td>
<td>10.4 ± 0.1</td>
<td>10 ± 0.2</td>
<td>9.5 ± 0.3</td>
</tr>
<tr>
<td>P2H-P2L(^7)</td>
<td>1.3</td>
<td>1.3</td>
<td>1.1</td>
<td>1</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
<td>1.1</td>
</tr>
</tbody>
</table>

\(^1\) Sow classification was determined by using the 25\(^{th}\) percentiles for NBA in both first and second parity.
\(^2\) P1H represents sows that were classified into the high NBA performance group (>12 NBA) in parity 1.
\(^3\) P1L represents sows that were classified into the low NBA performance group (<10 NBA) in parity 1.
\(^4\) P1H-P1L is the difference in the mean estimates in parities 3 through 10 between the parity 1 high and low categorized sows.
\(^5\) P2H represents sows that were classified into the high NBA performance group (>13 NBA) in parity 2.
\(^6\) P2L represents sows that were classified into the low NBA performance group (<11 NBA) in parity 2.
\(^7\) P2H-P2L is the difference in the mean estimates in parities 3 through 10 between the parity 2 high and low categorized sows.
Table 3.3 First and second parity performance (by number of piglets born alive -NBA- parity classification) used to predict lifetime number born alive LSM estimates ± SE for parities 4 through 8 from 105,719 sow records from farms the Mid-West U.S.

<table>
<thead>
<tr>
<th>Parity Classification</th>
<th>Parity 4</th>
<th>Parity 5</th>
<th>Parity 6</th>
<th>Parity 7</th>
<th>Parity 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>36.5 ± 0.4</td>
<td>47.4 ± 0.5</td>
<td>58.1 ± 0.6</td>
<td>68.9 ± 0.7</td>
<td>82.2 ± 0.9</td>
</tr>
<tr>
<td>H</td>
<td>41.3 ± 0.4</td>
<td>52.5 ± 0.5</td>
<td>63.7 ± 0.5</td>
<td>74.9 ± 0.6</td>
<td>88.7 ± 0.8</td>
</tr>
<tr>
<td>M</td>
<td>45.4 ± 0.4</td>
<td>56.9 ± 0.5</td>
<td>67.7 ± 0.5</td>
<td>79.2 ± 0.6</td>
<td>93.6 ± 0.9</td>
</tr>
<tr>
<td>H</td>
<td>42 ± 0.4</td>
<td>53.3 ± 0.5</td>
<td>64.5 ± 0.5</td>
<td>75.7 ± 0.6</td>
<td>89.4 ± 0.9</td>
</tr>
<tr>
<td>L</td>
<td>46.2 ± 0.4</td>
<td>57.8 ± 0.5</td>
<td>69 ± 0.5</td>
<td>80.7 ± 0.6</td>
<td>93.8 ± 0.8</td>
</tr>
<tr>
<td>M</td>
<td>50.1 ± 0.4</td>
<td>62 ± 0.5</td>
<td>73.2 ± 0.5</td>
<td>85.1 ± 0.6</td>
<td>98.5 ± 0.8</td>
</tr>
<tr>
<td>H</td>
<td>46.6 ± 0.4</td>
<td>58.5 ± 0.5</td>
<td>70 ± 0.5</td>
<td>82.4 ± 0.6</td>
<td>97.4 ± 1.1</td>
</tr>
<tr>
<td>M</td>
<td>50.9 ± 0.4</td>
<td>62.7 ± 0.5</td>
<td>74.3 ± 0.5</td>
<td>86.3 ± 0.6</td>
<td>100.5 ± 0.9</td>
</tr>
<tr>
<td>H</td>
<td>55 ± 0.4</td>
<td>66.9 ± 0.5</td>
<td>78.9 ± 0.5</td>
<td>91 ± 0.6</td>
<td>105.4 ± 0.8</td>
</tr>
</tbody>
</table>

1 Parity 1 classification was based on the lower and upper 25th percentiles of NBA in first parity. Parity 1 low (<10 NBA), medium (10 to 12 NBA), high (>12 NBA).
2 Parity 2 classification was based on the lower and upper 25th percentiles in NBA in second parity. Parity 2 low (<11 NBA), medium (11 to 13 NBA), high (>13 NBA).
3 All parity classification estimates are statistically different from each other within each end parity.
a) Low (<10 NBA) in parity 1

b) Medium (11-12 NBA) in parity 1
c) High (>12 NBA) in parity 1

**Figure 3.1** Number born alive (NBA: least squares means ± SE) in parities 3 through 10 based on parity 1 number of piglets born alive classification\(^1\) subdivided by parity 2 classification

3.1a) Represents sows classified as low (<10 NBA) in parity 1, subdivided by parity 2 classifications, low (<11 NBA), medium (11 to 13 NBA), and high (>13 NBA).

3.1b) Represents sows classified as medium (10 to 12 NBA) in parity 1, subdivided by parity 2 classifications, low (<11 NBA), medium (11 to 13 NBA), and high (>13 NBA).

3.1c) Represents sows classified as high (>12 NBA) in parity 1, subdivided by parity 2 classifications, low (<11 NBA), medium (11 to 13 NBA), and high (>13 NBA).

\(^1\) Sow classification was determined by using the 25\(^{th}\) percentiles for NBA in both first and second parity.

\(^2\) Statistical difference between the classifications are denoted as follows: *** denotes that the high and low, high and medium, as well as medium and low classification estimates are statistically different from each other. ** denotes that the high and low, as well as the medium and low classification estimates are statistically different from each other. * denotes that the high and low, as well as the high and medium classification estimates are statistically different from each other.
Figure 3.2 The effect of the interaction of first and second parity performance (by parity classification) used to predict removal parity from 105,719 sow records from farms the Mid-West United States

1 Horizontal axis: LL, LM, and LH represents a sow classified as low in parity 1 (<10 NBA). Subdivide into the following groups: LL represents a low class sow in parity 2 (<11 NBA), LM represents a medium class sow in parity 2 (11 to 13 NBA), and LH represents a sow classified as high in parity 2 (>13 NBA). ML, MM, and MH represents a sow classified as medium in parity 1 (10 to 12 NBA). Subdivide into the following groups: ML represents a low class sow in parity 2 (<11 NBA), MM represents a medium class sow in parity 2 (11 to 13 NBA), and MH represents a sow classified as high in parity 2 (>13 NBA). HL, HM, and HH represent a sow classified as high in parity 1 (>12 NBA). Subdivide into the following groups: HL represents a low class sow in parity 2 (<11 NBA), HM represents a medium class sow in parity 2 (11 to 13 NBA), and HH represents a sow classified as high in parity 2 (>13 NBA).

2 Vertical Axis: Represents the parity of removal.

3 Estimates are presented as LSM by parity classification group.
CHAPTER 4

AN ECONOMIC ANALYSIS OF SOW RETENTION IN A U.S. BREED-TO-WEAN SYSTEM

Modified from a paper to be submitted to the Journal of Swine Health and Production

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Abstract

Objective: To determine the number of parities a sow should be retained in a breed-to-wean system to maximize returns over total cost per weaned pig and net return on investment, and assess the sensitivity of returns over total cost per weaned pig to feed price and number born alive (NBA).

Materials and Methods: Data used to estimate NBA and pre-weaning mortality by parity were collected between 2001 to 2014 at 17 Mid-West (United States) farms which totaled 105,719 sows accounting for 502,491 total records. Projected budgets were compared for various parity distribution scenarios using a “steady-state” farm model that
included both variable and fixed costs associated with the farm and the proportion of sows by parity in the distribution.

**Results:** The cost of producing a weaned pig was minimized by culling after parities 5 through 9, and culling after late parities (i.e., parity 7 through 9), showed greater returns over culling after parities 1 through 4. Culling after parities 5 to 8 showed approximately a 15% net return on investment. When NBA increased, the scenarios culling after parities 5 through 9 had the highest returns. Culling after parities 6 through 9 showed greatest returns with low feed prices. With high feed prices all parity distributions costs exceed returns, though culling after parities 5 and 6 came closest to breaking even.

**Impactions:** Retaining sows in the herd longer has economic benefits that could increase the financial returns of a breed-to-wean system.

**Keywords:** Swine, economic analysis, optimal parity distribution, sensitivity analysis, sow longevity

### 4.1 Introduction

Higher parity sows wean heavier pigs and produce more pigs per year than females in lower parities (Lucia *et al.*, 1999; Carney-Hinkle *et al.*, 2013; Dhuyvetter, 2000b). For these reasons it has been recommended that producers keep culling levels low to reduce the number of dams in first or second parity within a breeding herd, as the ability to produce and wean more pigs per year directly influences the profit capability of a farm (Stevermer, 1991).

Sow retention rate drives optimal parity distribution (**OPD**) and the more productive parities should compose a greater proportion of sows in the herd parity
distribution (Morrison et al., 2002). It has been proposed that 52% of sows in a given herd should be sows in parities 3 through 6 as these are considered peak performance in the sow’s lifetime (Joaquin Spörke, 2007; Stalder et al., 2000).

A sow should not be replaced until the productivity of the later parity sow is less than that of a potential replacement gilt (Stevermer, 1991). Performance potential is influenced by the genetic merit of the animal. However, relatively little genetic progress is made if a sow is replaced in her early parties due to the slow genetic change made at the commercial level, as it is likely that the replacement gilts and culled sows are of similar genetic merit (Abell et al., 2010). It was shown that once a replacement gilt is introduced into the breeding herd to replace an older sow, the gain in genetic improvement will be recognized immediately regardless of how many parities the older sow was retained in the herd for, though allowing the sow to produce in the herd longer increases the profit level per animal (Abell et al., 2010). Furthermore, it has been reported that current replacements rates are not profitable if the reason for a system’s high replacement is to solely introduce new gilts at a higher percentage to keep up with gains in genetic improvement that are being observed at the multiplier and nucleus levels of production (Abell et al., 2010).

Dhuyvetter (2000b) and Abell et al. (2010) reported that maximum pigs weaned/sow/year are observed by allowing sows to remain in the breeding herd until their 8th parity and Stevermer (1991) reported that sows as old as parities 8 through 10 outperform sows in their first parity. A sow reaches a positive value for lifetime net income at her 3rd parity (Sasaki et al., 2012; Stalder et al., 2003); however, in the USA, the average culling parity is between 3.1 and 3.7 (Stalder et al., 2003) indicating that a
sows barely covers her replacement cost at the time of removal. This represents a loss in profit potential by not retaining that sow until later parities. If the cost of a replacement gilt can be spread over a greater number of pigs produced, such as the case when sows are retained longer, the cost to produce a market hog decreases (Abell et al., 2010).

The objectives of this analysis were to assess a series of parity distributions to determine the number of parities a sow should be retained in a breed-to-wean system to maximize returns over total cost per weaned pig and net return on investment, and assess the sensitivity of returns over total cost per weaned pig to feed price and number born alive (NBA).

4.2 Materials and Methods

Animal Care and Use Committee approval was not obtained for this study because the data used for this analysis were obtained from a single private company’s existing database.

4.2.1 Production data and data exclusion criteria

Data editing and categorization was conducted in R (R, 2015). Data were collected from 2001 to 2014 at 17 farms located in the Mid-West region in the United States. Both purebred and crossbred sows were included in the dataset. Data editing was performed to ensure data were within normal physiological ranges and free from recording errors. Outlier records were removed and any sow that did not have complete lifetime performance records was not included in the analysis. Individual records were considered outliers and removed from the data set if they were ± 3 standard deviations
from the mean for the following traits at each parity: number of piglets born alive (NBA), number of piglets weaned, total piglets born, number of stillborn piglets, wean to first service interval, and weaning age. Records greater than parity 10 were removed due to the small number of records in those high parities. Approximately 4% of the total litter observations needed to be adjusted for piglets fostered due to recording errors in either NBA, fosters or number weaned. These errors caused the recorded number of weaned pigs to be impractical based on the given values for NBA and cross fostered. The values for NBA, cross fostered, and number weaned were needed in the calculation of pre-weaning mortality. The Shapiro test was used on the model residual information as well as the examination of the normal plot to evaluate the dataset for normal distribution. The final data set included 502,491 records accounting for lifetime performance of 105,719 sows.

4.2.2 **Estimation of number born alive and pre-weaning mortality from the production data**

Statistical analyses were conducted using ASReml software. The first model used was to estimate pre-weaning mortality by parity. Fixed effects included parity, farm, year, breed, and piglet age at weaning. The random effect of sow was included to account for correlation among repeated dam records. Number born alive by parity was estimated using a second model. This model included fixed effects of parity, farm, year, breed, and wean to first service interval. Random effects of sow and contemporary group (farm by year by season) were also included.
4.2.3 Value of animals

Price per weaned pig sold was calculated by using the composite weighted average price of a 10-12 lb. weaned pig from the National Direct Delivered Feeder Pig Report NW_LS255. The weaned pig price used in the model ($36.90 per pig) was based on an average of weekly prices reported during the 2001-2014 period (USDA-AMS, 2016a). The price paid for replacement gilts was calculated using the monthly-negotiated Iowa/Minnesota Daily Direct Prior Day Hog Report LM_HG204 (plant delivered) prices for 2001-2014. An average weight of 275 lb. was used with a dressing percentage of 72% (Swine Grading, 2016), which lead to a value of $137.48 per head (USDA-AMS, 2016b). An additional $85.00 per head was added for genetic premium (Johnson, 1981; Stalder et al., 2003), which increased the value of a replacement gilt to $222.48 per head. The cull gilt price used assumed a weight of 285 lb. at a price of $142.48 per head from 2001-2014 (USDA-AMS, 2016b). It was assumed that approximately 20% of purchased gilts do not conceive and are culled from the breeding herd under all scenarios (Dhuyvetter, 2000a). The cull sow price used in this model ($42.39 per cwt. of live weight) was based on the Weekly National Direct Swine Report LM_HG214, national weighted average price of negotiated sows weighing 300-449 lbs. from 2002-2014 (USDA-AMS, 2016c). Table 4.1 provides a listing of animal and production values.

4.2.4 Model operation

The modeled enterprise was a 5,000 sow breed-to-wean operation. This facility was assumed to individually house sows during gestation and lactation, as it was the housing system used by the production company at the time data were being recorded.
Total number of sows, (5,000) and 2.32 litters per sow per year was held constant across all scenarios.

The budgets used in this analysis were developed by Dhuyvetter (2000a; 2000b) and used to demonstrate a breeding herd that culls sows after their first through tenth parities as a means to identify the optimal parity distribution based on returns over total cost per weaned pig. Conception rates play a large role in OPD. For this analysis gilt conception rate is slightly below 80% while conception rate at all other parities is approximately 86% (Dhuyvetter, 2000a). An example of one of the parity distribution scenarios is a system that culls sows after their first parity resulting in a breeding herd comprised completely of gilts, whereas a system that culls sows after their fourth parity would be comprised of dams through their fourth parity. Under current economic and tax situations it is not likely that producers would maintain a breeding herd of only gilts, but all of these scenarios were included for comparison purposes. A “steady-state” model was used to demonstrate returns based on an existing farm versus a system that is just entering production. Feed cost sensitivity analysis, as well as increased sow production, was conducted as a part of the economic analysis. The budget analysis is presented on a per weaned pig value basis.

4.2.5 Variable costs

Variability in feed consumption by parity was accounted for with a linear range for gestation diets of 5.15 to 6 lbs. per sow per day for parities 1 through 10 and a non-linear range for lactation intake of 10.25 to 12.55 lbs. per day per sow for parities 1 through 10 (Dhuyvetter, 2000a). The assumption was made that no creep feed was
provided prior to weaning. The price of base mix used in formulating sow diets was calculated using the average percentage price increase of 48%, which was calculated from the corn and soybean meal prices used in the present study in reference to those used by Dhuyvetter (2000b) and the percent increase was then applied to the price for base mix used by Dhuyvetter (2000b). Semen cost per litter was assumed to be $4.00 per dose, this price was provided from the company supplying the production data. It was assumed 2 semen doses per sow per litter as well as an additional $4.00 charge per sow that farrowed as a means to cover the expense of sows/gilts that were bred and did not conceive or farrow. The cost of insurance on the breeding herd was calculated as 1% of the total breeding herd investment divided by the number of weaned pigs sold per year (Dhuyvetter, 2000b). A complete variable costs breakdown can be found in Table 4.1.

4.2.6 Fixed costs

Total building and equipment investment costs accounted for the cost of gestation and farrowing crates, cost per square foot of building, and the equipment required in the building such as feeders and panels. A useful life of 20 years was assumed and applied to the building and a 12-year useful life for equipment was assumed and used in the depreciation calculation (Dhuyvetter, 2000b; Schulz, 2014). Insurance on buildings and equipment was an assumed value of 1%. A 10% salvage value was applied to buildings while a 0% salvage value was applied to all equipment and crates (Dhuyvetter, 2000b). A complete fixed costs breakdown can be found in Table 4.1.
4.2.7 Sensitivity analysis

Number born alive estimates were averaged over parity groups, 1 to 3, 4 to 5 and 6 to 9, as well as year groups, 2001 to 2005, 2006 to 2010, and 2011 to 2014. This model was used as a means to show how NBA has changed since 2001 across parities. As years 2011 to 2014 showed to be the most prolific, records from those years were analyzed using the original NBA and pre-weaning mortality models previously described. The estimates were then used in the budget analysis to assess how higher NBA and pre-weaning mortality affect the recommended parity distribution with all other inputs held constant.

Feed price was assessed in the sensitivity analysis. The 2 lowest costs for corn and soybean meal from the 14-year averages were selected and averaged and then used as the new value for both inputs. This was done again with the 2 highest prices for corn and soybean meal. All other factors were held constant.

4.3 Results and Discussion

Figure 4.1 presents the NBA and pre-weaning mortality estimates by parity that were used as inputs in the economic analysis. Number of piglets born alive was shown to be highest in third parity sows. An increase in NBA was observed until parity 3 and then steadily decreased until parity 10. Additionally, NBA differed between parities ($P < 0.05$). Older sows had a lower pre-weaning mortality rate than younger sows with the pre-weaning mortality falling below 14% in parity 7 through 10. This suggests that older sows are able to maintain and rear more piglets during the lactation period than younger sows. Pre-weaning mortality estimates also differed between parities ($P < 0.05$) except
parity 9 which showed a slight tendency toward significance differences with other parities \( (P < 0.09) \), and parity 10 which showed a trend that appears different from other parities \( (P < 0.25) \). The average number weaned per litter based on the given parity distribution is presented in Table 4.2. Across all parity distributions, an average of 9.65 pigs are weaned per litter based on the given parity distribution. Although older sows have fewer NBA, they wean a greater percentage of their pigs than younger sows, as shown by older sows weaning approximately the same number of pigs as the younger sows.

The number of replacement females needed to maintain 5000 breeding animals is shown in Table 4.2 with the associated replacement rate for each parity distribution. As sows are retained longer and culled later in life the replacement rate decreases. The cost associated with a higher replacement rate can be observed in the higher cost per weaned pig specifically associated with depreciation of the breeding herd (Table 4.3). Sows are considered assets of the farm and need to be depreciated throughout the number of pigs she weans in her lifetime. Replacement gilt costs need to spread across pigs weaned throughout her productive lifetime. The lower the replacement rate of the parity distribution, the lower the cost associated with breeding herd depreciation per weaned pig.

Litters per sow per year as well as sow inventory were held constant across all parity distribution scenarios, thus the number of litters produced per year was constant across all scenarios. However, it has been shown in previous studies that litters per sow per year is lowest in scenarios where culling occurred after first and second parity, and is consistent in distribution scenarios culling after parities 3 through 10 (Dhuyvetter,
2000b). Had this been considered, and the litters per sow per year lowered in distributions including only first and second parity sows, it would be expected that the optimal parity distributions would still favor those distributions having a proportion of older sows. These distributions would have had greater litters per sow per year, thus proving to be even more efficient than what is represented in the present study. The parity distribution where culling occurs after parity 1 sells fewer weaned pigs per year than any other scenario (Table 4.2). With more pigs sold per year, costs associated with annual production can be distributed among the larger number of pigs sold, thus decreasing cost on a per weaned pig basis. However, there are other costs associated with each parity distribution such as age and size of the sows that must be considered as well. Some additional costs that need consideration are, for example, feed costs will be greatest in older sows as they are heavier and have a higher maintenance level feed requirement (Van Heugten, 2001; English et al., 1977), but depreciation of the breeding herd is minimized in older sows as it is able to be spread over more parities.

The parity distribution that sells the most weaned pigs per year is the scenario that culls sows after their fourth parity (Table 4.2). Though culling after parity 4 was shown to produce the most salable weaned pigs, this is not the parity distribution that was shown to minimize the cost per weaned pig the most, as this is dependent on additional factors such as the variable costs represented in Table 4.3. The parity distribution that produced weaned pigs the most cost effectively, and had the greatest return over total cost, was observed to be culling after parity 6 (Table 4.3). Results from the present study indicate that retaining sows until later parities, (i.e., parity 8 and 9), could be economically advantageous over culling sows after parities 1 through 4 as shown by a higher return
over total cost. Though older sows produce and sell slightly fewer pigs per year than younger sows, the cost in producing a weaned pig is minimized in parities 5 through 9. The results shown in Table 4.3 are similar to those previously observed in other economic analysis studies, that the cost of a weaner pig is highest in first parity sows, and decreases in other parities (Dhuyvetter, 2000b). With the current average parity of culling in the U.S. at 3.1 to 3.7 (Stalder et al., 2003) results indicate there is a substantial profit gap, which could be reduced by keeping sows until later parities. Results from the present study indicate that a producer may be losing as much as $0.42 per weaned pig by culling at the current industry averages when compared to retaining sows until the returns over total costs is higher (Table 4.3). The advantage of retaining sows is clearly demonstrated as retaining a sow until her tenth parity is shown to have a greater rate of return than what most commercial pork producers are currently practicing today.

As this study analyzed returns over total costs on a per weaned pig basis, a recommendation on how the optimal parity distribution will be influenced when pigs are followed through finishing cannot be made. However, there are numerous studies showing the benefits in offspring from older sows through finishing. Offspring from primiparous dams have lower average daily gain (Carney-Hinkle et al., 2013; Mahan, 1998; Burkey et al., 2008) as well as increased mortality in the nursery and finishing phases when compared to offspring from older sows (Burkey et al., 2008). It has been reported that market hogs from mature sows were significantly more profitable than market hogs from first parity sows (Mabry, 2015). The difference seen in the offspring from first parity sows compared to the offspring from older dams is due, at least in part, to the reduced health status of the first parity offspring (Burkey et al., 2008; Carney-
Hinkle *et al.*, 2013; Mahan, 1998). We hypothesize that if this analysis was done on a per finished hog basis, the recommended parity distribution would still favor distributions with a greater percentage of older sows.

Table 4.4 includes net return on investment based on the parity distribution scenarios. The same trend that was seen in the budget analysis was also observed as the greatest return on investment is realized by culling sows after parity 6, followed closely by culling after parities 5 and 7, with culling after parities 5 through 8 all showing approximately a 15% return on investment. Return on investment is considered to be an indicator of profitability and it has been recommended that a company needs a minimum of 10 to 14% return on investment to fund future growth (Financial ratios, 2016). It has been shown that investment in a breed-to-wean operation was favorable over other investments given a similar risk profile based on the modified internal rate of returns (Rodriguez-Zas *et al.*, 2006).

As part of the sensitivity analysis in this study, greater NBA numbers as well as pre-weaning mortality estimates were used per parity with all other factors held constant. Through genetic improvement as well as better management practices, NBA has steadily increased (Loula *et al.*, 2010). Figure 4.2 illustrates the increase in NBA by year groups as well as parity groups. Since 2001 NBA has increased across all parities. Records from 2011 to 2014 were used to produce a more recent estimate of NBA and pre-weaning mortality which were then used in the sensitivity analysis. These updated estimates are shown in Figure 4.3. Parity 3 was again found to be the most prolific parity ($P > 0.05$), but pre-weaning mortality rates are greater than what is shown in Figure 4.1. The pre-weaning mortality increase shown is not advantageous for the producer, as the greater the
pre-weaning mortality rate, fewer pigs are weaned per sow. A large factor in this high pre-weaning mortality rate is the influence of the Porcine Epidemic Diarrhea Virus (PEDV) outbreak that occurred during these years (Productivity, 2014). However, even with pre-weaning mortality rates an average of 4% greater per parity in 2011 to 2014, sows still were shown to wean and sell more pigs than in the base scenario due to the increase in NBA (Table 4.5). The parity distribution that culled after parity 6 remained the most lucrative distribution from both a returns over total costs basis as well as net return on investment, followed closely by culling after parity 7. It was observed that culling after parities 5 through 9 showed greater economic returns over culling after parities 1 through 4 (Table 4.5). This is the same trend that was observed in the base scenario with a lower NBA and pre-weaning mortality rate, indicating that the increase in sow performance across all parities did not have a large effect on the optimal parity distribution. However, it can be seen that the difference in returns between culling after parity 6 and 7 was smaller in the scenario with higher NBA (Table 4.5). If NBA were to increase more, it can be hypothesized older sows (i.e., parity 7) become most profitable.

For the low feed price analysis soybean meal decreased 58%, which equated to a price of $181.54 per ton and the cost of corn decreased 52%, which equated to a price of $1.92 per bushel. The results of the low feed price sensitivity analysis are presented in Table 4.6. With low feed costs the optimal parity distribution favors older sows. Specifically, the greatest returns over total costs can be realized by retaining sows through their seventh parity, and retaining sows through their eighth or ninth parity has a greater rate of return over culling before a sow is through her fifth parity. In the high feed price analysis, soybean meal increased 66% bringing the price to $474.49 per ton and
corn increased 57.6% bringing the price to $6.41 per bushel. None of the parity distributions have positive returns over total costs with high feed prices (Table 4.6). However, the parity distribution culling after parity 6 was the closest to break-even followed closely by culling after parity 5.

### 4.4 Conclusions

By improving sow longevity, the profitability of the breeding herd should improve as costs associated with replacement gilt expenses are minimized. Although a replacement gilt may have greater genetic potential over a current sow in the breeding herd, the economic benefits of retaining sows into their later parities was shown by increased returns over total costs as well as increased net return on investment. The greatest return over total cost on a per weaned pig basis was observed in the parity distribution that culled after parity 6, though retaining a sow to her seventh through ninth parity resulted in a greater rate of return when compared to culling sows after parities 1 through 4. This study demonstrates that producers could increase returns per weaned pig above what is currently being realized in the commercial swine industry by retaining sows in the herd longer than what is currently in practice.

A number of educated assumptions were required as factors impacting the optimal parity distribution for this economic analysis. The validity for those assumptions must be tested over time.
Literature cited:


Table 4.1 Market prices, production values, investment costs, and miscellaneous expenses used in the economic analysis of sow retention for a 5,000 sow breed-to-wean operation (all prices, costs, and expenses in $U.S.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value used in analysis</th>
<th>Source of Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Market price and weight</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price for weaned pig, $/head</td>
<td>36.90</td>
<td>National Direct Delivered Feeder Pig Report ¹</td>
</tr>
<tr>
<td>Price for replacement gilt, $/head</td>
<td>222.48</td>
<td>Assumed (find in methods and materials)</td>
</tr>
<tr>
<td>Price for cull sow, $/100 lbs.</td>
<td>43.15</td>
<td>Weekly National Direct Swine Report ²</td>
</tr>
<tr>
<td><strong>Production values</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average age of weaning, days</td>
<td>21.00</td>
<td>U.S. Pork Industry Productivity Analysis ³</td>
</tr>
<tr>
<td>Average weaning weight, lbs.</td>
<td>12.98</td>
<td>U.S. Pork Industry Productivity Analysis ³</td>
</tr>
<tr>
<td>Litters/sow/year</td>
<td>2.32</td>
<td>U.S. Pork Industry Productivity Analysis ³</td>
</tr>
<tr>
<td>Sow mortality, %</td>
<td>8.34</td>
<td>Benchmarking summaries U.S. ⁴</td>
</tr>
<tr>
<td><strong>Variable Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean meal, $/ton</td>
<td>311.21</td>
<td>Index mundi, Commodity Price Indices ⁵</td>
</tr>
<tr>
<td>Corn, $/bushel</td>
<td>3.69</td>
<td>Farmdoc, Calendar year average price ⁶</td>
</tr>
<tr>
<td>Base mix: vitamins, minerals, etc., $/ton</td>
<td>677.00</td>
<td>Assumed (find in methods and materials)</td>
</tr>
<tr>
<td>Feed Processing, $/ton</td>
<td>9.09</td>
<td>Iowa Farm Custom Rate Survey ⁷</td>
</tr>
<tr>
<td>Utilities, fuel and oil / weaned pig, $</td>
<td>1.22</td>
<td>FinBin, University of Minnesota ⁸</td>
</tr>
<tr>
<td>Professional Fees: Legal, accounting / weaned pig, $</td>
<td>0.24</td>
<td>FinBin, University of Minnesota ⁸</td>
</tr>
<tr>
<td>Transport and marketing costs / weaned pig, $</td>
<td>1.00</td>
<td>FinBin, University of Minnesota ⁸</td>
</tr>
<tr>
<td>Building and equipment repairs, %</td>
<td>2.00</td>
<td>(Total building/equipment investment / pigs sold per year) x (2% assumed value)</td>
</tr>
<tr>
<td>Labor, annual salary, $</td>
<td>34000.00</td>
<td>Average provided by U.S. Swine Company</td>
</tr>
</tbody>
</table>
Table 4.1 continued

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>2001-2014</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Veterinary, drugs, supplies, $/weaned pig, $</td>
<td>3.62</td>
<td>FinBin, University of Minnesota</td>
</tr>
<tr>
<td>Depreciation on breeding herd, %</td>
<td>Varied</td>
<td>Based on cull rates of the parity distribution</td>
</tr>
<tr>
<td>Interest on breeding herd, %</td>
<td>7.19</td>
<td>Agricultural interest rates (KS, MO, NE): Operating loans</td>
</tr>
<tr>
<td>Insurance on breeding herd, %</td>
<td>1.00</td>
<td>Assumed (find in methods and materials)</td>
</tr>
<tr>
<td>Semen charge per litter, $</td>
<td>12.00</td>
<td>Assumed (find in methods and materials)</td>
</tr>
<tr>
<td><strong>Fixed Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depreciation on buildings, years of useful life</td>
<td>20.00</td>
<td>Assumed (find in methods and materials)</td>
</tr>
<tr>
<td>Interest on buildings and equipment, %</td>
<td>7.19</td>
<td>Agricultural interest rates (KS, MO, NE): Operating loans</td>
</tr>
<tr>
<td>Insurance on buildings and equipment, %</td>
<td>1.00</td>
<td>Assumed (find in methods and materials)</td>
</tr>
<tr>
<td>Salvage value in buildings, %</td>
<td>10.00</td>
<td>Assumed (find in methods and materials)</td>
</tr>
<tr>
<td>Total building and equipment investment, $</td>
<td>4775811.00</td>
<td>Calculated based on 5000 head sow herd</td>
</tr>
</tbody>
</table>

1. 2001-2014 Available at: https://www.ams.usda.gov/mnreports/nw_ls255.txt
2. 2002-2014 Available at: https://www.ams.usda.gov/mnreports/lm_hg214.txt
4. 2006-2014 Available at: http://www.pigchamp.com/benchmarking/benchmarking-summaries
5. 2001-2014 Available at: http://www.indexmundi.com/commodities/?commodity=soybean-meal&months=180
6. 2001-2014 Available at: http://www.farmdoc.illinois.edu/manage/uspricehistory/us_price_history.html
7. 2001-2014 Available at: https://www.extension.iastate.edu/agdm/crops/html/a3-10.html
8. 2001-2014 Available at: https://finbin.umn.edu/LvSummOpts/LvSummIndex
9. 2001-2014 Available at: http://www.kansascityfed.org/research/indicatorsdata/agcreditQuarterlyAgriculturalCreditService
### Table 4.2 Production values, inputs and outputs used in the economic analysis of sow retention of a 5,000 sow breed-to-wean operation

<table>
<thead>
<tr>
<th>Parity prior to cull²</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average parity³</td>
<td>1.00</td>
<td>1.46</td>
<td>1.90</td>
<td>2.32</td>
<td>2.70</td>
<td>3.07</td>
<td>3.40</td>
<td>3.76</td>
<td>4.05</td>
<td>4.32</td>
</tr>
<tr>
<td>Average removal parity⁴</td>
<td>1.00</td>
<td>1.86</td>
<td>2.62</td>
<td>3.26</td>
<td>3.79</td>
<td>4.29</td>
<td>4.68</td>
<td>5.08</td>
<td>5.41</td>
<td>5.64</td>
</tr>
<tr>
<td>Sow inventory</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>Replacement rate</td>
<td>295%</td>
<td>158%</td>
<td>113%</td>
<td>90%</td>
<td>78%</td>
<td>69%</td>
<td>63%</td>
<td>58%</td>
<td>54%</td>
<td>53%</td>
</tr>
<tr>
<td>Annual purchases</td>
<td>14764</td>
<td>7909</td>
<td>5642</td>
<td>4508</td>
<td>3902</td>
<td>3445</td>
<td>3164</td>
<td>2918</td>
<td>2723</td>
<td>2636</td>
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<tr>
<td>Total litters per year</td>
<td>11600</td>
<td>11600</td>
<td>11600</td>
<td>11600</td>
<td>11600</td>
<td>11600</td>
<td>11600</td>
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</tr>
<tr>
<td>Litters/sow/year</td>
<td>2.32</td>
<td>2.32</td>
<td>2.32</td>
<td>2.32</td>
<td>2.32</td>
<td>2.32</td>
<td>2.32</td>
<td>2.32</td>
<td>2.32</td>
<td>2.32</td>
</tr>
<tr>
<td>Pigs sold/sow/year</td>
<td>21.91</td>
<td>22.37</td>
<td>22.62</td>
<td>22.68</td>
<td>22.65</td>
<td>22.56</td>
<td>22.46</td>
<td>22.34</td>
<td>22.21</td>
<td>22.06</td>
</tr>
<tr>
<td>Pigs sold/year</td>
<td>109559</td>
<td>111829</td>
<td>113115</td>
<td>113391</td>
<td>113237</td>
<td>112808</td>
<td>112299</td>
<td>111695</td>
<td>111052</td>
<td>110319</td>
</tr>
</tbody>
</table>

¹ Values gathered from 2001 to 2014.
² Represents the parity distribution based on sow culling strategy. For example “4” indicates that in the parity distribution scenario sows are kept until parity 4 and then culled. Sows that are bred but do not conceive, or that do not show signs of estrus prior to the final parity in the distribution are culled.
³ Average parity is a weighted average of sows farrowing within each parity of the given parity distribution scenario.
⁴ Average parity of removal is a weighted average removal parity of sow culls and deaths at each parity of the given parity distribution scenario. Gilts that were culled prior to having a litter are not included in this value.
Table 4.3 *Budget analysis of sow retention in a 5,000 sow breed-to-wean operation on a per weaned pig basis (all prices, costs, and expenses in $U.S.)*

<table>
<thead>
<tr>
<th>Parity prior to cull</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable costs per pig sold:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain</td>
<td>5.29</td>
<td>5.36</td>
<td>5.43</td>
<td>5.52</td>
<td>5.62</td>
<td>5.72</td>
<td>5.83</td>
<td>5.95</td>
<td>6.06</td>
<td>6.18</td>
</tr>
<tr>
<td>Protein</td>
<td>2.80</td>
<td>2.86</td>
<td>2.91</td>
<td>2.96</td>
<td>3.01</td>
<td>3.07</td>
<td>3.12</td>
<td>3.18</td>
<td>3.24</td>
<td>3.29</td>
</tr>
<tr>
<td>Base mix: vitamins, minerals, etc.</td>
<td>1.34</td>
<td>1.36</td>
<td>1.38</td>
<td>1.40</td>
<td>1.42</td>
<td>1.45</td>
<td>1.48</td>
<td>1.51</td>
<td>1.54</td>
<td>1.57</td>
</tr>
<tr>
<td>Feed processing</td>
<td>0.47</td>
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<td>0.48</td>
<td>0.49</td>
<td>0.50</td>
<td>0.51</td>
<td>0.52</td>
<td>0.53</td>
<td>0.54</td>
<td>0.55</td>
</tr>
<tr>
<td>Labor</td>
<td>5.59</td>
<td>5.47</td>
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<td>5.40</td>
<td>5.40</td>
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<td>5.45</td>
<td>5.48</td>
<td>5.51</td>
<td>5.55</td>
</tr>
<tr>
<td>Veterinary, drugs, and supplies</td>
<td>3.16</td>
<td>3.16</td>
<td>3.16</td>
<td>3.16</td>
<td>3.16</td>
<td>3.16</td>
<td>3.16</td>
<td>3.16</td>
<td>3.16</td>
<td>3.16</td>
</tr>
<tr>
<td>Utilities, fuel, and oil</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
<td>1.22</td>
</tr>
<tr>
<td>Transportation and marketing costs</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Building and equipment repairs</td>
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<td>0.85</td>
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<td>0.84</td>
<td>0.84</td>
<td>0.85</td>
<td>0.85</td>
<td>0.86</td>
<td>0.86</td>
<td>0.87</td>
</tr>
<tr>
<td>Depreciation</td>
<td>1.27</td>
<td>1.24</td>
<td>1.23</td>
<td>1.23</td>
<td>1.23</td>
<td>1.23</td>
<td>1.24</td>
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<tr>
<td>Interest</td>
<td>0.56</td>
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<td>0.58</td>
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<td>0.60</td>
<td>0.60</td>
<td>0.61</td>
<td>0.62</td>
<td>0.62</td>
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<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Professional fees: legal, accounting, etc.</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>Interest on 1/2 variable costs</td>
<td>0.58</td>
<td>0.45</td>
<td>0.42</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td><strong>A. Total variable costs</strong></td>
<td><strong>38.88</strong></td>
<td><strong>30.67</strong></td>
<td><strong>28.38</strong></td>
<td><strong>27.50</strong></td>
<td><strong>27.19</strong></td>
<td><strong>27.06</strong></td>
<td><strong>27.09</strong></td>
<td><strong>27.17</strong></td>
<td><strong>27.29</strong></td>
<td><strong>27.52</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Fixed costs per pig sold:</strong></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation on bldgs and equip</td>
<td>2.51</td>
<td>2.46</td>
<td>2.43</td>
<td>2.42</td>
<td>2.43</td>
<td>2.44</td>
<td>2.45</td>
<td>2.46</td>
<td>2.48</td>
<td>2.49</td>
</tr>
<tr>
<td>Interest on bldgs and equip</td>
<td>1.67</td>
<td>1.64</td>
<td>1.62</td>
<td>1.62</td>
<td>1.62</td>
<td>1.62</td>
<td>1.63</td>
<td>1.64</td>
<td>1.65</td>
<td>1.66</td>
</tr>
<tr>
<td>Insurance on bldgs and equip</td>
<td>0.44</td>
<td>0.43</td>
<td>0.42</td>
<td>0.42</td>
<td>0.42</td>
<td>0.42</td>
<td>0.43</td>
<td>0.43</td>
<td>0.43</td>
<td>0.43</td>
</tr>
</tbody>
</table>
Table 4.3 continued

<table>
<thead>
<tr>
<th></th>
<th>4.62</th>
<th>4.52</th>
<th>4.47</th>
<th>4.46</th>
<th>4.47</th>
<th>4.48</th>
<th>4.51</th>
<th>4.53</th>
<th>4.56</th>
<th>4.59</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. Total fixed costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total cost per pig sold</td>
<td>43.50</td>
<td>35.20</td>
<td>32.86</td>
<td>31.97</td>
<td>31.66</td>
<td>31.55</td>
<td>31.60</td>
<td>31.70</td>
<td>31.84</td>
<td>32.11</td>
</tr>
<tr>
<td>D. Gross returns per weaned pig sold</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
</tr>
<tr>
<td>E. Return over variable costs (D - A)</td>
<td>-1.98</td>
<td>6.23</td>
<td>8.52</td>
<td>9.40</td>
<td>9.71</td>
<td>9.84</td>
<td>9.81</td>
<td>9.73</td>
<td>9.61</td>
<td>9.38</td>
</tr>
<tr>
<td>F. Return over fixed costs (D-B)</td>
<td>32.28</td>
<td>32.38</td>
<td>32.43</td>
<td>32.44</td>
<td>32.43</td>
<td>32.42</td>
<td>32.39</td>
<td>32.37</td>
<td>32.34</td>
<td>32.31</td>
</tr>
<tr>
<td>G. Returns over total costs $/head (D - C)</td>
<td>-6.60</td>
<td>1.70</td>
<td>4.04</td>
<td>4.93</td>
<td>5.24</td>
<td>5.35</td>
<td>5.30</td>
<td>5.20</td>
<td>5.06</td>
<td>4.79</td>
</tr>
</tbody>
</table>

1 Values gathered from 2001 to 2014.
2 Represents the parity distribution based on sow culling strategy. For example “4” indicates that in the parity distribution scenario sows are kept until parity 4 and then culled. Sows that are bred but do not conceive, or that do not show signs of estrus prior to the final parity in the distribution are culled.
**Table 4.4** Returns over total costs on a per weaned pig basis and net return on investment for a 5,000 sow breed-to-wean operation (all prices in $U.S.)

<table>
<thead>
<tr>
<th>Parity prior to cull²</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Returns over total costs</td>
<td>-6.60</td>
<td>1.70</td>
<td>4.04</td>
<td>4.93</td>
<td>5.24</td>
<td>5.35</td>
<td>5.30</td>
<td>5.20</td>
<td>5.06</td>
<td>4.79</td>
</tr>
<tr>
<td>Net return on investment</td>
<td>-7.0%</td>
<td>8.3%</td>
<td>12.8%</td>
<td>14.5%</td>
<td>15.1%</td>
<td>15.3%</td>
<td>15.1%</td>
<td>14.9%</td>
<td>14.6%</td>
<td>14.0%</td>
</tr>
</tbody>
</table>

1 Values gathered from 2001-2014.
2 Represents the parity distribution based on sow culling strategy. For example “4” indicates that in the parity distribution scenario sows are kept until parity 4 and then culled. Sows that are bred but do not conceive, or that do not show signs of estrus prior to the final parity in the distribution are culled.
Table 4.5 Production values, inputs and outputs used in the economic analysis of sow retention of a 5,000 sow breed-to-wean operation

<table>
<thead>
<tr>
<th>Parity prior to cull</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigs born alive/litter</td>
<td>11.64</td>
<td>11.88</td>
<td>12.01</td>
<td>12.06</td>
<td>12.05</td>
<td>12.02</td>
<td>11.98</td>
<td>11.92</td>
<td>11.85</td>
<td>11.79</td>
</tr>
<tr>
<td>Pigs sold/sow/year</td>
<td>22.86</td>
<td>22.88</td>
<td>22.94</td>
<td>22.92</td>
<td>22.86</td>
<td>22.78</td>
<td>22.70</td>
<td>22.60</td>
<td>22.48</td>
<td>22.35</td>
</tr>
<tr>
<td>Pigs sold/year</td>
<td>114194</td>
<td>114281</td>
<td>114567</td>
<td>114505</td>
<td>114206</td>
<td>113800</td>
<td>113401</td>
<td>112878</td>
<td>112285</td>
<td>111664</td>
</tr>
<tr>
<td>Returns over total costs $/head</td>
<td>-5.06</td>
<td>2.34</td>
<td>4.39</td>
<td>5.19</td>
<td>5.46</td>
<td>5.58</td>
<td>5.56</td>
<td>5.47</td>
<td>5.34</td>
<td>5.11</td>
</tr>
<tr>
<td>Net return on investment</td>
<td>-4.6%</td>
<td>9.6%</td>
<td>13.6%</td>
<td>15.1%</td>
<td>15.6%</td>
<td>15.8%</td>
<td>15.7%</td>
<td>15.5%</td>
<td>15.2%</td>
<td>14.7%</td>
</tr>
</tbody>
</table>

1 Values gathered from 2011-2014.
2 Represents the parity distribution based on sow culling strategy. For example “4” indicates that in the parity distribution scenario sows are kept until parity 4 and then culled. Sows that are bred but do not conceive, or that do not show signs of estrus prior to the final parity in the distribution are culled.
Table 4.6 Feed and total expense inputs in the sensitivity economic analysis of sow retention of a 5000 head breed-to-wean operation on a per weaned pig basis (all prices, costs, and expenses in $U.S.)

<table>
<thead>
<tr>
<th>Parity prior to cull²</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low feed cost analysis³</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain cost per pig sold</td>
<td>2.76</td>
<td>2.79</td>
<td>2.83</td>
<td>2.88</td>
<td>2.93</td>
<td>2.98</td>
<td>3.04</td>
<td>3.10</td>
<td>3.16</td>
<td>3.22</td>
</tr>
<tr>
<td>Protein cost per pig sold</td>
<td>1.64</td>
<td>1.67</td>
<td>1.70</td>
<td>1.73</td>
<td>1.76</td>
<td>1.79</td>
<td>1.82</td>
<td>1.85</td>
<td>1.89</td>
<td>1.92</td>
</tr>
<tr>
<td>Total variable costs</td>
<td>35.12</td>
<td>26.86</td>
<td>24.52</td>
<td>23.57</td>
<td>23.19</td>
<td>22.98</td>
<td>22.93</td>
<td>22.94</td>
<td>22.97</td>
<td>23.12</td>
</tr>
<tr>
<td>Total costs per pig sold</td>
<td>39.74</td>
<td>31.38</td>
<td>28.99</td>
<td>28.03</td>
<td>27.66</td>
<td>27.47</td>
<td>27.44</td>
<td>27.53</td>
<td>27.71</td>
<td></td>
</tr>
<tr>
<td>Gross returns per pig sold</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
</tr>
<tr>
<td>Net return on investment</td>
<td>-0.2%</td>
<td>15.4%</td>
<td>20.1%</td>
<td>22.0%</td>
<td>22.7%</td>
<td>23.0%</td>
<td>22.9%</td>
<td>22.8%</td>
<td>22.6%</td>
<td>22.1%</td>
</tr>
<tr>
<td><strong>Returns over total costs</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>High feed cost analysis⁴</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Protein cost per pig sold</td>
<td>4.27</td>
<td>4.37</td>
<td>4.44</td>
<td>4.51</td>
<td>4.59</td>
<td>4.68</td>
<td>4.76</td>
<td>4.85</td>
<td>4.93</td>
<td>5.02</td>
</tr>
<tr>
<td>Total variable costs</td>
<td>44.32</td>
<td>36.21</td>
<td>33.99</td>
<td>33.21</td>
<td>33.00</td>
<td>32.98</td>
<td>33.11</td>
<td>33.31</td>
<td>33.54</td>
<td>33.90</td>
</tr>
<tr>
<td>Total costs per pig sold</td>
<td>48.94</td>
<td>40.73</td>
<td>38.46</td>
<td>37.67</td>
<td>37.47</td>
<td>37.46</td>
<td>37.62</td>
<td>37.84</td>
<td>38.10</td>
<td>38.48</td>
</tr>
<tr>
<td>Gross returns per pig sold</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
<td>36.90</td>
</tr>
<tr>
<td>Net return on investment</td>
<td>-17.0%</td>
<td>-2.04%</td>
<td>2.20%</td>
<td>3.72%</td>
<td>4.11%</td>
<td>4.12%</td>
<td>3.83%</td>
<td>3.42%</td>
<td>2.96%</td>
<td>2.26%</td>
</tr>
<tr>
<td><strong>Returns over total costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/head</td>
<td>-12.04</td>
<td>-3.83</td>
<td>-1.56</td>
<td>-0.77</td>
<td>-0.57</td>
<td>-0.56</td>
<td>-0.72</td>
<td>-0.94</td>
<td>-1.20</td>
<td>-1.58</td>
</tr>
</tbody>
</table>

¹ Values gathered from 2001-2014.
² Represents the parity distribution based on sow culling strategy.
³ The 2 lowest feed prices from the years of 2001-2014 were averaged together for both protein (soybean meal) and grain (corn) input prices. All other factors were held constant in the analysis.
⁴ The 2 highest feed prices from the years of 2001-2014 were averaged together for both protein (soybean meal) and grain (corn) input prices. All other factors were held constant in the analysis.
Figure 4.1 Pigs born alive per litter and pre-weaning mortality. (Least squares means ± SE) estimates by parity, for parities 1 through 8 from 105,719 sows

1 Significant statistical difference was observed between parities for pigs born alive per litter; \( P < 0.05 \).

2 Values gathered from 2001-2014.
Figure 4.2 Number born alive per litter estimates by parity groups and year groups (Least squares means ± SE), from 105,719 sows

1 Estimates were averaged across parity groups (1 through 3, 4 through 6, and 7 through 9) and year groups (2001 to 2005, 2006 to 2010, 2011 to 2014).
2 Values gathered from 2001-2014.
Figure 4.3 Pigs born alive per litter ± SE and pre-weaning mortality (least squares means ± SE by parity, for parities 1 through 8)

1 * Denotes a significant statistical difference was observed between parities for pigs born alive per litter; ($P < 0.05$).

2 Values gathered from 2001-2014.
CHAPTER 5
GENERAL CONCLUSIONS

Sow retention in the breeding herd, as described in this thesis, has been shown to impact a producer’s profitability through increased returns over total costs as well as higher net return on investment. With the U.S. breeding herd’s average parity of removal at 3.1 to 3.7 parities (Stalder et al., 2000; Lucia et al., 1999) and the average parity of females in inventory at 2.55 (Anil et al., 2003) there is substantial room for sow longevity improvement. These averages indicate that a large portion of the U.S. sow herd is comprised of low parity dams, though it has previously been reported that sows in their first and second parity wean fewer pigs per year, as well as lighter pigs when compared to older sows (Lucia et al., 1999; Carney-Hinkle et al., 2013; Dhuyvetter, 2000b). This thesis described the financial impact of these implications, and it was shown that the parity distributions comprised of first, second, and third parity sows had the lowest returns per weaned pig as well as lowest net return on investment when compared to parity distributions that culled after parities four through 10. Specifically, it was shown that by culling after parities 5 through 9, the greatest returns per weaned pig are realized. It has previously been reported that a sow does not cover her initial expense as a gilt, or reach a positive net present value, until she has produced her third litter (Sasaki et al., 2012; Stalder et al., 2003). By increasing sow retention and culling after later parities, this thesis demonstrated that the sow is given the opportunity to spread her initial cost over a greater number of pigs, thus decreasing the cost per weaned pig.

The ability to select superior sows for prolificacy has been reported to increase herd longevity (Serenius, 2004). The classification of sows by first and second parity
performance has been demonstrated in this thesis as an effective means for identifying superior sows early in life. Sows in the low NBA classification were shown to have an average of 1 to 1.8 NBA less per parity in parities 3 through 7 when compared with sows in the medium and high NBA classification, respectively ($P < 0.05$). Conversely, sows that were classified as high NBA in parity 1 and parity 2 had greater NBA in all subsequent parities as well as total lifetime NBA when compared with sows classified as low or medium NBA ($P < 0.05$).

Through an understanding of the economic benefits associated with increased sow longevity as well as a means to select superior dams early in their life, the resources presented in this thesis can provide producers a method of making educated culling and selection decisions for their farms that can potentially lead to an increase in profit for their production system.
CHAPTER 6

LITERATURE CITED


