Comparing Two Systems of Sow Group-Housing: Animal Welfare & Economics

by

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ABSTRACT

The objective was to devise a simulation model that could economically compare two group-housing systems for sow operations, a conventional system (CONV) that uses partial-slatted concrete flooring and an alternative system (ALT) that uses straw-covered concrete. Further, the research aimed to determine the optimal parity in which to terminally cull sows. Data were collected on 121 sows between two experimental barns for 7 parities. These data were used to estimate a production function and a culling function. These functions, along with economic data, were used to create an economic simulation model. Production was best predicted by parity and lactation feed intake, and culling was best predicted by parity, weight, and gait score. Optimal terminal culling occurred after parity 6 in ALT and after parity 7 in CONV. Overall, ALT was more profitable than CONV.

ACKNOWLEDGEMENTS

First, I would like to thank the GSA, Manitoba Pork, ARDI, and Genesus Genetics without whom this research would not be financially possible. Also, I would like to thank my committee members – Drs. Hans Andersson, Laurie Connor, Derek Brewin and Gary Johnson. Specifically, thank you, Hans, for your help with the theory (and for the Swedish curry) on my trip to Uppsala. Thank you, Laurie, for continually believing the next deadline would be *the* deadline. And thanks, Derek, for the encouragement both with analysis and curling – of which I am an expert in neither. Lastly, thank you, Gary. Who would have thought two people with laidback attitudes could actually work well on *and complete* a thesis?!

Next, I would like thank everyone that helped out on the project. All the Glenlea swine guys helped me out on numerous occasions. Thanks, Agnieszka, for always being light-hearted and having an easily-pronounceable name. Thank you, Steinar, for caring for the sows and collecting the majority of the experimental data (and for showing me the ways of a Norwegian smoothie). Thanks, Brenda, for being forcefully encouraging: 'Get writing!' And thank you, Taryn, for keeping this thesis going – you have made Manitoba a treat. Thanks, Mom and Dad, for never faltering on the belief that I would finish. Thanks to all the staff, academics, and graduate students in the department – you know who you are – and in the whole Ag faculty. You have truly made this whole experience worthwhile, and have kept me from pulling the toaster into the bathtub on numerous occasions. Lastly, thank you, Nora, to whom this thesis is dedicated, for being an inspiration and keeping my interest in animal well-being well-kindled.

DEDICATION

Dr. Nora Lewis was the first person to welcome me to the Animal Science Department at the University of Manitoba. She had me working on a project in no time, naturally, an animal welfare project. Her ambition and enthusiasm for this research were the main reasons that I stayed on for graduate studies here in Winnipeg. And for that, I am truly thankful. Even in the last few months of working on the project, she was always keen to participate in every aspect of the research. I appreciate everything that she has done, and would have been thrilled to share the results of the project with her. And I know how excited the results would have made her. 'What? Animal welfare and economics can act synchronously?' Naturally, this thesis is entirely dedicated to, and in memory of, Nora.

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CHAPTER 1. INTRODUCTION

I. Problem Statement

The main objective of this research is to determine the timing of terminal culling for an average sow in order to maximize profitability of a breed-to-wean sow operation. Kristensen (1996) suggested that when the most limiting "herd restraint is a limited housing capacity, the number of animals in production is the scarce resource, and accordingly the relevant criterion of optimality is the maximization of net revenues per animal." For this reason, the objective is to devise a simulation model that can determine the optimal level of investment in an individual sow in a breed-to-wean operation that maximizes the present-value of net revenues. This will work two-fold to uncover the profitability of an operation under the current market conditions, and determine the optimal parity at which to terminally cull the average sow. Further, this model needs to be able to differentiate profitability between two systems of sow group-housing – the alternative system (ALT) that has straw over concrete and the conventional system (CONV) that has partially slatted flooring – including the ability to determine their respective optimal solutions.

Another objective is to determine the direct inputs given to a productive sow that have the greatest effect on improving weanling production, specifically the litter weights at weaning. To address this problem, the research aims to devise a regression model that estimates the contribution that each input variable has on weanling production. The effect that the respective housing system has on the efficiency of input usage will also be considered. The other sub-objective regards the prediction of culling; sow condition variables – such as body condition score – will be used to help predict the event of culling. To this end, the research intends to devise an estimation for the probability of culling based on these sow condition variables. Discovering the timing and reasons for culling are other goals that should enable the research to properly comment on the overall welfare of the sows in each respective system.

II. Hypotheses

The overall hypothesis for this research is that the alternative housing system is at least as profitable as the conventional housing system. An individual sow from ALT is expected to be more profitable than an individual sow from CONV, due mostly to the expected reduction in costs associated with replacement and medical treatment. Along these lines of reason, sows in ALT are expected to have better welfare due to having fewer structural issues, as observed by Ehlorsson et al (2002), than those in CONV. The optimal parity at which to voluntarily cull is also expected to be different between the two systems, although the direction and magnitude of this difference is unknown. The optimal parity in which to terminally cull an animal is expected to be above 6 parities, the upper limit of the most productive parities, as stated by Stalder et al (2003). Due mostly to increased labour and manure management expenses, the difference in the profit functions for the entire operations is more difficult to predict. As previously stated however, the alternative system is expected to be at least as profitable as the conventional system.

Another hypothesis is that the weight of the weaned litter produced by an individual sow will not be influenced by the housing system. In other words, few, if any, housing-input interaction variables are expected to be significant in the weanling production function. Both parity and feed are expected to be influential on weanling production however. The production curve is hypothesized to be concave downwards with respect to parity since production is expected to increase until about the 3^{rd} or 4^{th} parity, and then subsequently decrease, as observed by Stalder et al (2003). The feed intake during lactation is expected to have a positive relationship with litter weight, as this is an input that contributes directly to milk production and piglet rearing. The effects of feed intake during gestation, the number of semen dose, and the number of medical treatments on weanling production are unknown, but are predicted to have little impact.

Pertaining to the culling function, the expectations are for parity, gait score, and the number of functional teats to significantly affect the probability of culling. Parity and gait score are predicted to have a positive effect on the likelihood of culling while the number of functional teats will likely decrease the chance of culling since a sow with a better teat-line is likely to wean a heavier litter. The influence of weight, body condition score and backfat depth on culling is more difficult to predict. Though one may expect that higher values for these indicate increased energy stores for reproductive purposes, there is likely a limit, at which point, higher values become detrimental. For example, over fat sows have more difficulty farrowing, increased incidence of stillborn births, have a high tendency to crush their piglets, and have difficulty rebreeding (Buyoc, 2007). For this reason, weight, body condition score and backfat depth are all expected to have no effect on culling probability. Contrary to the prediction for the weanling production function, housing is expected to have some effect on the culling function. Longevity is predicted to be enhanced in ALT as compared to CONV, with ALT expected to have a higher average herd parity and later overall culling. Further, CONV is expected to suffer from increased culling for physical reasons, such as lameness, due primarily to the partially-slatted, concrete floors.

III. Chapter Outline

Chapter 2 will discuss the current status of the North American pork industry. This discussion includes details about the pig production cycle, the type of operations present, and the major players in pork processing. Further, the recent history of the Canadian pork industry – including trends in production and trade, as well as the vertical specialization of hog production – will be addressed. The occurrence of major events, such as mandatory country-of-origin labelling (COOL) in the U.S.A. and the ‘swine flu’ pandemic, and their impact on Canadian pork production will also be addressed in this chapter. Another aspect that will be covered is the influence that European consumers have on the North American market. The implementation of new animal welfare policies by the European Union Council, the science of animal welfare, and the demand for sow group-housing by North American processors and retailers will be discussed. Lastly, the relevance of this research for industry application will be solidified in this chapter; this will specifically address the importance of investigating sow longevity.

The theoretical model that will determine the optimal level of investment in a sow will be developed in Chapter 3. The model will be built from general firm theory, in which the firm – in this case, a breed-to-wean sow operation – acts to maximize profits over a given time horizon. The constraints, as well as the overall market structure, that pig producers are confined to will also be discussed in this chapter. Building from a basic static model, the model will be developed into a dynamic model using a profit function to determine an optimal solution. The efficacy of both a continuous, dynamic model and a discrete, dynamic model will be investigated. Additionally, previous models in the literature (Burt, 1965; Dijkhuizen et al, 1986; Rodriguez-Zas et al, 2006) will be considered and built upon. This chapter will also introduce Hamiltonian optimization, a method of optimization most suitable to the profit-maximization in this problem.

Chapter 4 will describe the experimental methods devised to solve the research problems. Firstly, the methods used to collect data from the animals will be detailed, including a description of the facilities, management system, and experimental design. The structure of the experimental data will also be described. Then a subset of relevant variables from this dataset will be extrapolated, and any transformations required to make these data suitable for analyses will be explained. This transformed data will be used for the estimations of a weanling production function and a culling function. In turn, these two estimations will be entered into a simulation model for an individual sow in a breed-to-wean pig operation. This chapter will describe the development of this simulation model, and the economic data used to make this model applicable in the current market. The steps to translate this individual sow model into an entire 600-sow barn model will also be detailed. Lastly, the methods used to determine optimality, and the sensitivity analyses around these analyses, will be described.

The results of the analyses and the arising discussion will be displayed in Chapter 5. This will include the estimated coefficients for the independent variables in the weanling production function, as well as those in the culling function. The results of all the model simulation runs will also be exhibited, including the respective runs for both the alternative and the conventional barn. From these runs, the optimal solution for terminal culling will be determined for each respective barn. The results of the sensitivity analyses for profitability – determined by varying the values of economic variables in the simulation model – will also be presented. The results of the sensitivity analyses for optimality yielded – by varying model variables – will also be displayed in this chapter. The discussion will be broken down into several key topics. The first key topic will be the culling profile and herd composition in the experimental data and how this compares to previous literature findings. The next topic will regard the results of the culling estimation. The production observed in the experimental herds and the resulting production estimation will also be discussed. Previous literature results will be compared to the results found in this research for optimal terminal culling, and the underlying reasoning behind these aforementioned results will be investigated and discussed. The discussion will also include the results for the sensitivity analyses, and the inferences of these sensitivities. Another important topic that will be addressed in this chapter is how these results relate to industry standards; specifically, the applicability of the research to the industry will be discussed.

Chapter 6 will be devoted to the conclusion of this research. The entire thesis will be summarized, and some conclusions regarding the overall findings of this research will be stated. Also, some suggestions for future research and the hog industry will be stated. Appendices will follow these chapters.

CHAPTER 2. BACKGROUND

The North American pork industry has undergone many changes in the last couple decades, and has seen dramatic development in production methods, scale of operations, production volume, and international trade. These developments were spurred on by changing domestic and international demand, new technology, superior breeding genetics, cost of production, and corporate involvement, amongst other things. Understanding the past, present, and future direction of the North American pork industry is crucial in addressing the need for this research. To thoroughly accomplish this objective, a few key areas need discussion including the pork production process, some industry statistics, international trade, animal welfare developments, and future industry direction.

I. North American Pork Production

Production Cycle

Despite variations in the type of pork operations, the typical pork production cycle in North America remains relatively constant. The production cycle is illustrated in Figure 2.1. Producers usually select or purchase breeding gilts when they are around 6 months of age, or approximately 110-120kg. These gilts are then raised on-farm until they reach around 130kg (Manitoba Pork Council (MPC), 2006). At this point, they are bred within their first three oestrus cycles. Breeding frequently occurs by artificial insemination (AI), but some producers still use boars to service their animals. During the breeding period, the animals are either group-housed or individually-stalled in breeding barns for 3-4 weeks. Failure to return to oestrus (heat) after 18-22 days and/or a pregnancy-check using ultrasound technology at around 4 weeks post-breeding are used to confirm pregnancy (Kemp, 2009). If pregnancy has not occurred, the producer may re-inseminate the animal when it comes into oestrus next; the heat cycle averages 21 days (Alberta Pork).

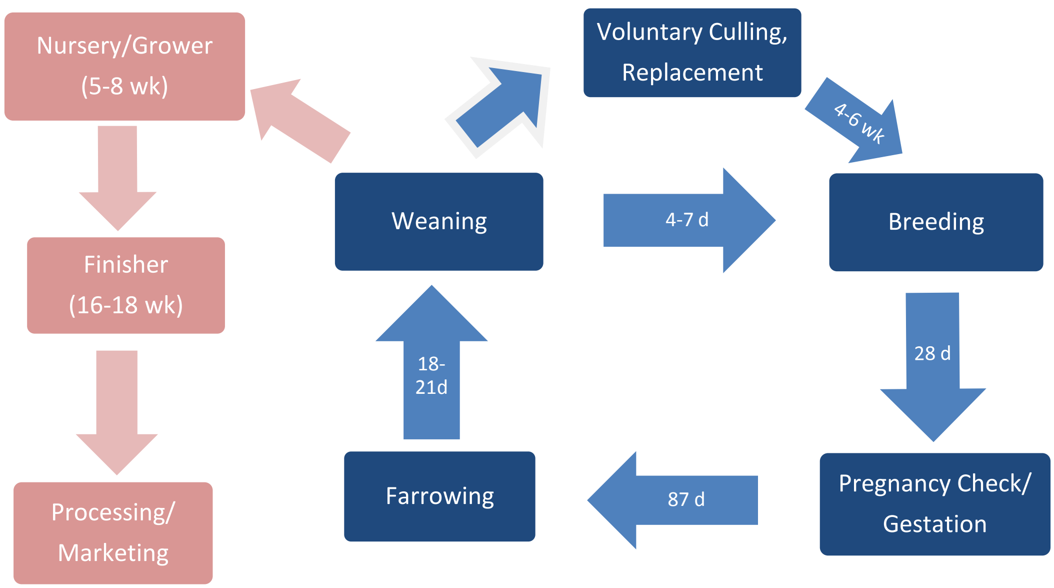


Figure 2.1. Pig production cycle (adapted from Alberta Pork; Kemp, 2009; MPC, 2006). Dark squares and arrows denote the dam's cycle in the breeding barn. Light squares and arrows denote the process of growing the offspring beyond weaning.

Pregnant gilts/sows (dams) are then moved into a gestation barn where they will remain for the majority of their 115-day gestation period. Current North American gestation barns usually have pregnant sows housed individually in stalls. However, a growing number of operations group-house their pregnant sows (MPC, 2006). At approximately 5-6 days prior to their expected farrowing dates, pregnant dams are moved to farrowing rooms where they are individually penned in farrowing crates. The animals will remain in farrowing pens or crates until their litter is weaned. Weaning usually occurs at 18-21 days (Kemp, 2009), depending on the production scheme, when the pigs are, on average, around 5- 6 kg.

The dams are then moved back into the breeding barn where they usually begin cycling (i.e. come into heat again) within 4-7 days after being removed from their piglets (MPC, 2006). The dam is considered a *gilt* until she farrows her first litter, at which time she become a *sow* (National Agriculture Statistics Service (NASS), 2009). The weaned pigs are then moved to nursery barns as weanling pigs. They will remain in the nursery for 5-8 weeks until they reach a weight of approximately 22 kg (50 lb.). At this point, the pigs are moved into grower/finisher (feeder) barns as feeders and raised for 16-18 weeks until they reach a market weight of approximately 115kg (MPC, 2006). The pigs are considered finishers at the last stage of this growth cycle in the feeder barn when the pigs are primarily laying down backfat, i.e. finishing. They are now considered *market hogs* and are sent to slaughtering facilities to be processed (NASS, 2009).

Type of Operations

The aforementioned production cycle does not necessarily occur at one given site. North American hog production is often segregated into operations based on the different stages in production. The classical operation is a farrow-to-finish operation, which breeds and farrows their sows, and raises the litters to 115 kg – market weight – at one site (NASS, 2009). Another common operation is a finishing operation, which purchases pigs as feeders at 22kg and raises them to market weight. This type of operation requires no breeding stock (NASS, 2009). Conversely, two other types of operation that have the breeding sows on-site are farrow-to-feeder and farrow-to-wean (or breed-to-wean) barns. Farrow-to-feeder barns raise their pigs up to feeder weight and sell them to finishing barns. Breed-to-wean operations raise their pigs to 5-6kg, at which time they sell them as weanlings to nursery operations. Nursery operations then raise them up to 22kg and sell them to finishing operations (NASS, 2009). Market hogs from the finishing operations are then sent to processors to be slaughtered and processed into pork products.

Processors

The North American pork industry is composed of a limited number of processors. In Canada, the main pork processors are Maple Leaf Foods, Olymel Foods, Tyson Foods and Cargill Foods, with numerous smaller processors contributing to pork production (Canadian Agri-Food Trade Alliance (CAFTA), 2008). Maple Leaf Foods leads the Canadian pork processing industry, processing 31% (6.8 million head) of all hogs slaughtered in Canada in 2009 (Maple Leaf Foods, Inc., 2010; Statistics Canada, 2010b). This gives them a fair amount of market power for both purchasing slaughter hogs and marketing pork products.

However, Canadian pork producers are also dependent on U.S. pork processing due to a limited local slaughter capacity. Total Canadian slaughter capacity was estimated at 480,000 head weekly in 2005 (Canada Pork International, 2007) – a maximum value of 25 million head annually. With 21.8 million hogs slaughtered in Canada annually (Statistics Canada, 2010b), total Canadian hog processing only undershoots its slaughter capacity by about 3 million head. However, this neglects to consider the limitations of hog transport caused by the location of pork processing plants. Though Manitoba produces 30% of Canadian pigs (9.0 million) (Statistics Canada, 2010b), Manitoba and Saskatchewan combined only have four federally-inspected pork processing plants with a slaughter capacity of around 5 million pigs (Agriculture and Agri-Food Canada (AAFC), 2010e). With Canadian pig production overshooting total potential slaughter capacity on a national level by close to 4 million pigs (AAFC, 2010b), in addition to regional slaughter limitations, it is clear that Canadian processing cannot currently keep up to Canadian hog production.

As is the case with the Canadian industry, the U.S. industry also has a select number of large pork processors. Smithfield Foods controls the largest portion of the U.S. pork processing market with 31% of the market share in 2008 (Smithfield Foods, Inc., 2008). Since many Canadian pigs are exported to the U.S. for growing, finishing, and slaughtering (AAFC, 2010b), Smithfield Foods also has considerable influence on Canadian pork production. The market share in 2008 for pork processors in the U.S. is illustrated in Figure 2.2. Both Maple Leaf Foods and Smithfield Foods significantly

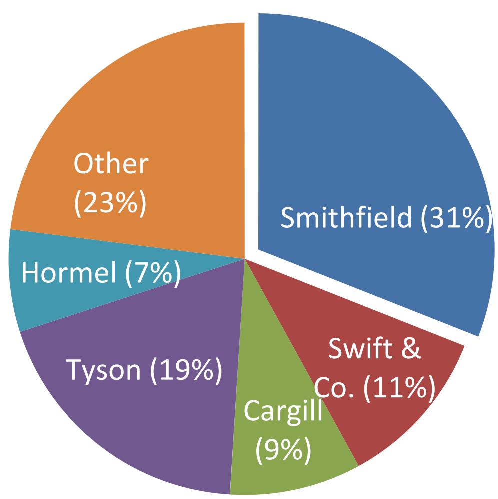


Figure 2.2. U.S. pork processors’ market share in 2008 (Smithfield Foods, 2008).

influence Canadian and U.S. pork production, respectively. Therefore, policy decisions made by these two processors are likely to heavily impact North American pork production.

II. North American Pork Industry

Historical Production and Trade Statistics

The past couple decades have seen rapid growth in Canadian hog production, with a gradual increase from 15.6 million pigs produced in 1990 up to 31.0 million in 2008 (Statistics Canada, 2010b). This 31.0 million head represented over 20% of the total production in Canada and the U.S. (NASS, 2010). Manitoba alone accounted for 9.0 million of these pigs produced, or about 30% of the total Canadian production (Statistics Canada, 2010b). Despite rising production numbers, the breeding herd inventory continued to decrease from the high of about 1.6 million head in 2005 to about 1.4 million in 2008 (Statistics Canada, 2010b). This demonstrates that fewer breeding animals are producing more pigs, which can be partially explained by improved genetics (NASS, 2009).

The number of hogs slaughtered also increased during the past 20 years up to 22.9 million head in 2004, with only a slight decline to 21.8 million by 2009 (Statistics Canada, 2010b). The difference between the total pigs produced and hogs slaughtered in Canada is accounted for by live pig exports. In 2009, Canada exported 6.4 million live pigs to the U.S. Despite still being a significant exporter, this number is dwarfed by the 9.3 million exported to the U.S. in 2008, which delivered CDN$519 million to the

Canadian economy (AAFC, 2010b). The Canadian hog industry is therefore extremely dependent on hog purchasers in the U.S. Pork exports to the U.S. also contributed CDN$834 million – amounting to 329,000 tonnes of pork products – to the Canadian pork industry in 2009 (AAFC, 2010b). Total processed Canadian exports to the U.S. in 2009 were 46,000 tonnes, contributing CDN$196 million. Conversely, Canada imported less than 1500 live pigs from the U.S. in 2009. However, imports of U.S pork products into Canada totalled 164,000 tonnes, amounting to CDN$609 million (AAFC, 2010d). Of this total, 33,000 tonnes were processed pork. However, U.S. imports of pigs and pork products into Canada are dwarfed by Canada's exports to the U.S.

Specialization in North American Pork Industry

Of the 9.3 million pigs exported to the U.S. in 2008, 7.0 million were sold as feeders (NASS, 2009). Specialization in Canadian feeder production was a growing trend even within the past few years from 65% of exports in 2005 being feeders up to 75% in 2008 (NASS, 2009). Key and McBride (2007) found that the U.S. pork industry had also specialized over the past decade, with a reduction in the proportion of farrow-to-finish pork operations and an increase in finishing operations. Canada produced many of the weanlings/feeders that stock these U.S. finish barns, and Canada has increasingly specialized in weanling production while the U.S. specializes in finishing and marketing the pigs (Key and McBride, 2007). In fact, feeder pig exports to the U.S. accounted for 23% of the total Canadian pig crop produced in 2008 (NASS, 2009) with the revenue acquired from the sale of feeder exports to the U.S. amounting to CDN$241 million (AAFC, 2010c). The U.S. provides the entire market for Canadian feeder pig exports.

Manitoba Weanling Production

Manitoba produces about 30% of Canadian pigs (Statistics Canada, 2010b), and is the largest weanling-producing province in Canada (Honey, 2009). Of the CDN$241 million in feeder pig export revenue, CDN$146 million was specifically contributed from the sale of Manitoban feeder pigs (AAFC, 2010c). These weanlings and feeders are produced by the numerous breed-to-wean and breed-to-feeder operations, respectively. The 2006 Canadian census demonstrated that about 16% of Manitoban pig operations are purely weanling producers (Honey, 2009), with the number of piglets (under 20kg) on Manitoba pig operations amounting to 1.08 million in January 2008 (Statistics Canada, 2010b). Admittedly, operation costs for finishing are lower in the U.S.A. as compared to Canada (Maple Leaf Foods, Inc., 2010), allowing for more competitive weanling prices. This becomes a significant incentive to export weanlings south. Manitoba thus provides numerous weanlings for finishing in U.S. hog operations. The main U.S. markets for these weanlings are Iowa, Minnesota, South Dakota, Nebraska, and Illinois (Honey, 2009). Understandably, with such a large share of feeders going south of the border (AAFC, 2010c) and a limited slaughter capacity (Statistics Canada, 2010b), Manitoba pig production is very dependent on U.S. finishing and processing.

Significant Events Affecting the Pork Industry

A number of significant events have severely impacted the Canadian pork industry. Both the Country-of-Origin Labelling (COOL) (Link, 2009) and the Manitoba hog operation moratorium (Manitoba Livestock Manure Management Initiative (MLMMI), 2008) came into effect in September, 2008. The COOL ensures that all pork products that are sold in the U.S. are labeled with the pig's country of origin (Link, 2009), which forces U.S. pork processors to sort Canadian-born pigs from those of American origin. This acts as a deterrent and trade barrier to accepting live Canadian pigs. The moratorium prevented the expansion of existing and construction of new hog operations in many hog-producing regions of Manitoba (MLMMI, 2008). Another key event was the detection of a new influenza virus – H1N1 – in humans in early 2009, expected to lead to a large-scale influenza pandemic (Chan, 2009). The problem, therein, is that it was labelled as 'swine flu' and caused hesitancy in consumers to purchase pork products. Further, Canada/U.S. border closures due to fear of 'swine flu' being spread in hogs impacted trade and the price of pork (Statistics Canada, 2010b).

With the U.S. being such a large purchaser of Canadian hogs, these 3 events have hit the Canadian pork industry hard, with export revenue for Canadian pigs declining by 33% (CDN$171 million) between 2008 and 2009 (AAFC, 2010b). Three other occurrences possibly linked to this struggling industry were the increasing value of the Canadian dollar (Bank of Canada, 2010), high feed prices and low pork prices (Manitoba Agriculture, Food and Rural Initiatives (MAFRI), 2009). The latter of these three was likely partially due to the aforementioned reasons.

Current Statistics

The current North American pork industry is quite large in scale, although recent declines in pork prices and some market uncertainty have led to declining livestock numbers in Canada (Statistics Canada, 2010b). The on-farm hog inventory was at a 12-year low of 11.6 million head – of which Manitoba contributed 2.45 million – and a 10-

year low of 1.3 million breeding animals in the first quarter of 2010 (Statistics Canada, 2010b). These marked a 16% and 12% decrease for total Canadian hog inventory and breeding stock inventory, respectively, as compared to those seen in the first quarter of 2008 (NASS, 2010). The U.S. has only observed a 3% decrease in hog inventory and a 6% decrease in the breeding inventory when comparing the last quarter of 2007 with that of 2009 (NASS, 2010). Total pigs produced dropped in Canada by 12% in that time-span (NASS, 2010) likely due in part to the federal Hog Farm Transition Program that pledged CDN$75 million to buy out breeding stock (United States Department of Agriculture Foreign Agricultural Service (USDA FAS), 2010). Manitoba feeder pig exports dropped significantly from exporting 7.0 million feeder pigs to the U.S. in 2008 – valued at CDN$241 million – down to only 5.2 million in 2009 – valued at CDN$184 million (AAFC, 2010c). As observed, the Manitoba pork industry and the Canadian industry as a whole have been struggling recently.

III. European Union (E.U.) Pork Trade

European Trade Statistics

In 2009, Canada exported 88 million kg of pork products to the E.U., which amounted to over CDN$151 million (AAFC, 2010a). This was significantly lower than the revenue generated from export to Europe in 2008 – CDN$341 million. The United States is also quite dependent on pork exports to Europe, which account for US$231 million (USFTD, 2010). For this reason, it would be advantageous for the North American pork industry to continue to meet the demands of European consumers. Losing marketability in the E.U. would be a significant issue for North American pork producers, and provides a large incentive for these producers to abide by European standards.

New E.U. Welfare Policies

The Council of the European Union (CEU) introduced new legislation regarding the housing of sows for pork production in 2001. The new legislation states that E.U. member states must put into effect regulations that prohibit the housing of pregnant sows in individual stalls (CEU, 2001). These sows must be kept in group-housing for the majority of their gestation period. The exception is the period from one week prior to their expected farrow date until 4 weeks post-servicing. All pig production in the E.U. must be in accordance with these regulations by January 2013. Further, member states are able to implement regulations that are stricter than this legislation – England is one such country that formalized stricter regulations for producers. They require their sows to be individually stalled no longer than the time period from 7 days pre-farrowing to weaning (Crown Copyright, 2003), while other countries can keep sows individually stalled until 4 weeks post-servicing (CEU, 2001). The E.U. legislation was brought forward – backed firmly by consumer demand and scientific findings – in attempt to improve animal welfare.

IV. Animal Welfare

Indicators of Welfare

The welfare of an animal is defined as its state as regards its attempts to cope with its environment (Broom, 1986); a failure to cope or difficulty in coping in an environment are indicators of poor welfare (Broom, 1991). Using this definition, Broom (1991) assures that animal welfare is able to be measured scientifically. Broom (1991) suggests using the following as indicators of poor welfare: impaired growth, impaired reproduction, body damage, disease, immunosuppression, adrenal activity, behavioural anomalies, and self-narcotisation. In light of these indicators, such objective measures as reproductive success, weight gain, presence of lameness, and disease occurrence can be used to effectively measure animal welfare.

Longevity and Welfare

Broom (1991) also emphasizes using longevity – defined as 'life expectancy' – as an indicator of welfare. Reduced longevity indicates the presence of stressors on an animal, and that, during some part or parts of its life, the animal has had poor welfare (Hurnik and Lehman, 1988). Hurnik and Lehman (1988) caution against the use of longevity as an indicator of animal welfare in production systems though since most animals do not live out their entire life potential, i.e., are culled before natural death. When animals are culled voluntarily due to low production or poor breeding success, for example, no inferences can be made about longevity. Situations in which death, disease or serious injury occurs are still indicative of reduced longevity, however. In these cases, longevity proves to be a reliable indicator of animal welfare (Hurnik and Lehman, 1988). Reduced longevity, in the case of a production system, is probably best measured by the occurrence of early, involuntary culling or death.

The literature review by Stalder et al (2004) found inconsistent results regarding the effect of housing on sow longevity. Group-housing sows may prove to enhance animal welfare above that seen for individually-stalled animals (Gregory, 2007). Morris et al (1998) used a system of group-housing sows – the Hurnik-Morris system – and found that this increased the average parity at cull and increased average lifetime production. In addition to a potential reduction in longevity, individually-stalled animals are also considered to be at higher risk of structural problems, such as foot and leg injuries and general lameness, than those in group-housing (Ehlorsson et al, 2002). Marchant and Broom (1996) found that sows in gestation crates also had poor muscle development and reduced bone density, which made them more vulnerable to structural problems. It was suggested that these structural problems are, in and of themselves, indicative of poor welfare (Broom, 1991). Further, since these structural problems increase the probability of a sow being involuntarily culled (Serenius and Stalder, 2007), the housing system has a direct impact on sow longevity as well. Lameness – most often brought on by structural weakness – can also cause higher returns to oestrus post-breeding – an indicator of reproductive failure (Andersen and Bøe, 1999). With the primary causes of early culling being breeding failure, poor reproductive performance, and locomotive disorders (Gregory, 2007), longevity is also compromised due to the aforementioned issues.

In addition to these indicators of poor welfare, individually-stalled gestating sows also exhibit stereotypies – abnormal, repetitive behaviours – as well as poor manoeuvrability due to limited space and general discomfort (Gregory, 2007). All these indicators suggest that individually-stalled sows have poor welfare. However, group-housing can vary greatly in housing design, feeding systems, and group management (den

Hartog et al, 1993), and not all group-housing systems will prove to enhance longevity or animal welfare. Friendship et al (1986) found no difference in longevity between stalls and group-housing. Backus et al (1997) also found that group-housed sows take longer to return to oestrus post-weaning than stalled sows – an indication of reduced reproductive success. Other detriments to welfare caused by group-housing sows are higher stress levels – denoted by high salivary cortisol (Mendl et al, 2002) – as well as increased fighting and general aggression (Barnett et al, 2002). However, with proper group management and pen design, these problems can be reduced (Barnett et al, 2002). One such way to reduce aggression, especially at the time of mixing is by supplementing straw (Kelley et al, 1980). Considering all the literature, there does seem to be some benefit from moving away from gestation crates towards group-housing systems.

Longevity and Profitability

Asides from enhancing animal welfare, improving sow longevity provides another advantage as well. A sow that remains in the herd longer is more likely to recoup its initial purchase cost by providing more litters. Stalder et al (2003) suggested that, under the current market conditions at the time, a sow must remain in the herd at least 3 parities to cover this investment cost. Sows removed for involuntary reasons – such as lameness – before 3 parities result in an economic loss to the producer. Further, peak production occurs in the 3rd and 4th parities (Stalder et al, 2003), so culling early would drastically reduce average herd production, not to mention the number of piglets produced per sow lifetime. If average herd production drops by even one weaned pig per sow per parity, it could result in a loss of around $2 million over a 20-year period for a 1200-sow breed-to-wean operation (at $35 per weanling). Thus, a system that reduces early culls would be extremely advantageous for the producer.

Increased longevity also requires the producer to replace his or her animals less frequently, thus avoiding unnecessary replacement costs. With the price of a crossbred breeding gilt hovering around $300 over the past 5 years (Genesus Inc., 2009), culling at an earlier parity would significantly impact producer profit. For example, if sows were consistently culled at an average of 2.5 parities instead of 4 parities, it would result in a loss of at least $2300 per sow space over a 20-year horizon, not mentioning the cost of rearing the replacement up to breeding weight. That is over $2.75 million in 20 years for a 1200-sow operation. Housing systems that optimize longevity are therefore beneficial to the animals, the producers, and the industry.

V. Changes in North American Pork Industry

New Expectations for North American Pork Industry

Aside from the effect on the North American pork export market, the growing consumer pressure in the E.U., coupled with the growing support of animal welfare science for sow group-housing is bound to raise the awareness of consumers and producers alike in North America. Further, consumer pressure is likely amplified by the numerous animal advocacy groups – such as People for the Ethical Treatment of Animals (PETA), World Society for the Protection of Animals (WSPA), and numerous branches of the Society for the Protection of Cruelty to Animals (SPCA) and humane societies – that are global in nature. Therefore, it would not be surprising to observe increasing consumer expectations in Canada and the U.S. in regards to meat production practices. There were also discussions arising in the WTO about incorporating animal welfare regulations into trade agreements (U.S. Department of Agriculture Foreign Agricultural Service (USDA FAS, 2009). The implications of this are self-explanatory. Overall, the new legislation in the E.U. may prove to be of significant impact to North American producers and policy-makers. Canada and the U.S. risk a reduction in European consumer demand for North American pork, which could dramatically reduce pork revenues. If North American consumer demands follow-suit with European demands, failing to adapt may lead to further reductions in revenues for North American pork retailers.

Smithfield Foods and Maple Leaf Foods Adoption of Group-Housing

Along these lines of reason, Smithfield Foods announced in January 2007 that they plan on undergoing a complete transformation to group-housing systems in their company-owned sow operations by 2017; they also encouraged their contracted producers to do the same (Smithfield Foods, Inc., 2007). Shortly thereafter, Maple Leaf Foods (Canada) also announced their intent to phase-out gestation stalls in favour of group-housing, endorsing the U.S. industry's direction (Maple Leaf Foods, Inc., 2007). Both companies claim this move was motivated by elevated consumer concern for animal welfare. From an economic standpoint, it might also allow these processors to more readily market their products to trading partners, such as the E.U., that have shown growing concern for animal welfare.

Economic Opportunities within North America

Adopting this new policy also allows for interesting marketing opportunities in the North American market. North American consumers are becoming more concerned with animal welfare, and are expecting producers, processors, and retailers alike to adhere to higher standards. For example, consumer demand has urged major fast-food chains, such as McDonald's, Wendy's and Burger King, to adopt policies regarding the animal welfare standards of their suppliers (McDonald's, 2006; Oldemark LLC, 2010; Martin, 2007). Pork retailers may be able to charge a premium for "group-housed" pork products, thus segregating the pork market. Without differentially labeling their pork products, however, there will be a pooled equilibrium in which consumers cannot distinguish "humane" products from all other products. Both Smithfield and Maple Leaf Foods have the ability to differentially label, which should enable them to market their products as "group-housed" products and capture this price premium. These policies pave the way, therefore, for segregated markets and increased marketability within the E.U. and North America.

Future Direction

With Smithfield Foods and Maple Leaf Foods making milestone decisions in regards to animal housing, and major fast-food chains making commitments to high animal welfare standards, there is some evidence that the majority of the North American market may follow-suit in the near future. However, both Canada and the United States have a history of making slow progress with animal welfare legislation. If the pork industries are to adopt group-housing, it is far more likely to occur due to market pressure. Even with some consumers becoming more concerned with animal welfare, the process of converting the industry from one with a majority of individual-stall systems into one of group-housed systems would be tedious and initially costly. However, there does appear to be some desire for change, triggered primarily by consumers and secondarily by these two large processors. Further, the Canadian pork industry – especially producers – is hurting from current market conditions and is looking for ways in which to rebound. Abandoning conventional stall systems and adopting group-housing systems may be one such way. Establishing an industry that is more conducive to meeting consumer expectations may help stabilize revenues for those in the pork industry.

VI. Relevance of Research to Industry

A movement towards sow group-housing makes research into various group-housing systems pertinent to the North American pork industry. As mentioned, the housing system affects the welfare of the animals and the economic bottom-line, so it is important to assess these systems for the sake of the pig and the producer. In the context of Canadian production, consideration for the specialization in weanling production is also necessary. This is more directly the case for Manitoba production with the increasing percentage of breed-to-wean and farrow-to-feeder operations. With such a dynamic industry – as the North American pork industry has proven to be – ongoing research that addresses the effect of these changes, in addition to research that investigates future possibilities, becomes increasingly important. Chapter 3 will present the theoretical groundwork to address optimal sow replacement for two unique breed-to-wean, group-housing systems.

CHAPTER 3. THEORETICAL MODEL

Chapter 2 explained the dynamic state of the North American pork industry and the influential factors that have recently affected it. The chapter also displayed the significance of this research to address issues and gaps of knowledge in the industry. To begin to investigate this research problem, the behaviour of breed-to-wean pork producers needs to be considered. Acknowledging their behaviour will set the groundwork for building the theoretical model that will allow for optimal sow replacement decisions. This, in turn, will maximize profitability for these producers.

I. General Firm Theory

Utility Function

Since breed-to-wean pork producers act as economic agents, they can be assumed to attempt to maximize their individual utility. Though producers are often risk-averse (Moschini and Hennessy, 2001), this model will assume that these pork producers operate as objective producers with a profit function representing their utility, i.e., the producers are assumed to be risk-neutral. Uncertainty, therefore, does not play a role in their utility, and the profit function becomes their utility (or objective) function. In other words, they act as profit-maximizing agents in accordance with neoclassical firm theory; their primary objective is to optimize investment in order to maximize profits over a given production path.

Market Structure

The market structure for weanlings is assumed to be competitive and, thus, breed-to-wean producers are expected to maximize profits by equating marginal revenue (MR) to marginal costs (MC). Due to the competitive market structure, producers are also assumed to be price-takers in regards to both input and output prices (Johnson, 1950) – they have no market power and are unable to manipulate market prices. In this regard, producers are only able to vary revenue by varying production output. Producers can only market their weanlings at a pre-set weight, and will sell all current weanlings at any given price since they will incur a larger loss by not selling them. In other words, the supply function of these producers is assumed to be highly inelastic in the very short-run (Johnson, 1950). In the longer run, however, producers are able to modify their production output based on the current market price. More positively, an almost perfectly elastic demand curve allows producers to sell any number of weanlings at any given time at the market price. Producers are also assumed to be able to purchase any quantity of inputs at any given time. In other words, they are assumed to have infinite marketing and input-purchasing capability.

II. Production Constraints

Unconstrained conditions in production, especially biological production, are exceedingly rare, and optimization is often subject to production constraints. In breed-to-wean operations, the first of these constraints is the physical constraint of sow reproduction, bound primarily by biological feasibility. Another set of constraints are government regulations, which may regulate the wages, production practices, and other production factors and costs. The size of the production facility also constrains production by limiting the number of reproducing sows. Production is not space limited as much by the total sows in an operation as it is by the number of available farrowing spaces (crates). Thus, farrowing spaces are considered the major space-limiting factor. The combination of this constraint on herd size and maximum reproductive potential limits the total weanling production. In order to maximize profits there is an optimal level for weanling production subject to these constraints. For the purpose of this model, the operation's capacity for weanlings produced is assumed to be limitless, i.e., the barn can store as many weanlings as the limited number of farrowing spaces can produce.

As discussed in Chapter 2, culling plays a significant role in pork production. Culling enters the model as another constraint on production; this constraint, however, can be at least partially manipulated. When culling a sow, the feasibility of quick replacement needs to be considered, specifically the purchasing and rearing of replacement gilts. The system is constrained by the price and availability of replacements, and the producer's cash-flow. If replacements are unable to be sourced, the sow population within the barn may drop below capacity. The sow population, however, is kept (artificially) constant since the replacement potential from external sources is essentially infinite – any number of replacement gilts can be purchased to replace culled sows. From the perspective of an individual firm, there is an infinite supply of replacement gilts purchasable at market price. Due partially to this reasoning and to higher reproductive potential in later parities, the optimal culling rate is far from the point where the replacement constraint needs to be considered. For the sake of parsimony, replacement rate can always be assumed to match the culling rate.

III. Static Model

Profit Function

A profit function – also, in this case, representing a *utility* or *value* function – appears as follows:

$$\begin{aligned} \pi &= TR - TVC - TFC \\ &= p \cdot q - c^h \cdot x^h - c^j \cdot x^j \\ &\text{s.t.} \quad q = f(x^h) \\ &\qquad\quad p, q, c^h, x^h, c^j, x^j \geq 0 \end{aligned} \tag{3.1}$$

where π represents total profits, TR represents total revenue, TVC represents total variable costs, and TFC represents total fixed costs. Total revenue is equal to the product of output price, p and output quantity, q, while the total variable costs, $c^h \cdot x^h$, and total fixed costs, $c^j \cdot x^j$, are equal to the quantity of variable and fixed inputs multiplied by the unit-costs of the variable and fixed inputs, respectively. All symbols and formula notations for Chapter 3 are represented in Appendix A.

The optimization of production in a breed-to-wean sow operation can be deconstructed into a profit function for the individual sow and a separate profit function for the entire operation. However, when the herd size is the main constraining factor, optimizing net revenues in a sow operation is accomplished by optimizing investment in the individual sow (Kristensen, 1996). Since farrowing pens are the limiting factor, profitability of an individual farrowing space will be used as the measure of an individual unit. Thus, over a given time horizon, multiple sows may occupy this space. For this reason, this unit will be referred to as an ‘individual sow space’ henceforth.

Equation (3.1) is expanded to investigate the optimization of an individual sow space in a breed-to-wean operation. This is represented as follows:

$$\pi_i = p \cdot q^i - c^h \cdot x^{ih} - c^j \cdot x^j \qquad (3.2)$$
$$\text{s.t.} \quad q^i = f(x^{ih})$$
$$p, q^i, c^h, x^{ih}, c^j, x^{ij} \geq 0$$

where π_i is the profit function of an individual farrowing sow space, p is the market price of the output (weanlings), q^i is the quantity of output (weanlings) produced by this individual sow space, x^{ih} is the set of all variable inputs invested in sow i, c^h is the cost of variable input h, x^{ij} is the set of all fixed inputs, and c^j is the cost of fixed input j. Once the fixed costs are sunk, i.e., c^j and x^j disappear from the profit function, this long-run profit function becomes a short-run function. Prices, costs, inputs, and outputs are non-negative.

The model is assumed to be in equilibrium in the static case. This suggests that only the variable inputs – along with the current price and production – need to be considered, neglecting the fixed (capital) inputs. Equation (3.2) can therefore be readjusted to omit the fixed costs for the static model. This is shown by the first order condition:

$$\frac{\partial \pi}{\partial x^{ih}} = p \cdot \frac{\partial f(x^{ih})}{\partial x^{ih}} - c^h = 0 \qquad (3.3)$$

Alternatively, if the inverse of the production function exists, i.e., $x^{ih} = h(q^i)$, and equation (3.3) can be written as:

$$\frac{\delta \pi^i}{\delta q^i} = p - c^h \cdot \frac{\delta h(q^i)}{\delta q^i} = 0 \qquad (3.4)$$

The static model is independent of time as it is not inter-temporal. In other words, none of the variables are functions of time. The same is true for the profit function of the entire breed-to-wean operation, which appears as:

$$\pi = \sum_{i=0}^{n}(p \cdot q^i - c^h \cdot x^{ih} - c^j \cdot x^j) \qquad (3.5)$$
$$\text{s. t.} \quad q^i = f(x^{ih})$$
$$p, q^i, c^h, x^{ih}, c^j, x^{ij} \geq 0$$
$$n \in [0, N]$$

where π is the profit function for the breed-to-wean sow operation, n is the number of productive animals in the operation, and N is the operation's capacity (herd constraint) for sows, i.e., farrowing spaces. This equation suggests that the profit of the entire operation can be determined by summing the profit functions of the individual sow spaces. This further suggests that optimizing investment in the individual sow space optimizes the profit of the entire operation, at least in the static model. The optimal solution for the static model, however, needs investigation.

Optimal Solution

In order to maximize profits, culling decisions must be made by the producer to replace low-productivity sows with replacement gilts. The cost for a replacement gilt, as well as the current sow's salvage value, needs to be considered. If total profit is considered, the sow should be kept as long as its marginal revenues are greater than or equal to its marginal costs. Mathematically, this point is shown by (3.6), where the left-hand side (LHS) contains total revenues from the sow, and the right-hand side (RHS) contains the total costs of keeping the sow, given profits must be greater than or equal to zero:

$$p \cdot q^i + \sigma^i \geq c^h \cdot x^{ih} + c^g \qquad (3.6)$$

where c^g is the price for purchasing a replacement gilt plus the cost of rearing this gilt up to a successful breeding weight, and σ^i is the sow's salvage value. For the static model, maximizing profits comes down to the first order condition as shown in equation (3.3) or in the alternative based on the inverse production function. Equation (3.3) can be rewritten as:

$$p \cdot \frac{\delta f(x^{ih})}{\delta x^{ih}} = c^h \qquad (3.7)$$

$$p = c^h \cdot \frac{\delta l(q^i)}{\delta q^i} \qquad (3.8)$$

given that the second order conditions are met, this can be interpreted as the marginal revenue from a sow equal to the marginal costs of the sow.

Difficulties with Static Model

As previously stated, using a static model assumes that the system is in equilibrium. This is not the case for the majority of biological systems and cannot be assumed for weanling production. Optimizing production in sow breed-to-wean barns is an inter-temporal problem. In other words, weanling production varies over the lifespan of a sow. Specifically, weanling production is known to vary across parities (Stalder et al, 2003). Therefore, to properly address this issue, dynamic modelling is necessary. The dynamic model considers the inter-temporal nature of weanling production, including consideration for potential future production. The optimal solution of the dynamic model will differ from that of the static model due primarily to the foregone production revenues from a sow due to the event of culling – the marginal user-cost.

IV. Dynamic Programming

Dynamic programming differs from static programming in that it considers the system's inter-temporal nature. In other words, it takes into account time, and how time impacts the optimization of production. The variables of a dynamic model are functions of time, resource renewability, and discounting (Conrad & Clark, 1987). This becomes relevant when considering a system whose state varies with time – as a biological system, weanling production falls into this category. Dynamic programming uses mathematical techniques to optimize the timing of asset replacement, considering both current and future investment. A replacement model from firm investment theory will be used to address optimization of weanling production in sow breed-to wean barns.

Discount Rate

When considering a dynamic problem, discounting becomes crucial to ensure that returns over the span of a planning horizon are measured in the same terms. It is best to measure these in current monetary value. The concept of discounting suggests that money earned in the present is at least as valuable as money earned in the future. The discount rate can be considered the expected rate of return of investing money in other sectors of the economy – this is most often set at the loan rate price in agricultural studies. The discount factor – which is applied multiplicatively to the value function – is represented as $e^{-\delta t}$ in the continuous model and as β^t, which equals $\frac{1}{(1+r)^t}$, in the discrete model, where δ and r are the discount rates in the continuous and discrete models, respectively, that fall between 0 and 1. Discount factors help the value function converge (Arrow & Kurz, 1970), which is helpful in infinite-horizon optimizations.

Past Dynamic Models

Burt (1965) introduced ground-breaking theory in the area of asset replacement by suggesting a method to maximize the present-value of net revenues when an operation is subject to a risk of involuntary asset replacement. He specifically addressed replacement under risk by using a distribution that described the probability of an asset surviving from the current to the subsequent time period with full production – a *survival* probability. Burt deduced that optimal replacement is achieved at the point when the expected marginal net revenue from the current asset minus the expected replacement cost becomes less than the average lifetime expected net revenue from a replacement (Equation 3.9).

$$\widetilde{R}_{T+1} - \left(\varphi_{T+1} c_{T+1}^{Vr} - \frac{c_T^{Vr}}{\beta}\right) \leq \frac{\left[\sum_0^T w_t \widetilde{R}_t - w_T \varphi_T c_T^{Vr}\right]}{\sum_0^T w_t} \leq \widetilde{R}_T - \left(\varphi_T c_T^{Vr} - c_{T-1}^{Vr}/\beta\right) \qquad (3.9)$$

where $\widetilde{R}$ is the conditional expected value of net revenue of the asset, φ is the probability that the asset will survive to the next production period with normal productivity, c^{Vr} is the voluntary replacement cost, T is the terminal time, β is the discount factor, and w is the weighted (compounded) probability of involuntary replacement.

Using a marginal approach, an elementary supposition is to continue production with an asset up to the time that the net-present value (NPV) in that time period is greater than both the NPV in the previous and subsequent periods (Burt, 1965). This concurs with the basic economic statement that a firm will produce until the marginal revenue is less than or equal to the marginal cost. To prove this intuitively, consider the NPV in time T–1: for the NPV to increase to time T, the asset must still be profitable, i.e., be generating positive net revenues. For NPV to decrease into time T+1, the net revenue at time T+1 must be negative. Thus the terminal time (T) is the point at which the marginal revenues become less than the marginal costs. This, however, considers only the current asset, neglecting the value inherent in a replacement.

Dijkhuizen et al (1986) borrowed from Burt, utilizing survival probabilities to calculate the average profit accumulated from a replacement gilt, as well as a measure they labelled the *retention pay-off* (or RPO). Burt's model was subsequently adapted to address the issue of livestock replacement in a sow operation by Rodriguez-Zas et al (2006). Burt's model required revision to address sow replacement since it did not consider the replacement asset's value, and this value needs to be considered in investment models concerning biological assets. Inclusion of this value in the profit function is achieved by including the price of the replacement within the function.

Borrowing from land valuation, the market value of replacement gilts can be assumed to be equal to the income stream plus the intrinsic value of the replacement (Murray et al, 1983). The market value of replacement gilts can be determined by dividing the income stream of that replacement by the market capitalization rate as:

$$c_t^g = \frac{I_t}{\kappa_t} \tag{3.10}$$

where I_t is the expected income stream from replacement gilt at time t, and κ is the market capitalization rate. Inversely, the expected income stream of the replacement can be discovered:

$$I_t = c_t^g \cdot \kappa_t \tag{3.11}$$

This is important as it illustrates that the expected income stream from the replacement (when considering an infinite time horizon) is built into the replacement cost, which in turn is included in the profit function. Thus the expected value of replacements is inherent to the models.

The adapted model (Rodriguez-Zas et al, 2006) appears as:

$$V(T) = [\sum_1^T w_t \cdot \widetilde{R}_t - w_T \cdot \varphi_T \cdot c_T^{Vr}]/[(1-\beta)\sum_1^T w_t] \quad (3.12)$$

$$\text{s.t.} \quad \widetilde{R}_t = \varphi_t \cdot \theta_t - (1-\varphi_t)c_t^{Ir}$$

$$w_t = \begin{cases} 1, \text{if } t = 1 \\ \beta^{(t-1)} \prod_{z=1}^{T-1} \varphi_z, \text{if } t > 1 \end{cases}$$

where w_t is the weighted and discounted survival probability at time t, $\widetilde{R}_t$ is the conditional expected net sow revenue at time t, φ_t is the probability that this sow will survive from time t to time t+1 with normal productivity, c_T^{Vr} is voluntary cost of culling at terminal time T, θ_t is the net revenue from the sow without involuntary culling at time t, c_t^{Ir} is the involuntary replacement cost at time t, and φ_z is the probability that the sow survives from time z to z+1. The average expected net revenue for sows can be determined using equation (3.12), and by assuming that herd data adequately predicts the production of the replacement. This assumption makes intuitive sense as the replacement, on average, will perform similarly to the average sow from a given herd. This also makes the implicit assumption that sows can only be brought into the herd as gilts, which is true for the North American market.

The model by Rodriguez-Zas et al (2006) provides a method to address involuntary and reproductive culling using survival probability as a tool. The method by all three of these papers (Burt, 1965; Dijkhuizen et al, 1986; Rodriguez-Zas et al, 2006) relies on Markovian recursive estimation – solving the set of equations by "backwards-induction" from the terminal time to the purchase of the asset. This approach will not be used in its true form for this model, since no transition probabilities will be estimated. Dijkhuizen et al (1986) used (averaged) aggregate herd data; for this reason, only optimal average parity, not optimal parity at which to cull, can be deduced. Rodriguez-Zas et al (2006) used individual sow records from numerous herds. However, these records only contain production output data, thus a production function cannot be estimated. In addition, the accuracy of culling information in the databases used for these experiments is questionable. Since this research enabled input and condition data, as well as production output data, to be collected, a production function can be estimated. Data on the condition of each respective sow were collected in addition to production data. These data allow for a more in-depth analysis of culling, and thus this model is unique to previous sow models.

One study that collected real, individual data to address a different, yet theoretically-similar, problem was Rust (1987). His research considered optimal replacement of bus engines. The state variable that tracked the condition of these bus engines was *accumulated mileage* – the number of miles that the engine had travelled since the last replacement. Rust (1987) developed a simple *regenerative optimal stopping* model for the replacement of these bus engines that decoupled the decision with time. Instead, the replacement decision was a function of the accumulated mileage among other unobserved variables, which acted to estimate the future expectations/costs of the current bus engine. In other words, Rust (1987) used condition data to predict engine failure. His research also used a 'bottom-up' approach that can only be applied if the data available include real-life individual observations and are disaggregated. Although Rust (1987) also used Markov processes, his employment of a regenerative stopping model, combined with the use of a 'bottom-up' approach, applies best to this research's sow replacement problem.

Optimal sow replacement is similar to optimal engine replacement in a number of ways. Sow replacement decisions are also based on future expectations, either of the current sow or replacement gilt. Like future expectations of bus engines, the future expectations of sows can, on average, be approximated by their current condition, a major determinant of this being parity. Another similarity between the researches is that parity acts as a measure of a sow's condition just like accumulated mileage does of an engine's condition. Using parity as a measure allows for sow condition to become independent of time. This distinction allows for a similar regenerative optimal stopping model to Rust's (1987) to be developed to address optimal sow replacement. Though Markov processes will not be used, the sow model will be solved by a backwards-induction approach.

Decision Variables

Dynamic programming is comprised of decision variables, which are divided into *control* and *state* variables (Conrad & Clark, 1987). Control variables act to manipulate the system while state variables allow for the observation of the system. The value of the system, V(t), is a function of these variables, which describes the expected total returns in a given planning horizon (Kristensen, 1996). Borrowing from Rust (1987), the state variable for the subsequent models is parity. Parity is defined as the number of litters a sow has produced. The control variable is a little trickier for this system. One decision made is the choice between straw-flooring and partial-slatted concrete-flooring. This, however, is a decision between two technologies, which does not represent a control variable. The control variable for this model concerns the culling rate of sows.

Culling has two components. One component is culling due to physical ailments – illness, lameness, disease, and death – which the manager has little control over, but for the choice of technology, medical care, and criteria-setting. The second component involves herd genetic improvements – culling due to low production and reproductive issues – which are more directly based on managerial judgement. This second component determines the number of sows culled in attempt to improve the herd's performance. It determines the average age of sows, weanlings produced per sow lifetime, and weanlings produced per time period. The sum of these two culling components constitutes the total culling rate. Weanling production is dependent on this culling rate because it determines the cross-sectional composition of parities within the system. Since litter size tends to vary with parities (Stalder et al, 2003), the average parity of sows directly affects weanlings produced per time period, and thus culling has an impact on production. Though the state and control variables function within each respective technological scheme, the optimal decisions for the control variable(s) within each respective scheme may, and are expected to, vary.

V. Continuous, Dynamic Model

Dynamic programming can be used to address sow optimization with the continuous case investigated first. The continuous model for the optimization in an individual sow space appears as:

$$\pi_i = \int_0^T \left(e^{-\delta t}\left[p \cdot q_t^i\left(x_t^{ih}, x_{p_t}^i, k_t^i\right) - c^h \cdot x_t^{ih} - k_t^i(cd_t^i, x_{p_t}^i) \cdot c_t^{ir}\right]\right)dt \qquad (3.13)$$

$$\begin{aligned} \text{s. t.} \quad & c_t^{ir} = c^g - \sigma_t^i \\ & p, q^i, x^{ih}, x_p^i, c^h, c^{ir}, c^g, \sigma^i \geq 0 \\ & k^i = \begin{cases} 0, \text{if sow kept in herd} \\ 1, \text{if sow culled or dies} \end{cases} \\ & \delta \in [0,1] \end{aligned}$$

where T is the terminal time, x_p^i is the parity of the individual sow in the farrowing space,

k^i is the binary culling variable, cd^i is the vector of condition variables for the current sow, and c^{ir} is the total cost of replacing a sow. The total replacement cost is equal to the price of a replacement gilt and the cost of rearing this gilt up to a successful breeding weight, c^g, less the salvage value received for the current sow, σ^i. As displayed in (13), weanling production, q^i, is some function of variable inputs, x^{ih}, parity, x_p^i, and culling, k^i; culling is some function of sow condition, cd^i, and parity. This demonstrates how the production function and culling function become integrated into the profit function. The terminal time, in the case of an individual sow space, remains the same as that for the entire operation – the expected functional lifespan of the operation. As previously mentioned, sows will be culled and replaced, and, thus, multiple sows will fill this space during the operation's lifespan.

Culling is introduced as a binary dummy variable that takes on the value 0 when the sow remains in the herd and the value 1 during the time period when the sow is culled and replaced. Culling therefore affects production in a 'bang-bang' fashion with the parity of the current animal following a 'most rapid approach path' (MRAP) (Conrad & Clark, 1987). When the culling event occurs, the production for that sow instantly drops to zero and the parity of the sow space returns to 1, i.e., the space is filled with a gilt. The culling term, k^i, is applied to the profit function so that the total cost of replacement, c^{ir}, is only valued at the time of replacement. Production revenues, as well as variable costs, are still expected to accrue since a new replacement gilt will fill that sow space (almost) immediately. Another variable that needs to be included in the production function is farrowing rate. For the purpose of these models, farrowing rate is assumed to be already incorporated into the production function; an unsuccessful breeding is usually evident by a non-productive period.

The profit function for the entire production system can also be investigated using the continuous case, and is presented as:

$$\pi = \sum_{i=0}^{n} \int_0^T \left(e^{-\delta t}\left[p \cdot q_t^i\left(x_t^{ih}, x_{p_t}^i, k_t^i\right) - c^h \cdot x_t^{ih} - k_t^i\left(cd_t^i, x_{p_t}^i\right) \cdot c_t^{ir}\right]\right)dt - c^j \cdot x^j - c^g \cdot n_0 \quad (3.14)$$

$$\text{s.t.} \quad c_t^{ir} = c_t^g - \sigma_t^i$$

$$p, q^i, x^{ih}, x_p^i, c^h, c^{ir}, c^j, x^j, c^g, \sigma^i \geq 0$$

$$k^i = \begin{cases} 0, \text{if sow kept in herd} \\ 1, \text{if sow culled or dies} \end{cases}$$

$$\delta \in [0,1]$$

$$n \in [0, N]$$

where n_0 is the initial number of farrowing spaces in the operation, i.e., the number at time 0. The replacement cost will be greater than 0 since the price of a replacement gilt always outweighs the salvage value received for a sow. Also, the salvage value depends on the sow's weight (one measure of the sow's condition) while the replacement gilt price is independent of the current sow. Since the total replacement cost is a function of the salvage value and the salvage value is dependent on sow condition, it too is dependent on sow condition. The term $[c^g \cdot n_0]$ refers to the initial investment of gilts into the operation. The other fixed costs refer to the rest of the initial investment into capital, such as facilities and equipment. This function is a summation of the farrowing spaces over time, with the production lifespan set to a finite horizon T. Optimization of these profit functions will be investigated using the Hamiltonian approach.

Hamiltonian Optimization

The objective of modeling weanling production is to maximize the net-present value (NPV) from current and replacement sows over a given planning horizon. The general principle is: “the longer a sow remains in a herd the greater opportunity to recuperate the initial cost” (Rodriguez-Zas et al, 2006). One computation method to solve dynamic allocation problems with constraints uses Lagrangian multipliers (Conrad & Clark, 1987). The Lagrangian is presented as:

$$\mathcal{L}[\cdot] = V[\cdot] - \lambda[F[\cdot] - \gamma] \tag{3.15}$$

$$\frac{dV[\cdot]}{dY} - \lambda \cdot \frac{dF[\cdot]}{dY} = 0 \tag{3.16}$$

where $\mathcal{L}[\cdot]$ denotes the Lagrangian equation, λ is the co-state (or adjoint) variable, F[·] is the constraining function, and γ is some constant that makes [F[·] – γ] equal to zero. Equation (3.16) shows the optimized condition.

The Hamiltonian ($\mathcal{H}$) is an optimization method derived from the Lagrangian method used for most optimal investment problems, especially those dealing with renewable resources. The Lagrangian does not account for the lost returns from removing a sow from the operation – the marginal user-cost – however. The Hamiltonian *does* incorporate this cost into the optimization. This ensures that the optimal solution is truly dynamic. Though the approach is unique in addressing the optimization of weanling production, it remains consistent with classical firm theory in that it still suggests that production should continue until the marginal revenue drops below the marginal cost. However, the optimal time to cull becomes:

$$MR^{s} \leq MC^{s} - MC^{s}_{user} \tag{3.17}$$

where MC^{s}_{user} is the marginal user-cost of culling the current sow. The marginal user-cost takes on a positive value, which approaches zero through time. This suggests that optimal culling will occur later when the user-cost is considered as compared to when it is not. It makes sure that a sow is not culled prematurely. The marginal user-cost can be determined mathematically using the Hamiltonian.

The continuous-time Hamiltonian equation takes on the following form (Conrad and Clark, 1987):

$$\mathcal{H}[X_t, Y_t, \lambda_t, t] \ = \ V[X_t, Y_t, t] \ + \ \lambda_t F[X_t, Y_t, t] \tag{3.18}$$

where λ_t is the co-state (or auxiliary) variable, $F[X_t,Y_t,t]$ is the biological constraint, and the optimal solution occurs at $\frac{\partial \mathcal{H}(\cdot)}{\partial Y_t} = 0$. The control variables – with respect to the state and auxiliary variables – are considered optimized when the Hamiltonian is maximized (Arrow & Kurz, 1970). The Hamiltonian, $\mathcal{H}[\cdot]$, can be interpreted as the total rate of change in asset values, $V(\cdot)$ as the flow of net returns, and $\lambda_t F(\cdot)$ as the change in the asset's value. When a discount rate is implemented into the Hamiltonian, it becomes the current-value Hamiltonian, $\widetilde{\mathcal{H}}$:

$$\widetilde{\mathcal{H}}[X_t, Y_t, \lambda_t, t] = V[X_t, Y_t, t] + \mu_t F[X_t, Y_t, t] \tag{3.19}$$

where $\mu_t = e^{-\delta t} \cdot \lambda_t$. Applying the Hamiltonian, the continuous sow model from (3.13) becomes:

$$\widetilde{\mathcal{H}}^i[\cdot] = p \cdot q_t^i\left(x_t^{ih}, x_{p_t}^i, k_t^i\right) - c^h \cdot x_t^{ih} - k_t^i(cd_t^i, x_{p_t}^i) \cdot c_t^{ir} + \mu_t \cdot F(x_{p_t}^i, k_t^i) \tag{3.20}$$

$$\begin{aligned} \text{s. t.} \quad & F\left(x_{p_t}^i, k_t^i\right) = \dot{x}_p^i = \frac{dx_p^i}{dt} \\ & c_t^{ir} = c^g - \sigma_t^i \\ & p, q^i, x^{ih}, x_p^i, c^h, c^{ir}, c^g, \sigma^i \geq 0 \\ & k^i = \begin{cases} 0, \text{if sow kept in herd} \\ 1, \text{if sow culled or dies} \end{cases} \\ & \mu_t = e^{-\delta t} \cdot \lambda_t \\ & \delta \in [0,1] \end{aligned}$$

where $\widetilde{\mathcal{H}}^i[\cdot]$ is the current-value Hamiltonian for the individual sow. The biological constraint in the case of sow investment is the change in parity, the state variable. Though the exact functional form is unknown for $F(x^i_{p_t}, k^i_t)$ in the continuous model, it is known that it is positive when $k^i = 0$ and negative when $k^i = 1$. The functional forms of $q^i_t(x^{ih}_t, x^i_{p_t}, k^i_t)$ and $k^i_t(cd^i_t, x^i_{p_t})$ are also unknown.

The optimal conditions for investment in an individual sow can be determined by solving the Hamiltonian from equation (3.20). The first-order conditions (FOC) appear as:

$$\frac{d\widetilde{\mathcal{H}}^i[\cdot]}{dk^i} = 0; \qquad \frac{d\widetilde{\mathcal{H}}^i[\cdot]}{dx^i_p} = 0; \qquad \frac{d\widetilde{\mathcal{H}}^i[\cdot]}{d\mu} = \dot{x}^i_p = F(x^i_{p_t}, k^i_t) \tag{3.21}$$

in which $d\widetilde{H}^i[\cdot]/dk^i$ is the optimality equation and $d\widetilde{H}^i[\cdot]/d\mu$ is the state equation. Taking the partial derivations of $\widetilde{\mathcal{H}}^i[\cdot]$, the middle first-order condition from (3.21) becomes:

$$\frac{\partial\widetilde{\mathcal{H}}^i}{\partial x^i_p} = p \cdot \frac{\partial q}{\partial x^i_p} - c^{ir} \cdot \frac{\partial k^i}{\partial x^i_p} + \mu \cdot \frac{\partial F(\cdot)}{\partial x^i_p} = 0 \tag{3.22}$$

which can be rearranged into:

$$c^{ir} \cdot \frac{\partial k^i}{\partial x^i_p} - p \cdot \frac{\partial q}{\partial x^i_p} = \mu \cdot \frac{\partial F(\cdot)}{\partial x^i_p} \tag{3.23}$$

and the optimality equation from (21) becomes:

$$\frac{\partial\widetilde{\mathcal{H}}^i}{\partial k^i} = p \cdot \frac{\partial q}{\partial k^i} - c^{ir} + \mu \cdot \frac{\partial F(\cdot)}{\partial k^i} = 0 \tag{3.24}$$

which can be rearranged into:

$$c^{ir} - p \cdot \frac{\partial q}{\partial k^i} = \mu \cdot \frac{\partial F(\cdot)}{\partial k^i} \tag{3.25}$$

Equations (3.23) and (3.25) reveal that optimal replacement occurs at the point at which the marginal cost of replacement minus the current production revenue is equal to the potential revenues from future production. The LHS of equation (3.25) roughly represents the marginal user-cost of sow removal – the loss of future revenues from culling at that time. Intuitively, a sow should remain in the herd while its future revenues are worth more than those of a replacement, and should be culled when its future revenues drop below the value of a replacement. One assumption that the model works on is that a replacement has the same expected value of the average sow.

To investigate this further, the direction of the terms in equations (3.23) and (3.25) can be considered. As previously mentioned, c^{ir} and p are always positive. The term $\frac{\partial k^i}{\partial x_p^i}$ is negative with the probability of culling increasing with increasing parity. Contrarily, the term $\frac{\partial q}{\partial x_p^i}$ would be positive during the first few parities while production is increasing, and negative thereafter. Thus, the LHS of (3.23) would increase over time. Due to weanling production decreasing through time, the future revenues continue to decrease and the RHS, though positive, continues to decrease. Replacement, therefore, optimally occurs later in a sow's productive life, preferably in the interval when the term $\frac{\partial q}{\partial x_p^i}$ is negative, i.e., following peak production. Equation (3.25) depicts the same scenario, though the terms $\frac{\partial q}{\partial k^i}$ and $\frac{\partial F(\cdot)}{\partial k^i}$ are both non-positive. At the time k^i becomes 1, the RHS becomes strongly negative and the LHS becomes strongly positive, and thus current revenues overwhelm future revenues, i.e., it is the beneficial time for that culling to occur.

Since the barn model is a simple aggregation of the individual sow model, and, since only the variable costs are necessary for optimization, the optimal solution for the individual sow model will represent the optimal solutions for both models as suggested by Kristensen (1996). However, due to the functional forms of the production function and culling function being unknown, the partial derivatives of these functions cannot be solved for, and, thus, the optimal solution cannot be uncovered theoretically. Instead, it is necessary to deduce these functional forms empirically and solve for the optimal solutions as such, as will be described in Chapter 4. Despite this inability, these series of equations hint at the appearance of the optimal solution.

Difficulties with Continuous Model

The most distinctive difference between the continuous and the discrete model is that the discrete model is divided into time periods. The distinction dissolves as the time periods become increasingly small and approach zero. This makes intuitive sense since the continuous model considers marginal change in which the time period length is essentially zero. The sow investment problem falls primarily into the category of discrete, dynamic modelling. Weanling production, especially for the individual sow, occurs in very distinct time periods due to its biological nature. On the entire breed-to-wean operation level, the discrete nature is less apparent. This is due to the fact that production occurs more frequently at this level – a batch of sows will farrow (produce) once monthly as compared to 2 to 3 times annually (on average) for the individual sow. Both the individual sow and the entire operation, despite this discrepancy, need to be analyzed using discrete models.

VI. Discrete, Dynamic Model

The dynamic model of sows in a breed-to-wean operation is discrete in nature due to the biological timing associated with weanling production. Adapting the continuous sow model from equation (3.13) is relatively simple. Instead of integrating the profit function from time 0 to the terminal time, it is instead divided into time periods that are summated from the first time period to the terminal time. The sow model becomes:

$$\pi_i = \sum_{t=0}^{T}\left(\beta^t\left[\begin{matrix} p \cdot q^i\left(x^{ih}(t), x_p^i(t), k^i(t)\right) - c^h \cdot x^{ih}(t) + \\ k^i\left(x_p^i(t), cd^i(t)\right) \cdot c^{ir}(t) \end{matrix}\right]\right) \qquad (3.26)$$

$$\begin{aligned} \text{s. t.} \quad & \beta^t = \left(\frac{1}{1+r}\right)^t \\ & c^{ir}(t) = c^g - \sigma^i(t) \\ & p, q^i, x^{ih}, x_p^i, c^h, c^{ir}, c^g, \sigma^i \geq 0 \\ & k^i = \begin{cases} 0, \text{if sow kept in herd} \\ 1, \text{if sow culled or dies} \end{cases} \\ & r \in [0,1] \end{aligned}$$

where r is the discrete discount rate. The overall model does not appear to differ dramatically from the continuous model. Applying the current-value Hamiltonian, the model becomes:

$$\widetilde{\mathcal{H}}^i[\cdot] = \sum_{t=0}^{T}\left(\left[p \cdot q^i\left(x^{ih}(t), x_p^i(t), k^i(t)\right) - c^h \cdot x^{ih}(t) + \right.\right.$$
$$\text{kixpit,cdit}\cdot\text{cirt}+\mu(t)\cdot\text{F(xpit,kit)} \qquad (3.27)$$

$$\begin{aligned} \text{s. t.} \quad & \Delta x_p^i(t) = F\left(x_p^i(t), k^i(t)\right) \\ & \beta^t = \left(\frac{1}{1+r}\right)^t \\ & p, q^i, x^{ih}, x_p^i, c^h, c^{ir}, c^g, \sigma^i \geq 0 \\ & k^i = \begin{cases} 0, \text{if sow kept in herd} \\ 1, \text{if sow culled or dies} \end{cases} \\ & \mu(t) = \beta^t \cdot \lambda(t) \\ & r \in [0,1] \end{aligned}$$

The state function, $F\left(x_p^i(t), k^i(t)\right)$, takes on a more concrete form in the discrete model. Since the discrete model progresses in parities, x_p^i will always increase by 1 per time period when the sow remains in the herd. At the point where the sow is culled ($k^i = 1$), the sow space is filled with a gilt and therefore the parity of that space returns to 1. Mathematically, the state function appears as:

$$\Delta x_p^i(t) = F\left(x_p^i(t), k^i(t)\right) = \left(x_p^i(t+1) - x_p^i(t)\right) = \begin{cases} 1, \text{ if } k^i(t) = 0 \\ 1 - x_p^i(t), \text{ if } k^i(t) = 1 \end{cases} \tag{3.28}$$

As for the similarity between equations (3.13) and (3.26), the same similarity appears between the continuous and discrete models for the entire barn.

Similar to the continuous case, the barn model in the discrete case is an aggregation of the individual sows over time. The individual component here is also considered to be sow space. The discrete profit function for the entire breed-to-wean operation becomes:

$$\pi = \sum_{i=0}^{n} \sum_{t=0}^{T} (\beta^t \left[p \cdot q^i \left(x^{ih}(t), x_p^i(t), k^i(t)\right) - c^h \cdot x^{ih}(t) + k^i\left(x_p^i(t), cd^i(t)\right) \cdot cir(t)\right) - cj \cdot xj - cg \cdot n0 \tag{3.29}$$

$$\text{s. t.} \quad \beta^t = \left(\frac{1}{1+r}\right)^t$$

$$c^{ir}(t) = c^g - \sigma^i(t)$$

$$p, q^i, x^{ih}, x_p^i, c^h, c^{ir}, c^j, x^j, c^g, \sigma^i \geq 0$$

$$k^i = \begin{cases} 0, \text{if sow kept in herd} \\ 1, \text{if sow culled or dies} \end{cases}$$

$$r \in [0,1]$$

$$n \in [0, N]$$

An important point to mention is that a producer, in addition to optimizing the level of inputs being invested, needs to consider the number of animals he or she is breeding. The most limiting factor in a breeding barn is usually the number of farrowing crates. Thus, the number of animals able to farrow at any given time is restricted – the producer therefore has to consider the (expected) successful farrowing rate and survival rate of the group of sows being bred. These two rates multiplied by the number of sows in the group should equal the total number of farrowing crates available. This will optimize production subject to the farrowing crate constraint. Once again, the Hamiltonian for the barn need not be considered.

Optimal Solution

The optimal solutions for the discrete models are similar to those for the continuous models. The optimal solution for the discrete sow model is almost identical to that of the continuous model as described in equation (3.21) and is derived through similar means. The FOC appear as:

$$\frac{\Delta\widetilde{\mathcal{H}}^{i}(\cdot)}{\Delta k^{i}} = 0; \qquad \frac{\Delta\widetilde{\mathcal{H}}^{i}(\cdot)}{\Delta x_{p}^{i}} = 0; \qquad \frac{\Delta\widetilde{\mathcal{H}}^{i}(\cdot)}{\Delta \mu} = \Delta\dot{x}_{p}^{i} = F(x_{p}^{i}(t), k^{i}(t)) \tag{3.30}$$

Further, the optimal conditions and marginal user-cost are revealed as in (3.23) and (3.25) with more definition due to the knowledge of the state equation's functional form in (3.28):

$$c^{ir} \cdot \frac{\Delta k^{i}}{\Delta x_{p}^{i}} - p \cdot \frac{\Delta q}{\Delta x_{p}^{i}} = \mu \cdot \frac{\Delta F(\cdot)}{\Delta x_{p}^{i}} \tag{3.31}$$

$$c^{ir} - p \cdot \frac{\Delta q}{\Delta k^{i}} = \mu \cdot \frac{\Delta F(\cdot)}{\Delta k^{i}} \tag{3.32}$$

Since $\frac{\Delta F(\cdot)}{\Delta x_{p}^{i}}$ is always positive until the act of culling, the RHS of (3.31) takes on a positive value and represents the marginal user-cost. And, since the probability of culling increases across parities and production is known to be decreasing near culling, $\frac{\Delta k^{i}}{\Delta x_{p}^{i}}$ and $\frac{\Delta q}{\Delta x_{p}^{i}}$ are known to be positive and negative, respectively. On the contrary, the RHS of (3.32) is known to be negative since $\frac{\Delta F(\cdot)}{\Delta k^{i}}$ is definitely negative according to (3.28). The term $\frac{\Delta q}{\Delta k^{i}}$ is once again negative, as was the case in the continuous model. These determinations preach the same tale as in the continuous case – the current sow should be kept up until its future revenues drop below the difference between its replacement cost and its current revenues. The replacement decision should thus occur in the time period before this occurs so that a replacement gilt is ready to enter that farrowing space. This practice optimizes profitability for the individual sow.

The optimal solution will be empirically discovered by altering the parity in which sows are terminally culled, and therefore, as previously mentioned, will be solved by a backwards-induction approach. By maximizing profitability in the discrete sow model, the optimal culling rate and optimal parity at culling can be determined for the individual sow. These values provide insight into the optimized solution for the entire barn, which should enable producers to ensure optimal investment. These theoretical models and optimal solutions will vary when considering the experimental data being applied to them. However, they provide a good basis for investigating profitability in breed-to-wean operations.

VII. Summary of Theory

The first model considered to address profit-maximization in sow breed-to-wean operations was a static model. It could be further deconstructed into an individual sow model and an entire farm model, which was an aggregation of the individual one – this revelation was carried through into the dynamic models. The static model unveiled the most basic profit function and discovered that the optimum solution occurs where marginal costs are equal to marginal revenue. However, this method of optimization does not deal with the inter-temporal nature of this biological system, neglecting discounting and the marginal user-cost associated with sow replacement. To begin to delve into these complications, a continuous, dynamic model was used. This allowed for the consideration of the true effect of culling, as well as the dynamic nature of weanling production. This also fell short of efficiently addressing the problem. Weanling production and voluntary culling occurs in discrete time periods and therefore requires the utilization of a discrete, dynamic model. Thus, the discrete model was adopted to address this problem. Optimization of this model was achieved by using the Hamiltonian method, which distinctly uncovers the marginal user-cost inherent to the sow replacement problem. Since weanling production occurs in a discrete nature, the data need to be sliced into discrete time periods that logically represent the length of a production cycle. These time periods will have to be carefully discounted using a reasonable interest rate. The method by which this occurs, as well as all other experimental methods, will be discussed in Chapter 4.

CHAPTER 4. METHODS

With the relevance to the industry, as outlined in Chapter 2, along with firm foundation in economic theory, as developed in Chapter 3, this chapter will describe the methods by which the research was conducted. The methods include the experimental data collection, the estimation of a production and culling function, and the development of an economic simulation model.

I. Experimental Data Collection

Description of Facility

All animal data for this experiment were collected at Glenlea Swine Research Unit of the National Centre for Livestock and the Environment (NCLE) at the Glenlea Research Station, University of Manitoba. The facility consists of two-144 sow, farrow-to-finish swine barns. One barn – the conventional barn (CONV) – houses the sows on partially-slatted, concrete flooring that is designed for liquid manure management. Manure, in this system, falls through the slatted floor and is collected in shallow pits below the barn, then flushed regularly into a covered, earthen manure storage lagoon outside the barn. The other barn – the alternative barn (ALT) – houses the sows on a solid concrete floor covered by straw. Manure management for the alternative barn requires weekly removal for composting. This solid manure is stored onsite in a covered, concrete-base shed; it is turned every couple weeks to guarantee proper decomposition.

Both barns are designed to group-house the breeding stock during breeding and gestation. The barns were populated in six groups of 24-26 breeding animals, which are in rotation at all times in each respective barn. The sows farrow in these groups (or 'batches'). There are 4 gestation pens in each operation that house approximately 24 animals at any given time (depending on breeding success). The gestation pens in ALT are larger than those in CONV permitting greater space allowance – ALT pens have 70 m^2 while CONV pens have $57m^2$. Maximum stocking density for the gestation pens in ALT is 2.7 m^2 per sow; maximum stocking density in CONV is 2.2 m^2 per sow, which complies with the Recommended code of practice for care and handling of farm animals: pigs (AAFC, 1993) and the Canadian Council of Animal Care guidelines (CCAC, 1993). The pens are more internal to the barn in the conventional barn than in the alternative barn – both barns are designed in consideration of animal flow through the system. The alternative barn has higher ceilings in the gestation area with 3 external walls and thermostatically-adjustable curtains. Both the conventional and alternative barns have mechanical ventilation throughout to ensure adequate air movement for heat and ammonia displacement.

Each barn has 2 breeding rooms that are adjacent to the gestation pens. The breeding rooms appear almost identical, the main difference being the flooring. All breeding rooms have 7 regular pens housing between 3 and 6 animals with another 7 side-pens for housing sick or difficult sows, young gilts, and boars (of which each barn has 2-4). The main breeding pens have free-access feeding stalls to separate the animals during feeding. This minimizes aggression, ensures equal feed distribution (and thus appropriate nutrition), and enables individual handling. Breeding, for the most part, is conducted by artificial insemination (AI). Natural mating occurs on occasion, mostly for breeding gilts. The breeding rooms also have 26 free-access feeding stalls, in which the sows from the gestation pens are brought in as a group for their once-daily, morning feeding. Feed is formulated identically for both barns at the onsite feed facility.

Each barn also has 4 separate farrowing rooms consisting of 12 individual farrowing crates with adjoining creep areas. Each farrowing group is divided between 2 of these farrowing rooms according to their expected farrowing date. The farrowing crates are conventional farrowing crates with cast-iron slatted flooring for the sow and plastic-coated, perforated metal floors in the creep areas on either side of the sow. At weaning, the piglets are transferred to the nursery rooms across the hallway from the farrowing rooms. These rooms also consist of 12 pens for the 12 respective litters. The farrowing and nursery rooms lie most central to the barns.

The barns were both managed as commercial operations with a consistent set of management guidelines. The objective of this was to ensure that both barns were managed consistently and in accordance with commercial conditions. The similarity of the barns attempts to allow only the housing system to vary, holding all other factors constant. The animals were cared for in compliance with the Canadian Council on Animal Care (CCAC) (1993), and the Recommended Code of Practice for the Care and Handling of Farm Animals: Pigs (Agriculture and Agri-Food Canada (AAFC), 1993) and its addendum for early weaned pigs (Canadian Agri-Food Research Council (CARC), 2003). In addition, both barns took precautions to ensure bio-security – all employees, researchers, veterinarians, and visitors are required to shower in and wear designated barn attire. There were also designated boots and disinfectant foot baths specifically for the farrowing rooms.

Description of Experiment

The experiment began when the barns were first populated in 2006. A sample of F1 Landrace-Yorkshire cross breeding gilts from the same genetic line (Genesus Genetic Inc.) was selected from an original breeding stock. The gilts were brought into the barns as groups, with the barns being designed to accommodate 6 unique groups. Sixty (60) gilts were selected from five of these original groups in the alternative barn and 61 were selected from four of these original groups in the conventional barn. These gilts were selected out of the entire population to be representative of a newly-established commercial operation. Upon arriving onto the experiment, gait and body condition scoring were performed on the gilts; in addition, vulva presentation, the number of functional (and underdeveloped) teats, and weight measurements were recorded. To be incorporated into the experiment, the gilts had to be considered an appropriate representation of a commercial animal, in good health and be successfully bred within 10 weeks of entering the barns.

The gilts had an average weight at initial breeding of 133±1.1 kg, slightly higher than the target of 120 kg (Buyoc, 2007). The backfat depth at initial breeding at the P2 probe site averaged 17.1±0.3 mm, which is close to the industry target of around 18-20mm (Buyoc, 2007). Body condition scores for the gilts averaged 3.37±0.01 at initial breeding on a 5-point scale with 3 meaning a sow is in good conditions and 4 meaning the sow is slightly overweight (Patience et al, 1995). The gilts were deemed to meet industry standards. The first group of gilts entered the operation in February 2006. Data collection on the animals occurred over a 3-year period beginning in March 2006 and terminating in April 2009.

Data were collected on the animals at breeding, 30 days post-breeding (pregnancy-check), 2 days prior to their expected farrowing date (2-d prior), weaning, and prior to culling. Data collection occurred from the time that the animals entered the experiment as gilts until either culling or the experiment's termination. Farm records provided data on breeding, medical treatment, feed intake, and production. Each breeding group was provided the opportunity to undergo 7 reproductive cycles. In other words, each animal was provided the opportunity to produce 7 litters (i.e., reach 7 parities) given that they were successfully bred and farrowed 7 consecutive times. Parity, as mentioned in Chapter 3, is defined as the number of litters a sow has produced. All data were considered relevant, though 2-d prior data was disregarded if the sow was unable to successfully farrow that litter. Breeding and pregnancy-check data was, however, used even if the sow was unable to successfully farrow.

Relevant Variables from Experimental Data

Certain data were used to estimate the weanling production function, as well as the cull function. Inputs – feed, medications, and inseminations – as well as the sow's parity, were utilized to estimate the production function. Individual lactation feed intake (LF) was monitored while the sow was nursing her piglets. Since accurate data for feed intake during gestation was not available, an approximation for this measure was necessary. This was approximated by using the average daily gestation feed intake in the herd multiplied by the cumulative non-lactating days (NLD) for this individual animal.

Though the true variation of daily feed intake during gestation was not accounted for in individual sows, the number of NLD was able to vary. Medical treatments (MEDS) administered to individual animals were also taken into account. A treatment was defined as one particular drug administered on one or multiple consecutive day(s) to treat one particular problem in an individual animal. The number of semen doses (AI) was also recorded; for ease of analysis, the few animals naturally bred, i.e., by a boar, were also considered to have received a 'dose of semen' for each breeding day. Additionally, the parity was included in the regression since production is known to vary with parity (Stalder et al, 2003).

The dependent variable in the production function is litter weight at weaning (LW). Since production in a breed-to-wean operation is based on weanlings, it is logical to assume that revenue depends on the number of weanling and their respective weight. Since the experimental units are the sows, the entire litter in a given parity is relevant. Though weanling pricing is usually set on a 'per head' basis at 5-6 kg (Stevenson, 2009), litter weight was chosen to capture the variation in weaning age and thus individual pig weights. The time-series nature of the dataset allowed for the weaning weights to be left unadjusted. The litter weights were calculated by aggregating the weight of all individual weanlings in the litter. These weights were collected using a Sutter® Zeigerschnellwaage 50 kg weigh scale.

Weaning age ranged from 13 to 31 days . However, the average weaning age for both barns was 19.5 ± 0.1 days, and 63.9% of the observations were captured within the industry standard of around 18-21 days (Kemp, 2009). The 95% confidence interval lay between 15 and 24 days. Early-weaned pigs (under 18 days) often weighed less than 5 kg while late-weaned pigs (over 21 days) mostly weighed more than 6 kg. Revenue was, however, still determined on a ‘per head’ basis; to deduce the revenue, the litter weight (in kg) was divided by 6 kg. Despite the fact that this underestimates and overestimates the number of younger and older weanlings, respectively, the revenue lost/gained is roughly accounted for by the difference in input costs during lactation and the number of days between farrowing and re-breeding. For example, though a litter weaned at 30 days receives higher revenue, they also incur additional costs from lactation feed and longer productive cycles. Using this method, the average pigs weaned per sow per year were 21.8 and 26.0 in CONV and ALT, respectively, while the average litters per sow per year was 2.20 for both barns. The industry averages are around 17-22 pigs weaned per sow per year and 2.0-2.3 litters per year (Buyoc, 2007).

The cull function, in contrast, was estimated from sow biological data. It is a function of parity, number of unsuccessful breedings (MISS), sow weight (WT), body condition score, back-fat depth (BF), gait score (GS), and number of functional teats (FT). Sow weight was measured in kilograms using a Digi-Star SW600 walk-in weigh scale. The technique to collect the latter 4 of these measurements is described in Table 4.1. Measures for BCS and BF were collected at breeding, 30-d post-breeding, 2-d prior, and before culling. Gait score was collected at the same time junctures; however, the observations at 2-d prior were neglected since most pregnant animals were not observed walking at this time. FT was determined at 2-d prior. MISS was calculated by subtracting the number of periods that the sow had occupied the sow space by one plus the sow’s

Table 4.1. Sow condition measurements

Measurement	Scale	Interpretation of scale	Source
Body condition score (BCS)	1-5	1: poor (hips and backbone prominent); 3: good (hips/backbone felt with firm palm pressure); 5: fat (hips/backbone heavily covered)	Patience et al, 1995
Back-fat depth (BF)	in mm	Measure of back-fat at P2 probe site with Noveko VETKOPlus ultrasonic probe	MLC, 2002
Gait score (GS)	0-5	0: even strides; 1: abnormal stride length; 2: short stride, lame limb detected; 3: minimum weight-bearing on lame limb; 4: lame limb raised off floor; 5: sow will not move	Main et al, 2000
Functional teats (FT)	number of teats	Number of intact, uninjured teats with developed mammary tissue at farrowing	N/A

parity at the beginning of that time period. For example, if the sow misses a breeding in period 3, but has been successfully bred up to that point, i.e., has had 2 litters, MISS will equal to 1 in period 4. A binary variable for culling (CULL) represents the dependent variable in this function, with zero (0) indicating that the animal was not culled during that production cycle and one (1) indicating a culling event.

Structure of Experimental Data

The dataset was sliced into 143 day (143-d) time periods, starting from the gilts' initial successful breeding until their removal from the trial. The time period aims to capture an entire production cycle with 115 days for gestation, 21 days for lactation, and 7 days for re-breeding. There were a total of 8 cross-sections, with a depreciating number of animals in each subsequent cross-section (Table 4.2). Thus, the experimental data became cross-sectional, time-series data – also called panel data. Panel data can be constructed in either a balanced or unbalanced manner. A balanced data set requires the same number of observations in each cross-section while unbalanced has uneven cross-sections (Greene, 1997). This dataset is unbalanced due primarily to the biological nature

Table 4.2. Observations per cross-section

Cross-section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**ALL**
Observations in conventional barn	61	61	52	48	44	41	35	5	347
Observations in alternative barn	60	60	56	56	44	40	33	4	353
Total observations in cross-section	121	121	108	104	88	81	68	9	700

of the experimental units, i.e., the sows. When a sow is removed or culled from the herd, data can no longer be collected on it, and the data is therefore truncated at that point. The use of panel data introduces problems inherent to both cross-sectional data and time-series data, respectively; these could include – but are not limited to – autocorrelation, non-stationarity, heteroskedasticity, and multicollinearity (Greene, 1997). Panel data is the most comprehensive type of data, however, and therefore very useful for accurate estimation of discrete problems.

Manipulation of Raw Data

Variables within the dataset were transformed in order for them to fit into the panel data framework. This was necessary for meaningful analysis. Parity was considered to be the accumulated number of litters that a sow had at the start of the time period; sows gained parity after weaning a litter, but, if the litter either died or were entirely cross-fostered before weaning, parity was accumulated at farrowing. Feed intake was recorded in the period it occurred, sometimes being split between periods. Inseminations and medications were recorded in the period in which the first day of application occurred, and litter weight in the period in which the weaning date occurred. If two weaning events occurred within an individual time period, the litter weights were summed in the dataset.

This was possible if a weaning event occurred within the first few days of a given time period and the subsequent production cycle was less than 143 days, i.e., the subsequent weaning event occurred within the last few days of the same time period. However, this only occurred for 1.9% of total observations.

Culling data were usually collected within 30 days prior to the sow leaving the barn. If culling data were not specifically collected but there was previously-collected data within 60 days, those data were used. If these previous data, however, were collected within the same time period as the culling event, they were only used once in the dataset to avoid double-accounting. If no data was collected within 60 days of the culling event, the culling data was considered missing. Reasons for culling were divided into four categories: low production (PROD), reproductive issues (REPRO), physical reasons (PHYS), and terminal culling (TERM) (Table 4.3). For culling due to productivity reasons, the culling event was assumed to have occurred at the last weaning date. For all other reasons, it was assumed to be at time of shipping to market or on-farm death. Some sows were considered to be culled for reproductive reasons if they were not serviced within 28 days post-weaning, within 28 days of the last unsuccessful breeding event, or

Table 4.3. Definitions of reasons for culling

Reason for culling	**Definition**
Low production (PROD)	Sows culled primarily for producing low number of liveborns or weanlings, or low litter weights, or poor milk production, or poor udder condition
Reproductive issues (REPRO)	Sows culled primarily due to anoestrus, weak heats, abortion, returns to service, or being non-pregnant (open)
Physical issues (PHYS)	Sows that died on-farm, or culled primarily due to lameness, osteochondrosis (OCD), poor structure, broken bones, prolapsed uteruses, other injuries, size, mastitis, infections, or other sickness
Terminal culls (TERM)	Sows culled at termination of experiments (or artificially in data manipulation)

were unsuccessfully re-bred twice consecutively. These criteria were consistent with industry standard (Kemp, 2009). This occurrence truncated the data of 8 sows in CONV and 7 in ALT at the time of that event, despite them actually remaining in the herd. Sows successfully surviving to the experiment's termination that were not cited to be culled by barn management before the next breeding were considered to be terminal culls. Those that were unsuccessfully bred ("open") at the time of termination were considered to be culled for reproductive reasons. All data for WT, BCS, BF, and GS, respectively, were averaged in each time period to ensure minimal missing values and easy comparison. If an observation for FT was missing in a time period, the value from the last time period was assumed. This partially-transformed time-series data was collected in a stacked form (Appendix B) for regression analysis.

II. Estimations

Culling Function

Since culling, the dependent variable, in this function is a binary variable and the model is a probabilistic one, it was necessary to analyze it as such. The two main methods to estimate probability models are Probit, which has normally-distributed variables, and Logit, which has logistically-distributed variables (Liao, 1994). Since GS and MISS have logistic distributions about their means (Appendix G), Logit was employed in this analysis. The culling function does not follow an ordinary linear form. In fact, due to the culling variable taking on a binary form, the model is analyzed by a specialized Logit function. Its full form appears as such:

$$\text{Log}\left[\frac{P(\text{CULL}=1)}{1-P(\text{CULL}=1)}\right] = \delta_0 + \delta_1\text{Parity} + \delta_2 D_H \cdot \text{Parity} + \delta_3\text{WT} + \delta_4 D_H \cdot \text{WT}$$

$$+\delta_5\text{BCS} + \delta_6 D_H \cdot \text{BCS} + \delta_7\text{BF} + \delta_8 D_H \cdot \text{BF} + \delta_9\text{GS} + \delta_{10} D_H \cdot \text{GS}$$

$$+\delta_{11}\text{FT} + \delta_{12} D_H \cdot \text{FT} + \delta_{13}\text{MISS} + \delta_{14} D_H \cdot \text{MISS} + e \quad (4.1)$$

where P(CULL=1) is the probability of culling, which ranges between 0 and 1.

A simple analysis to test the correlation between the independent variables concluded that sow weight was correlated with both parity and back-fat depth with correlation coefficients (r) of 0.84 and 0.69, respectively. Further, when sow weight was regressed on the other independent variables, the resulting R^2 was 0.84. Though values under 0.9 are often tolerated, this value suggests that sow weight might be collinear with these two other independent variables. To err on the side of caution, all three variables were left as explanatory variables in the culling function. All other explanatory variables underwent backward removal if their significance level was greater than p=0.1. This developed a reduced culling function that appears as follows:

$$\text{Log}\left[\frac{P(\text{CULL}=1)}{1-P(\text{CULL}=1)}\right] = \delta_0 + \delta_1\text{Parity} + \delta_2\text{WT} + \delta_3 D_H \cdot \text{WT} + \delta_4\text{BF} + \delta_5\text{GS}$$

$$+\delta_6 D_H \cdot \text{FT} + e \quad (4.2)$$

Let the right-hand-side (RHS) be represented by $\sum_{k=1}^{6} \delta_k x_k$, where $\delta_k x_k$ are all of the coefficients and associated variables. Simplifying equation (4.2) into an easier form to understand and analyze:

$$P(\text{CULL} = 1) = e^{\sum_{k=1}^{6} \delta_k x_k} / (1 + e^{\sum_{k=1}^{6} \delta_k x_k}) \quad (4.3)$$

The analyses of this function were conducted using PROC LOGISTIC to determine the influence of parity, BF, GS, and FT on culling. The dataset, as conducted with the production function, was analyzed as one population. Periods 2 through 6 were considered in these analyses. Optimization was achieved by maximum likelihood using Fisher's scoring algorithm (SAS Institute Inc., 2008). Out of the 502 total observations, only 5 were missing, leaving 497 observations for analyses. Period 1 was omitted in this analysis since no culls occurred during it, due mainly to the criteria of dam inclusion in the experiment. Period 7 was omitted as well since it was assumed that all sows were culled by the end of it, i.e., it acted as the ultimate terminal cull. Thus CULL was always equal to 0 and 1 in periods 1 and 7, respectively. The predicted probabilities and observed responses proved to be concordant with each other 69.8% of the time.

Weanling Production Function

Litter weight (LW) is the main state variable in this research. Accordingly, a weanling production function needed to be estimated using litter weight as the dependent variable. The empirical model of LW for an individual sow needed to consider the aforementioned variables – parity, LF, NLD, AI, and MEDS, as well as the effect of the housing system. Since certain variables, such as parity, were expected to influence LW in a non-linear manner, the entire function took on a squared functional form. This required all the variables plus their squared form to be included in the function. The housing variable was not squared, and, before housing was even included in the production function, it was necessary to decide whether to analyze both barns simultaneously or as two distinct sub-populations.

The Fisher's F-test comparing the means of two populations (Fisher, 1970) failed to reject the null hypothesis that the two datasets came from the same population with $F(11, 669) = 0.97$. Thus, the dataset was analyzed in its entirety with dummy variables for housing (D_H). Multiple slope-shifting dummy variables were applied to all previous variables except the parity variables. The housing variable was combined with each of the other sow variables as interaction variables since the coefficient (β) values of the variables are expected to differ for each respective housing system. The resulting production function appears as such:

$$\begin{aligned} LW_t^i = {} & \beta_1 Parity_t + \beta_2 Parity_t^2 + \beta_3 LF_t + \beta_4 D_H \cdot LF_t + \beta_5 LF_t^2 + \beta_6 D_H \cdot LF_t^2 \\ & + \beta_7 NLD_t + \beta_8 D_H \cdot NLD_t + \beta_9 NLD_t^2 + \beta_{10} D_H \cdot NLD_t^2 + \beta_{11} AI_t \\ & + \beta_{12} D_H \cdot AI_t + \beta_{13} AI_t^2 + \beta_{14} D_H \cdot AI_t^2 + \beta_{15} MEDS_t + \beta_{16} D_H \cdot MEDS_t \\ & + \beta_{17} MEDS_t^2 + \beta_{18} D_H \cdot MEDS_t^2 + e_t \qquad (4.4) \end{aligned}$$

With the dummy variables and squared forms, the function includes 18 independent variables with no intercept term. The conventional barn is represented by D_H=0 while the alternative barn is represented by D_H=1.

All estimations were performed using SAS 9.2 (SAS Institute Inc., 2008). PROC PANEL was used to estimate the production function. Since all the independent variables, aside from the housing variable, were randomly distributed, the regression was run as a random-effects model. Though a specification which depends both on the cross-section it belongs *and* the time period it belongs in is generally analyzed as a two-way model (SAS Institute Inc., 2008), the parity variables absorb the effect of the time period, and, thus, the model can be analyzed as a one-way model. Since the dataset is both unbalanced and consists of random effects, the ordinary least squares (OLS) estimation is performed using the Wansbeek and Kapteyn (WK) method (SAS Institute Inc., 2008) and restricted maximum likelihood (REML). The regression is, therefore, a one-way, random-effects model estimated using the WK method and REML. The regression analyses were conducted on only the first 7 periods due to the lack of observations in the 8^{th}, all of which were incomplete observations. The corrected R^2 for this model was 0.591.

Due to the nature of this dataset, econometric issues needed to be considered. Multicollinearity was investigated by performing correlations of the independent variables – parity, LF, NLD, AI, and MEDS – upon each other using Excel 2007 (Microsoft Corporation, 2006). None of these independent variables in the production function had a correlation coefficient (r) with an absolute value higher than 0.51. However, when each of the explanatory variables from equation (4) was regressed upon the others, respectively, they all yielded R^2 values over 0.8 (with a number of them having values above 0.9). Though this is only a rough test for multicollinearity, the test fails to reject the presence of multicollinearity. Therefore, erring on the side of caution, all explanatory variables were analyzed simultaneously in the model, i.e., the model cannot be reduced to a smaller form. Non-stationarity due to the time-series nature of the data was addressed by inserting parity – a proxy for time – into the production function.

Heteroskedasticity and autocorrelation were the biggest concerns when dealing with this panel dataset since they can cause the estimates to become inefficient and biased. Both heteroskedasticity and autocorrelation were addressed by estimating using REML. The REML method ensures efficient and unbiased estimates when the disturbance (error) term approaches normality (Greene, 1997). In a large numbers case, the error term asymptotically approaches a normal distribution (Kennedy, 2008). Since the dataset has 691 observations, 673 degrees of freedom, and only 18 independent variables, the model qualifies as a large numbers case and, thus, heteroskedasticity and autocorrelation are considered and corrected for. Further, the estimators asymptotically converge upon the true value of the coefficients (Kennedy, 2008). In other words, the estimators (b) approach the true value of the betas (β).

III. Simulations

The purpose of the simulation modeling was to devise models that would predict the net revenues of each housing system under specific economic conditions. One model considered the profitability of an individual sow space while the other considered the profitability of an entire breed-to-wean operation. The default setting for the model represented recent economic costs and pricing, i.e., values relevant in the last 5 years. STELLA 9 was the chosen modeling software used to build these models because of its visual and object-oriented interface, as well as its focus on a systems approach (Richmond, 2004). This software was also chosen to be able to build the sow model into an existing barn model (Jackson et al, 2006). This enables ease-of-use for industry application. In order to make the model fully applicable, it was necessary to use recent market data relevant to Manitoba markets. These also ensured accurate and practical simulations.

Economic Data

Economic data were collected from numerous sources, and default values for variables were determined, as displayed in Table 4.4, to run the models. All values were based on costs associated with running a 600-sow breed-to-wean operation. If the values

Table 4.4. Cost and prices for simulation model variables

Variable	Unit cost/ Price[1]	Unit	Transformation	Time-span	Frequency of data	Source
6-kg weanling	34.67	head	averaged	5 yrs	annually	MAFRI (2005-2009)
Dressed (cull) sow	#1,2: 69.45 #3: 60.53	100 kg live-weight	averaged #1,2; averaged #3; minus transport cost	5 yrs	weekly	MAFRI (2010a); Millar(2009)
Culled boar	60	100 kg live-weight	averaged	5 yrs	annually	MAFRI (2005-2009)
Carcass disposal	46	per cull	observed[2]	N/A	continuous	Philippe (2010)
Replacement gilt[3]	304	head	averaged	5 yrs	weekly	Genesus Inc. (2005-2009)
Replacement boar	300	head	averaged	2 yrs	annually	MAFRI (2008-2009)
Weanling sales fees[4]	2.09	per head	averaged	5 yrs	annually	MAFRI (2005-2009)
Weanling vaccinations[5]	0.2056	per pig	calculated	N/A	continuous	Agri-Mart (2009)
Creep feed	1297.80	tonne	averaged	5 yrs	annually	MAFRI (2005-2009)
Lactation ration	264.40	tonne	averaged	5 yrs	annually	MAFRI (2005-2009)
Gestation/ boar ration	255.20	tonne	averaged	5 yrs	annually	MAFRI (2005-2009)
Medicinal treatment	7.43	treatment	averaged[6]	3 yrs	continuous	experimental
Semen	7.50	dose	averaged	2 yrs	annually	MAFRI (2008-2009)
Sow/gilt vaccination[7]	1.26	dose	calculated	N/A	continuous	Agri-Mart (2009)
Wages[8]	15	per hour	averaged	2 yrs	annually	MAFRI (2008-2009)
Straw	12	1500 lb bale	observed[9]	N/A	continuous	MAFRI (2010b)
Maintenance & repairs	8.15	per sow, annum	averaged	5 yrs	annually	MAFRI (2005-2009)
Herd health check	7.25	per sow, annum	averaged	5 yrs	annually	MAFRI (2005-2009)
Manure management	20.33	per sow, annum	averaged[10]	5 yrs	annually	MAFRI (2005-2009)
Hydro & propane (CONV)	57.12	per sow, annum	averaged	5 yrs	annually	MAFRI (2005-2009)
Hydro & propane (ALT)	51.63	per sow, annum	calculated[11]	3 yrs	monthly	experimental
Buildings/ equipment insurance	1.15	per sow, annum	averaged	5 yrs	annually	MAFRI (2005-2009)

Table 4.4 – continued

Breeding stock/weaner insurance	0.88	per $100 value	averaged	5 yrs	annually	MAFRI (2005-2009)
Business interruption coverage	9.36	per sow, annum	averaged	5 yrs	annually	MAFRI (2005-2009)
Misc.[12]	2.00	per sow, annum	averaged	5 yrs	annually	MAFRI (2005-2009)

[1]2009 Canadian dollars (CDN$)
[2]Transport and labour fee of $30 plus $12-20 dump fee
[3]F1 Yorkshire x Landrace gilts from Genesus Genetics
[4]Marketing, board and levy
[5]FerroForte and Excede injections
[6]Total medicinal treatment expenses divided over 3 yrs divided number of treatments
[7]FarrowSure Plus B; 2 doses pre-breeding for gilts; 1 dose per parity for sows
[8]Includes farm manager wage and benefits
[9]Observed straw listings for various straw varieties across Manitoba; rough average
[10] Haulage averaged for 2005-9; odour control for 2008-9; 21 L manure/sow/d from 2009
[11]ALT expenses 9.6% less than CONV expenses; proportion applied to MAFRI average
[12]Miscellaneous expenses, e.g., office supplies, computers, etc.

were not already available in a per-sow basis, they were calculated by dividing the expense of the entire operation by 600, the herd size. Some non-economic data, which were not determined from the experiment, were necessary for modeling. The default values for some of these data are represented in Table 4.5. All economic and operating data proved necessary in building the simulation models.

Table 4.5. Operating and management data

Variable	Value	Unit	Transformation	Time-span	Frequency of data	Source
Boar ration	3	kg/d	averaged	2 yrs	annually	MAFRI (2008-2009)
Creep feed	0.5	kg/pig	averaged	5 yrs	annually	MAFRI (2005-2009)
Gilt ration	4	kg/d	averaged; fed ad libidum 3-5kg	N/A	N/A	Stevenson (2009)
Straw usage	3.472	bales/ sow/yr	calculated[1]	3 yrs	annually	experimental
Labour hours (CONV)	0.2	h/sow/ wk	averaged	2 yrs	annually	MAFRI (2008-2009)
Labour hours (ALT)	0.233	h/sow/ wk	calculated[2]	3 yrs	weekly	experimental
Gilt farrow rate	90.4	%	calculated[3]	N/A	continuous	experimental
Boar cull rate	50	% per annum	averaged	5 yrs	annually	MAFRI (2005-2009)
Boar weight at culling	225	kg	averaged	5 yrs	annually	MAFRI (2005-2009)
Gilt weight at breeding	133	kg	averaged	N/A	continuous	experimental

[1]500 bales per annum in 144-sow operation
[2]ALT requires 16.7% more labour than CONV; proportion applied to MAFRI average
[3]Initial herd of F1 Yorkshire x Landrace gilts in NCLE barns

Analyses of Optimality

Both models – the individual sow model and the barn model – were run over a 51-period time-frame with 143-day periods. The length of simulation, therefore, represented 20 years, which approximates the functional life of hog buildings (MAFRI, 2009). All simulations were run at an annual discount rate of 5%. These analyses used the present-value of accumulated net revenues (PVNR) at the termination of the 20-year simulation as the variable to determine optimality, with production being considered secondarily. An annuity was also calculated for each run to represent the annual net revenues a producer could expect given a specific discount rate. The sow-period in which the ultimate terminal cull occurred was varied from seven down to three, ceteris paribus, for each respective barn. Adjusting the period of terminal culling (TERM) in discrete period intervals was the best method to test optimality due to the discrete nature of culling. PVNR was recorded for each simulation. The median, range, and standard error were also determined. The cull rates and the resulting composition of parities within the barns were averaged from the 1000 iterations across all time periods in each respective barn for both the optimal run and the 7-period run. In this regard, the individual sow model did not act to follow the data of every individual sow, but, instead, used the individual sow data to model one average, representative animal.

Sensitivity Analyses

Sensitivity analyses were conducted on multiple variables to determine the effect of each specific variable, ceteris paribus, on PVNR (Table 4.6). Additionally, sensitivity analyses were conducted on optimal TERM; the variables investigated in these analyses were weanling price, salvage values, and gilt price. The culling rate in period 2 was also

Table 4.6. Price/cost variables and associated sensitivity values around default values

Variable	**Sensitivity Values (%)**
Weanling price	-60; ±5, 10, 20; +100
Salvage values[1]	±5, 10, 20, 80
Price of gilt/boar replacements	±5, 10, 20
Feed costs	±10, 20
Semen cost	±20, 40
Medicine/vaccination costs	±20, 40
Straw cost	±50, 100
All revenues[2]	±5, 10, 20
All pig prices[3]	±5, 10, 20
Market-vulnerable costs[4]	±10, 20
Set costs[5]	±10, 20

[1]Prices for dressed sows #1,2, dressed sows #3, and culled boars
[2]Salvage values and weanling price
[3]Salvage values, weanling price, and replacement prices
[4]Straw, feed, and transport costs
[5]Replacement prices, semen cost, and medicine/vaccination costs

altered in each barn to determine if that had a significant effect on optimal TERM; 2nd

period culling was artificially set to 2.5, 5, 12.7 and 25% in each respective. The default estimated culling rate was 5% and 12.7% in ALT and CONV, respectively. All aforementioned sensitivity analyses were conducted on the individual sow model alone using a 5% annual discount rate. The effect of different discount rates – 0, 5, and 10% – on PVNR, ceteris paribus, was also investigated for completeness.

Individual Sow Model

The model was split into 9 sectors: Housing Decision, Periodic Inputs, Periodic Condition Data, Production Function, Cull Function, Biological, Revenues, Costs, and Net Revenues. The Housing Decision consisted of a switch that selects for either alternative or conventional housing. The Periodic Inputs and Period Condition Data sectors included the inputs required for equation (1) and the condition variable values required for equation (4), respectively, for each housing system across time. The average periodic values for these variables were determined from the data (Appendices C and D). The Production Function sector used these values to predict the litter weight (in kg) produced during a given time-period according to (1). The Culling Function sector used the condition data values to calculate a probability of culling from (4).

The Biological sector follows the dams from their purchase as gilts to culling; the dams may either be culled as gilts or subsequent to a productive herd life as sows. If the dam joined the breeding herd, it accumulated periods (sow-periods) within the model, starting at a period of 1, while it occupied the sow space – a new cycle began when a new dam was brought into the sow space. Enough gilts were purchased every period to ensure that the sow space would be filled if necessary, taking the gilt farrowing rate into account. For example, if the sow space needed filling and the farrowing rate was 80%, 1.25 gilts would be purchased. In the individual sow model, any gilts not required were sold back at full replacement cost – thus there was no economic penalty. If a new gilt was required, it was moved into the sow space, with the remaining portion of gilts – the proportion that was not bred or did not farrow – being sold as full-value culls.

If culled post-production, the sow could be sold at full, reduced, or no value, depending on the nature of the cull. A culled sow was assumed to have received full salvage value if it was shipped for non-physical reasons while, if it was shipped for physical reasons, it was considered to have received the reduced salvage value. The sow received no salvage and, in fact, incurred a disposal cost if the sow died or was euthanized on-farm. Sixty-one percent (61%) of sows in CONV were culled for non-terminal reasons (Appendix L). Of these non-terminal culls, 25% received no salvage revenue, while 21.5 and 53.6 % received the lower and full salvage values, respectively. Conversely, 69% of sows in ALT were culled for non-terminal reasons (Appendix K). Of these non-terminal culls, 92.9% had some salvage value (7.2% with the lower salvage value and 85.7% with the full salvage value), leaving only 7.1% of culls with no salvage value.

The Logit function to determine culling probability, as calculated in the Cull Function sector, was used to run a Monte Carlo (MC) simulation that would ultimately determine if a sow was to be culled in any given period. If the sow was culled, two additional MC simulations would determine the salvage value – full, reduced, or none – based on experimental data. Terminal culls would automatically warrant full salvage value, thus the MC simulations disregarded these. If culled for non-terminal reasons, the first MC simulation randomly chose if the culled sow received any salvage revenue, and, if so, the other MC simulation determined whether it was salvaged at full or reduced value. These two simulations used the experimental salvage percentages as a base for random selection. To ensure reliable results, the MC simulations consisted of 1000 runs. This sector also included a simplistic rotation of boars through the barn with one boar being needed for every 200 sows as according to MAFRI (2008; 2009).

The Revenues sector observed the revenues received from weanling sales, translating the per-head price into a per-kg price and multiplying it by the litter weight predicted by the production function. The revenues from culled gilts, sows and boars were also observed. The Costs sector included direct sow, weanling and boar expenses, as well as those for cull disposal, labour, replacements, and operations. Direct sow expenses accounted for all the inputs in the production function plus semi-annual vaccinations. Weanling expenses consisted of those for feed, vaccinations, and fees – marketing, board, and levy – at time of sale. Boar expenses considered feed and replacement costs. Sow replacement costs included two pre-breeding vaccinations and feed during the gilt development period – the time between purchase and breeding, which averaged 45 days – and the purchase cost of the gilts. Operating costs include the expenses for insurance, hydro and propane, maintenance and repairs, herd health checks, manure management, straw (for the alternative barn), and other small miscellaneous expenses, e.g., office supplies. The Net Revenues sector acted to accumulate the revenues while subtracting the costs, both of which were subjected to discounting. This sector thus played host to the main state variable, PVNR. As mentioned, the individual sow model traced an average, representative sow through the sow space.

Barn Model

Though the ideal method to formulate the barn model, as discussed in Chapter 3, would have been to aggregate individual simulations of the sow model, this was computationally tedious. Instead, the barn model acted as a simple multiplication of the individual sow model (Appendices E and F). In other words, the barn model did not simultaneously run an aggregation of individually-unique sows through sow spaces; it simply multiplied the one representative sow by the herd size. Since the majority of cost data was derived from MAFRI (2005-2009) based on a 600-sow breed-to-wean barn, the natural choice was to build the barn model based on this herd size. The framework from the individual sow model was used. However, the herd size of 600 was applied to all necessary values, including those for culling, production, and inputs, in a multiplicative manner. Analyses conducted on this model therefore produced results extremely similar to the individual sow model. All simulations were run using Euler's method of integration.

The results of the estimations will be displayed first in Chapter 5. Further, the average values generated from integrating these estimations into the simulation models will be presented. This will allow for the relative comparison between the experimental data and the estimated results. Lastly, the following chapter will include the results of the optimality analyses and the associated sensitivity analyses.

CHAPTER 5. RESULTS & DISCUSSION

The previous chapter outlined the methods that were utilized to address the problem of optimal sow replacement. These included the experimental methods, as well as the methods to estimate regression equations for weanling production and culling probability. Further, they considered the application of these two functions in a simulation of an individual sow model and a barn model for breed-to-wean hog operations. This simulation was used to economically compare the two sow group-housing systems – the alternative system (ALT) and conventional system (CONV). Sensitivity analyses were also conducted to determine the model's sensitivity to specific variables, and, further, to emphasize some of the major causal factors in the model. The results are displayed below.

The results observed also require some consideration and interpretation. Firstly, to investigate the estimations of both the culling and production functions, the experimental data must be considered. Since the estimations are an approximation of these data, the estimated culling profile and production values must reflect the actual happenings in the experimental barns. Further, the effects that the sow condition variables have on culling and the input variables have on production, respectively, should be theoretically sound and enlightening. The inferences gained from the estimation will thus be discussed. The results of the simulation runs and their implications on optimal culling in the barns will also be considered, as well as the sensitivity of these findings to economic shocks.

I. Estimation of Culling

The Logit estimation found that there was no effect of backfat depth (BF), body condition score (BCS), or the number of unsuccessful breedings (MISS) on probability of culling; body weight (WT), gait score (GS), and the number of functional teats (FT) all proved to have some effect though (Table 5.1). As parity increased, the probability of a sow being culled increased in both barns. WT was also observed to have a significant relationship with the probability of a sow being culled; however, this relationship was

Table 5.1. Estimation of culling function

VARIABLE	COEFFICIENT ESTIMATE (± SE)
Intercept	3.01 ± 1.58*
Parity	0.50 ± 0.17**
WT	-0.028 ± 0.008**
[§]Barn x WT	0.022 ± 0.007**
BF	0.018 ± 0.035
GS	0.51 ± 0.22**
[§]Barn x FT	-0.38 ± 0.13**

*Significant at alpha level of 0.10
**Significant at alpha level of 0.05
[§]0 indicates conventional system; 1 indicates alternative system

negative and only present in CONV. A higher GS was shown to increase the probability of culling in both barns. FT had a significant relationship with culling probability in ALT, with a lower FT increasing the chance of a sow being culled. The average periodic values for the condition variables in each respective barn determined the estimated culling rates used in the simulation model (Table 5.2). These values do not comment on statistical significance, but are merely estimated values from average input data. The estimated

Table 5.2. Estimated culling rates (%) across periods

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Alternative barn	0	5.0	6.0	9.3	12.6	17.4	100
Conventional barn	0	12.7	7.4	5.6	7.4	9.7	100

*Note: Period 1 and 7 were pre-set values not determined by estimation values depict CONV as having higher culling rates earlier, i.e., in period 2 and 3. A crucial difference occurred in period 2 with the culling rate in CONV being more than 150% greater than that in ALT. After period 3, ALT is estimated to have higher culling rates than CONV.

II. Causal Factors in Culling Estimation

The culling estimation stated that backfat depth (BF) had no effect on the probability of a sow being culled. However, Young et al (1991) suggested that a reduced BF would increase the probability of a sow being culled. BF acts as a relative measure of the energy stores that a sow has for growth, maintenance, and piglet-rearing; a low BF often indicates poor condition (Dourmad et al, 1994). Though this might be the case, the results suggest that body weight (WT) might have stronger explanatory power for energy stores than BF at least as a predictor for culling. However, WT might have been capturing some of the significance that BF plays on culling probability since WT and BF were relatively correlated ($r = 0.69$). WT did prove to influence culling probability in CONV with a reduced WT increasing the probability. WT might not have shown as significant in ALT because the environment in ALT may be better suited for sows to make a quick recovery from poor condition, e.g., due to sickness. Thus, they would be more likely to recover from poor WT and less likely to be culled for that reason. As suggested in Chapter 4, there may be collinearity between WT and BF; this may result in an artificially-inflated standard error (SE) around BF, thus causing its significance to be falsely rejected. More likely the case is that WT and BF are variables for the same measure.

BCS was probably inconsequential due to barn management, as it is closely monitored and controlled (sows in poor condition during gestation receive extra feed). Thus, BCS has minimal variation, with most sows falling between 3.25 and 3.5 on the 5-point scoring scale. Further, the influence of BCS is likely captured by BF and/or WT. The lack of significance for MISS is troubling, as one would expect to observe higher culling rates for REPRO when MISS is high. However, this measure might also have little variation, with sows being culled before MISS can become large. Further, the organization of the data might lead to MISS being under-represented; MISS would not increase until one period after the missed breeding. Industry practice is to cull a sow within 28 days post-weaning if she fails to come back into heat or is unsuccessfully bred (Kemp, 2009). Thus, if a sow was culled due to being unsuccessfully bred, it is likely to occur before the period in which MISS increases.

Unsurprisingly, increasing parity increased the probability of culling. As a sow ages, her future net revenues decrease and probabilities of involuntary culling also compound, as mentioned in Chapter 3. The estimation suggested that sows in ALT were more likely to be culled for having fewer functional teats at farrowing (FT) than sows in CONV. This measure may act as an indicator of a sow's ability to produce and provide adequate milk to her litter, and thus is a production measure. Since more PROD culls are observed in ALT as compared to CONV, this result was not surprising. This finding in ALT is in contrast to the findings of Brandt et al (1999); however, CONV, which more closely approximates this previous study's conditions, shows a similar result of FT having no effect on culling probability. The positive relationship between gait score (GS) and culling was expected, with GS being a measure of lameness (Main et al, 2000). Sows with high GS were likelier to be culled for PHYS; Brandt et al (1999) found that even just 'slight or temporary defects' in leg quality increased the risk of sows being culled in parities 1-4. This concurred with this experiment's results.

III. Experimental Values for Culling

The raw experimental data suggest that the total culling rate was higher in later periods in the alternative barn (ALT), and higher in earlier periods in the conventional barn (CONV) (Tables 5.3 and 5.4). A large difference was specifically observed in the

Table 5.3. Culling rates (%) in alternative barn per period (derived from Appendix K)

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
% of sows remaining at start of period	**100**	**100**	**93.3**	**93.3**	**73.3**	**66.7**	**55.0**	**6.7**
Low production (%)	0	0	0	12.5	0	0	12.1	0
Reproductive issues (%)	0	5.0	0	7.1	9.1	15.0	24.2	25.0
Physical issues (%)	0	1.7	0	1.8	0	2.5	3.0	0
TOTAL NON-TERMINAL CULL RATE (%)	**0**	**6.7**	**0**	**21.4**	**9.1**	**17.5**	**39.4**	**25.0**
Terminal culls	0	0	0	0	0	0	48.5	75.0
TOTAL CULL RATE (%)	**0**	**6.7**	**0**	**21.4**	**9.1**	**17.5**	**87.9**	**100**

Table 5.4. Culling rates (%) in conventional barn per period (derived from Appendix L)

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
% of sows remaining at start of period	**100**	**100**	**85.2**	**78.7**	**72.1**	**67.2**	**57.4**	**8.2**
Low production (%)	0	0	0	0	2.3	9.8	14.3	0
Reproductive issues (%)	0	9.8	3.8	0	2.3	2.4	8.6	20.0
Physical issues (%)	0	4.9	3.8	8.3	2.3	2.4	5.7	0
TOTAL NON-TERMINAL CULL RATE (%)	**0**	**14.8**	**7.7**	**8.3**	**6.8**	**17.1**	**28.6**	**20.0**
Terminal culls (%)	0	0	0	0	0	0	57.1	80.0
TOTAL CULL RATE (%)	**0**	**14.8**	**7.7**	**8.3**	**6.8**	**14.6**	**85.7**	**100**

second period. Further, 21% of all sows in CONV (Appendix L) were culled for physical reasons – such as lameness – as compared to only 7% in ALT (Appendix K). In contrast, more sows were culled in ALT for low production than CONV, starting in period 4. In total, 18% of sows in ALT were culled for production, with 38% culled for reproductive issues and 31% at terminus (Appendix K). Sows in CONV were culled for production, reproductive issues, and at terminus 16, 23, and 39% of the time, respectively (Appendix L). The specific reasons for culling are provided in Appendices H and J. Pinilla and Lecznieski (2010) suggested aiming for 68% of culls for voluntary reasons, i.e., production and age, and only 23% for reproductive issues and 9% for physical issues. The CONV undershot the target level of voluntary culls by 13%, instead culling more sows for physical issues (Appendix L). The ALT, in contrast, culled less than target values for physical issues, but drastically more for reproductive issues (Appendix K).

As demonstrated in Figure 5.1, culling rates in ALT and CONV followed a similar pattern. The exception to this was the higher culling in period 2 and 3 in CONV, and the higher culling in period 4 in ALT. The bi-modal culling in CONV caused the herds to have a different parity profile during the 3rd and 4th periods, with CONV having fewer sows from the original herd during these periods. The simulation model demonstrated a close association between its results and the experimental results for culling rates per period (Appendix O). Simulated culling in CONV was observed to be bi-modal with peaks in the 2nd and 7th period. To the contrary, culling increased gradually throughout the time periods in ALT.

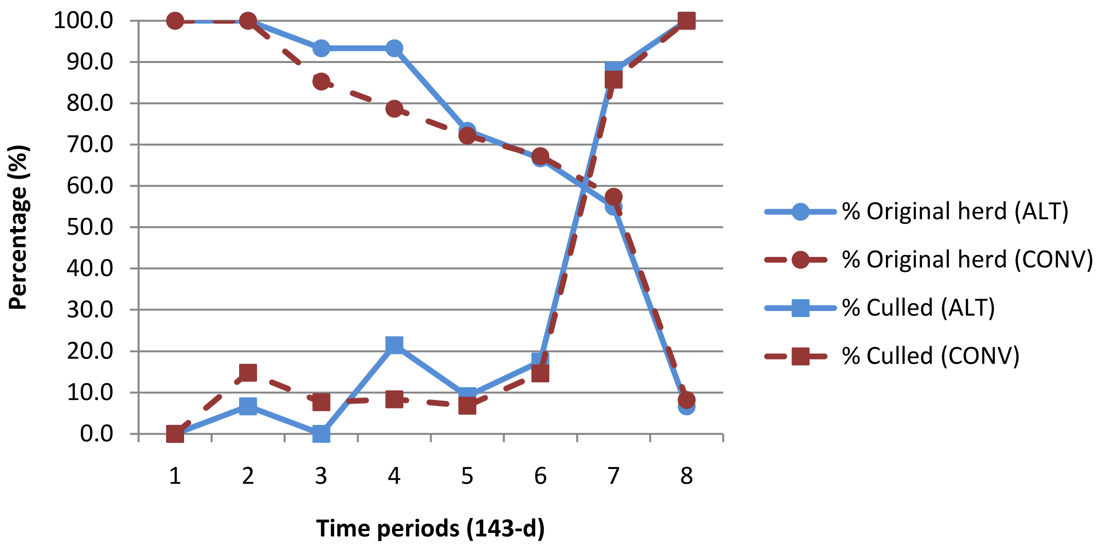


Figure 5.1. Culling rates and percentage of original herd remaining across periods

CONV witnessed high early culling due to reproductive (REPRO) and physical (PHYS) issues, similar to what was observed by Lucia et al (2000). Physical ailments, such as locomotive issues, may be exacerbated by harsher housing conditions. The straw flooring in ALT, for example, likely provided adequate cushioning that prevented these issues from surfacing. Ehlorsson et al (2002) confirmed this theory by showing that sows on straw had less foot injuries and lameness, and were at a lower risk of being culled than sows on partially-slatted floors. In fact, partially-slatted flooring – as used in CONV – was more likely to cause sows to become lame than even plastic slats (Gjein and Larssen, 1995). If these locomotive issues do arise, the sows are likelier to recover from them on a more forgiving surface, such as the straw provides. ALT experienced higher culling for REPRO in later parities; this may suggest that the physically 'inferior' sows – such as the ones culled early in CONV – remained in the herd longer in ALT. This theory is unable to be proven through this experiment, however.

IV. Implication of Culling on Animal Welfare

The CONV had higher culling rates in earlier parities due to involuntary factors – physical and reproductive issues – than ALT (Tables 5.3 and 5.4). This result has a direct implication on sow longevity, as 21% of the sows in CONV do not make it through the 4th period. Both CONV and ALT had 33% of their sows culled before period 6; however, only 65% of those in ALT were due to involuntary reasons as compared to 95% in CONV (Appendices K and L). Hurnik and Lehman (1988) warned against making conclusions about longevity in animal production system. The large number of involuntary culls in CONV, however, suggests that longevity has been reduced. This might be, in and of itself, indicative of reduced welfare in CONV as compared to ALT.

In addition to their effect on longevity, these housing systems also affect other aspects of animal welfare. Broom (1991) suggested using body damage as an indicator of welfare. In this regard, the number of physical culls or deaths might prove useful in measuring welfare. Over the course of the experiment, 21% of the sows in CONV were culled due to physical issues – 13% for locomotive issues and 3% that simply died on-farm (Appendix J). In contrast, only 7% of culls in ALT were for physical issues. One of these culls (2%) was for sickness, however; another (2%) was due to the sow becoming too large for the farrrowing crate, and the remaining 3% were for lameness. As mentioned, this finding concurs with Ehlorsson et al (2002). The occurrence of death or sickness is unarguably indicative of poor animal welfare (Broom, 1991); so too are the presence of structural issues. Concerning these two indicators, ALT has higher animal welfare than CONV.

Breeding failure can also be used as an indicator of animal welfare, though it may not be indicative of animal suffering – objective, unpleasant feelings (Broom, 1991). In this case, ALT may prove to have reduced welfare with 42% of the sows being culled for reproductive issues as compared to only 23% in CONV. However, the presence of structural issues, as seen in high frequency in CONV, is likelier to reduce welfare as compared to poor reproductive success (Broom, 1991). Following this logic, the alternative group-housing system seems to have enhanced welfare as compared to the conventional group-housing system. Production may also act as an indicator for welfare (Broom, 1991) with poor production suggesting poor welfare – the following sections investigate the differences in production between the two systems.

V. Estimation of Weanling Production

The regression of input variables on litter weight at weaning (LW) uncovered significant influences of parity, $parity^2$, feed intake during lactation (LF), and LF^2 on LW (Table 5.5). The estimates show that a positive relationship exists between parity and LW, and a negative relationship exists between $parity^2$ and LW. This states that that litter weights increase at a decreasing rate as the sows gain parities. More specifically, this function predicted that litter weights increase up to parity 3 and decrease thereafter, i.e., peak in the 3^{rd} parity. This finding follows the biological production function. LW also increased at a decreasing rate with additional LF; no value of LF observed within the experiment caused the production function to decline. No other variables were significant at $p<0.05$, including barn-interaction variables. Using the average periodic values for the

Table 5.5. Estimation coefficients of production function

VARIABLE	COEFFICIENT ESTIMATE (± SE)
Parity	6.30 ± 1.50**
Parity^2	-0.98 ± 0.26**
Inseminations	0.65 ± 2.65
*Barn x Inseminations	0.47 ± 3.44
Inseminations^2	-0.051 ± 0.443
*(Barn x Inseminations)^2	-0.065 ± 0.553
[Ŧ]NLD	0.079 ± 0.157
*,[Ŧ]Barn x NLD	-0.21 ± 0.20
[Ŧ]NLD^2	-0.00093 ± 0.00113
*,[Ŧ] (Barn x NLD)^2	0.0013 ± 0.0015
[ø]LF	0.99 ± 0.09**
*,[ø]Barn x LF	0.13 ± 0.12
[ø]LF^2	-0.0037 ± 0.0006**
*,[ø] (Barn x LF)^2	-0.00034 ± 0.00079
[§]Meds	1.94 ± 3.36
*,[§]Barn x Meds	-2.30 ± 6.17
[§]Meds^2	-0.35 ± 1.15
*,[§] (Barn x Meds)^2	0.18 ± 2.39

**Significant at alpha level of 0.05
*0 indicates conventional system; 1 indicates alternative system
[Ŧ]Non -lactating days; acts as proxy for total feed intake during non-lactating period
[ø]Feed intake during lactation
[§]Number of medical treatments

input variables in each respective barn, the estimated production curve for the alternative barn (ALT) lay slightly above that of the conventional barn (CONV) (Figure 5.2). This

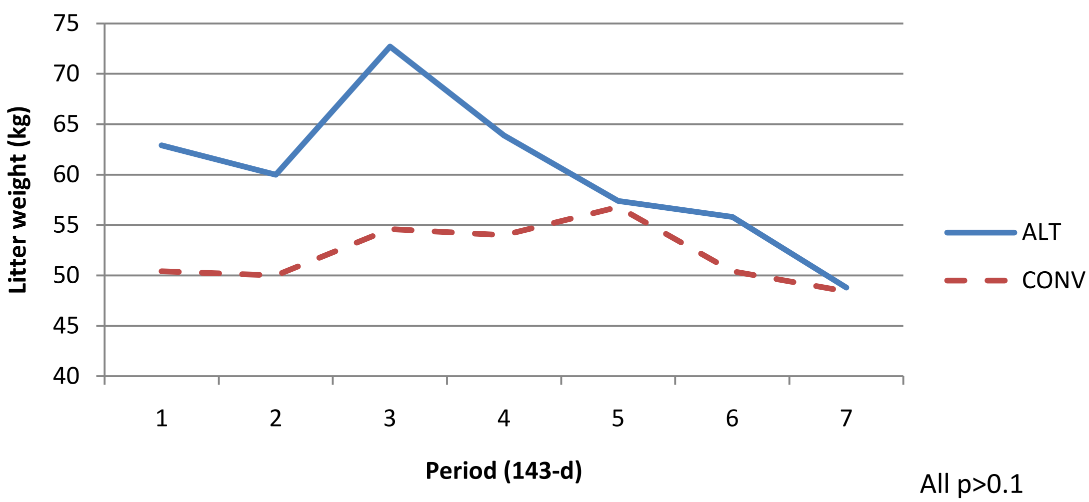


Figure 5.2. Estimated litter weights at weaning across periods

does not reflect a significant difference between the barns, however, as inputs values for the two barns differed – these input values are merely estimated values based on the averaged input data (Appendices C and D).

VI. Experimental Values for Production

When the raw experimental data is considered with inconsistent time periods, i.e., parities, litter weights at weaning were found to be consistently higher across *parities* in the alternative barn (ALT) than the conventional barn (CONV), and were significantly higher (at an alpha level of 0.05) in parities 2, 3, 6 and 7 (Figure 5.3). Production, as measured by weaned litter weight, was seen to peak at parity 3 in ALT (at a value of 77.36 ± 1.52 kg) and at parity 4 in CONV (at a value of 70.38 ± 1.90 kg). The peak value in ALT was significantly higher than that in CONV. Further, the average number of pigs

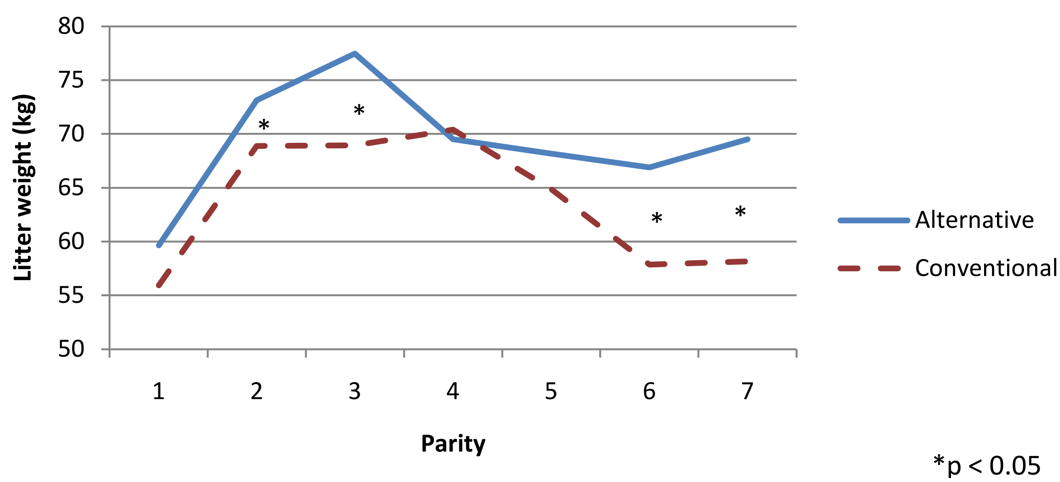


Figure 5.3. Average litter weights at weaning across parities; experimental results

weaned per litter was significantly greater in ALT (11.28 ± 0.19) than in CONV (10.44 ± 0.22) in the 3rd parity (Figure 5.4). Both barns had peak production – as measured in weanlings per litter – in parity 3. No significant differences were seen between barns in regards to number of piglets born alive (Appendix M); liveborns also peaked in parity 3.

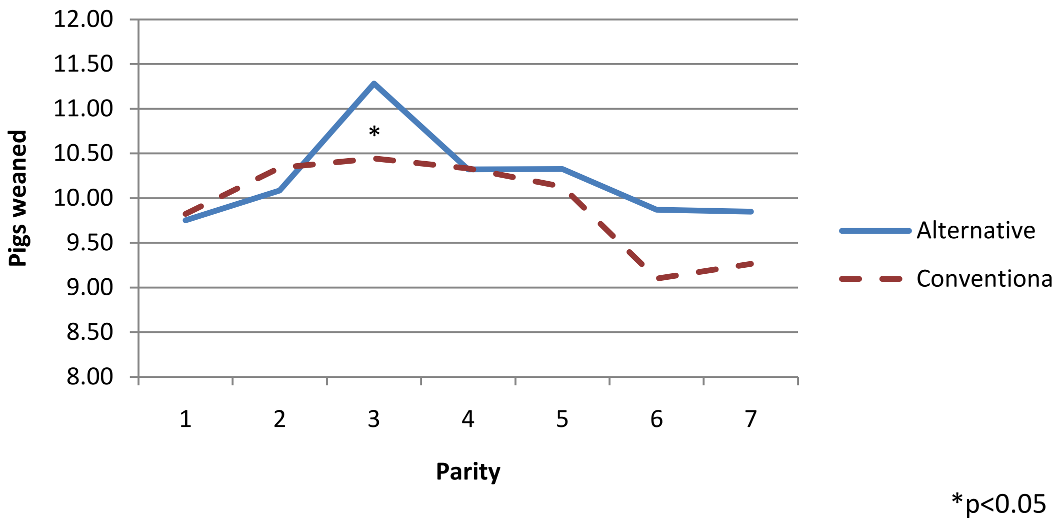


Figure 5.4. Average number of pigs weaned per litter across parities; experimental results

The difference observed in *per-parity* production, as measured in litter weight (LW), between barns may have been partially caused by variations in management, such as different weaning ages, during different parities. Later weaning results in greater LW, but is counteracted by lengthening the production cycle. This occurrence is accounted for in the simulation model, however, by splitting production into *time periods* instead of *parities*. The number of weanlings produced in parity 3 was significantly higher in ALT than in CONV though (Figure 5.4). And, despite some cross-fostering, the average number of weanlings should depict a sow-driven difference, i.e., the number represents the herd's possible production. The increased production in ALT may have been a reflection of better selection for sows in parity 3, or, inversely, the inability of CONV to select for superior sows in early parities. Both barns were seen to peak around parity 3, which is in concordance with Stalder et al (2003).

Though per-sow production was shown to have significant differences between barns when comparing production on a *per-parity* basis, these differences disappeared when the production data were organized into consistent*143-d time periods*. Weaned litter weights on a *per-period* basis were seen to peak in period 3 in both barns (Table 5.6). This coincided with the timing of peak production seen *across parities* in ALT, but did not coincide with the timing of peak production in CONV, which was observed in parity 4 (Figure 5.3). *Periodic* production in ALT was observed to drop below the production seen for gilts, i.e., period 1 production, in both period 5 and 7. This

Table 5.6. Average weanling production per sow (in kg) across periods; experimental results

PERIOD	**CONVENTIONAL**		**ALTERNATIVE**	
	n	Production (±SE)	n	Production (±SE)
1	61	50.77 ± 17.21	60	51.27 ± 21.04
2	61	58.48 ± 32.13	60	61.93 ± 35.42
3	52	61.02 ± 26.02	56	80.57 ± 29.12
4	48	56.87 + 29.79	56	60.83 ± 29.28
5	44	58.07 ± 26.61	44	50.50 ± 36.03
6	41	53.31 ± 25.18	40	59.14 ± 33.88
7	35	52.14 ± 25.26	33	49.33 ± 32.72
8	5	49.98 ± 28.93	4	61.68 ± 41.78

occurrence only happened in period 7 in CONV. Conversely, *per-parity* production (up to parity 7) never dropped below gilt production (Figure 5.3). Since SE for *periodic* production were quite high, significant differences were neither seen between barns nor *across periods*.

This could have been due to a variety of reasons. Some periods contained no production and most periods were a mosaic of sow parities; both events would dramatically increase variation around the means, decreasing the chance of accepting a true difference. The observed production in both barns may have been slightly lower than expected because of the presence of partial periods – periods with less than 143 days – caused by culling. No partial period contained two weaning events, i.e., productions, like some full periods do, and partial periods were more probable to contain no production. Since partial periods were treated as full periods, true herd production was probably understated. However, the lost production due to having empty sow spaces for partial periods should likely be incorporated in the total, true cost of culling. Despite these setbacks, it is still important to break production into consistent time periods for the simulation model.

VII. Causal Factors for Production Estimation

The lack of significance between the barns for production on a per-period basis likely explains the lack of significance found in the barn-interaction variables. The non-significance suggests that housing had little effect on how efficiently sows converted inputs, such as feed, into weanling production. This, at least, confirms that the sows in both barns came from the same genetic pool, and any variations in barn production are a function of the different culling profiles and/or inputs. As mentioned previously, the culling profiles between the barns varied with fewer productive sows being present in CONV during peak production. Also worth noting is that, during these peak periods, the inputs used vary between barns (Appendices C and D). Most importantly, lactation feed intake (LF) was consistently – although not significantly – higher in ALT as compared to CONV. Since every kilogram of LF roughly increases LW by 1 kilogram, it is not surprising that ALT exhibits higher production on the barn level. Therefore, though productive ability may be no different between barns on the sow level, the uncontrolled nature of the experiment allows for production to vary between barns on the barn level. Production was estimated in the simulation model to differ; however, this may be the product of using averaged input values in the production function which would not capture the true variation in production, as seen in Table 5.6.

Doses of semen (AI) were shown to have no effect on production, likely due to minimum variation with both a high or low number suggesting low production. The number of medication treatments (MEDS) could be argued to promote better production, since producers would not bother treating their animals if MEDS had no effect. However, improvement may be observed only in subsequent periods. Further, a malady – which likely decreased production, at least temporarily – must first have occurred for MEDS to be administered. Possibly due to these counteracting forces, MEDS appeared to have no effect on production. Parity had the expected relationship with LW – a concave relationship with a negative slope after the 3rd litter, as was observed by Stalder et al (2003).

The number of non-lactating days (NLD) – a proxy for gestation feed intake – had no effect on production. This was a surprising result. However, NLD had relatively low variation due to the natural reproductive cycle and the fact that gestation feed intake was managed in the barns to ensure consistent body conditions. Though increased feed intake during the non-lactating period would seemingly enhance performance, the highest values, i.e., those indicating NLD being close to the maximum value of 143 days, usually also indicated a non-productive period. Thus, high observed gestation feed intake might lead to low production. Further, it may still not be optimal to maximize gestation feed intake for pregnant sows. Lawlor and Lynch (2007) suggested that sows should be fed only the requirement for maintenance, body growth, and growth of developing fetuses during gestation; inadequate feed leads to poor conditioning prior to farrowing, while over-feeding leads to a depressed appetite during lactation.

Avoiding this depressed appetite is essential since LF was found to be very influential on production. The rule-of-thumb would be to maximize LF in order to maximize LW, since no reasonable amount of LF had a negative impact on LW. Lactation feed provides energy and nutrients for milk production (Dourmad et al, 1994), which, in turn, improves weanling size. It has also been reported to improve reproductive performance by decreasing the weaning-to-first service interval and increasing subsequent production (Young et al, 1991; Tummaruk et al, 2000). One pre-cautionary note about LF is that this variable also captures weaning age, i.e., as weaning age increases, so too does LF. As mentioned, increasing weaning age also increases the length of the production cycle, which would actually decrease overall productivity. Since weanling prices are set primarily on a per-head basis, and only secondarily by weight, there is not much advantage to raising them past the market weight of 6 kg.

VIII. Model Simulations

Running the simulation over a 20-year time horizon for an individual sow space, it was found that ALT was most profitable when all remaining sows were objectively culled before the 7th period, i.e., following the 6th period. CONV was observed to be most profitable when sows remained in the herd until the end of the 7th period (Table 5.7). ALT yielded an annuity of over $60 per farrowing space when culling occurred optimally. Conversely, CONV lost $7 per farrowing space even when culling optimally. Though the present-value of accumulated net revenues (PVNR) was maximized when terminal culling (TERM) occurred in period 6 in ALT and period 7 in CONV, weanling

Table 5.7. PVNR, annuity and total weanling production (mean ± standard error (SE)) for individual sow space, varying period in which TERM occurred

Period of terminal cull	**3**	**4**	**5**	**6**	**7**
PVNR, ALT (CDN$)	-230.09±2.85	491.13±4.16	689.52±4.43	754.33±4.48	728.43±4.31
Annuity, ALT (CDN$)	-18.47±0.23	39.43±0.33	55.36±0.36	60.56±0.36	58.48±0.35
Production, ALT (kg)	3316.8±0.3	3303.8±0.2	3240.5±0.3	3191.3±0.4	3126.5±0.8
PVNR, CONV (CDN$)	-1819.67±5.69	-1028.87±7.71	-539.91±7.93	-306.85±8.51	-87.35±9.17
Annuity, CONV (CDN$)	-146.10±0.46	-82.61±0.62	-43.35±0.64	-24.64±0.68	-7.01±0.74
Production, CONV (kg)	2620.1±0.1	2648.0±0.2	2688.7±0.3	2658.0±0.2	2615.2±0.3

production was actually maximized when TERM occurred in period 3 for ALT and period 5 for CONV, respectively. ALT lost money, on average, when TERM occurred prior to period 4, while CONV was never profitable regardless of when TERM occurred. Further, the variation surrounding the mean PVNR for CONV was greater than that for ALT, suggesting increased risk. The standard error (SE) increased gradually in both barns in succeeding periods.

When TERM occurred at the optimal level for maximizing PVNR, CONV was found to be unprofitable for 56.7% of the 1000 simulated runs with a minimum value around -$1200. ALT, in contrast, was profitable for all 1000 simulated runs with a median value of $793 and a minimum value of $127. Figure 5.5 displays the distribution of 1000 model iterations for an individual sow's profitability over a 20-year time period in each respective barn.

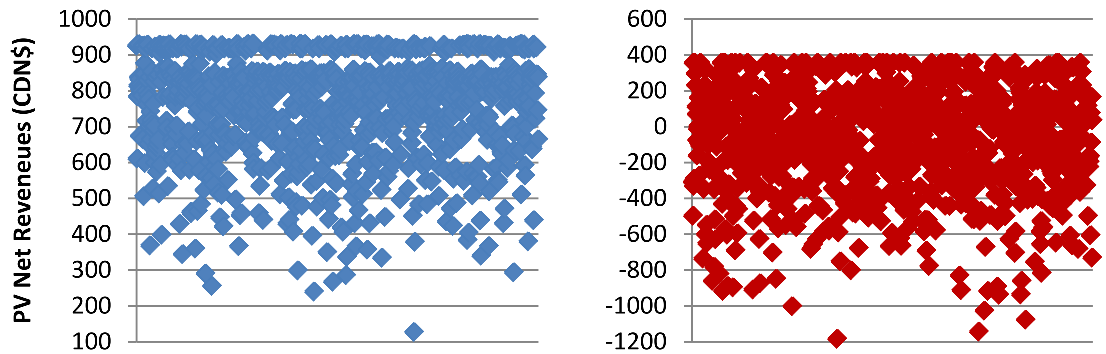


Figure 5.5. Distribution of model iteration results (using PVNR) for individual sow space in ALT (left) and CONV (right) with optimal TERM

As was observed in the individual sow model, the 600-sow barn model predicted that PVNR over a 20-year period was optimized in ALT and CONV when TERM occurred at the end of the 6th period and 7th period, respectively (Table 5.8). If the values from the individual model are multiplied by the herd size (600), the results closely approximate the values observed for the barn model. Maximum production was, once again, observed with TERM occurring in an earlier period than the period in which PVNR is optimized. A 600-sow barn operating like ALT produced 1.91 million kg of weanlings – roughly 320,000 weanlings – over a 20-year period, and profited over $450,000 (or $35,000 annually) when performing TERM optimally. Under the same conditions, CONV produced 1.61 million kg of weanlings – roughly 270,000 weanlings – but lost over $47,000 ($3800 annually). Performing TERM one period earlier than optimal caused CONV to lose an additional $150,000; ALT also lost $43,000 and $19,000 when TERM occurred one period earlier and later, respectively. When TERM

Table 5.8. PVNR, annuity and total weanling production (mean ± SE) for 600-sow barn, varying period in which TERM occurred

Period of terminal cull	**3**	**4**	**5**	**6**	**7**
PVNR, ALT (CDN$)	-138,077 ± 1743	298,041 ± 2562	410,440. ± 2598	453,703 ± 2694	434,856 ± 2684
Annuity, ALT (CDN$)	-11,086 ± 140.	23,929 ± 206	32,953 ± 209	36,427 ± 216	34,914 ± 215
Production, ALT (kg)	1,990,063 ±164	1,982,413 ± 124	1,944,134 ± 165	1,914,834 ± 243	1,876,891 ± 482
PVNR, CONV (CDN$)	-1,091,768 ± 3405	-622,092 ± 4566	-328,209 ± 4839	-197,089 ± 5292	-47,120. ± 5445
Annuity, CONV (CDN$)	-87,656 ± 273	-49,947 ± 367	-26,351 ± 388	-15,824 ± 425	-3783 ± 438
Production, CONV (kg)	1,572,028 ± 79	1,588,607 ± 107	1,613,376 ± 160.	1,594,818 ± 127	1,568,798 ± 190.

was performed optimally for both barns, ALT was observed to have higher production and profitability at the barn-level than CONV. In addition to the differences in profitability, the standard errors around the mean values for PVNR were also consistently lower – suggesting less risk – in ALT as compared to CONV.

There were some slight differences between the estimated production values predicted used in the simulation models and the average values from the experimental data. The estimation predicted peak production in ALT in period 3, which coincided with the experimental data, and in CONV in period 5, two periods later than the experimental data suggested. Since estimated production in CONV displayed a later peak than in the experimental data, the optimal terminal cull (TERM) may have been falsely pushed back. ALT, conversely, had matching peaks, suggesting that the optimal TERM was likelier to be true. Even the seemingly large margin between those values in the 1st period in ALT was not significant (when considering the SE from Table 5.6). The large, yet insignificant, overestimation of initial (1st period) production in ALT, however, may have caused TERM to be falsely favoured earlier. With lower overall production estimated in

CONV, an earlier TERM was unlikely to be optimal, due primarily to the cost of replacement and the higher risk inherent in replacement gilt survival in CONV.

However, the production estimation did slightly overestimate production, on average, in ALT and slightly underestimated it in CONV (Figure 5.6). Though this was

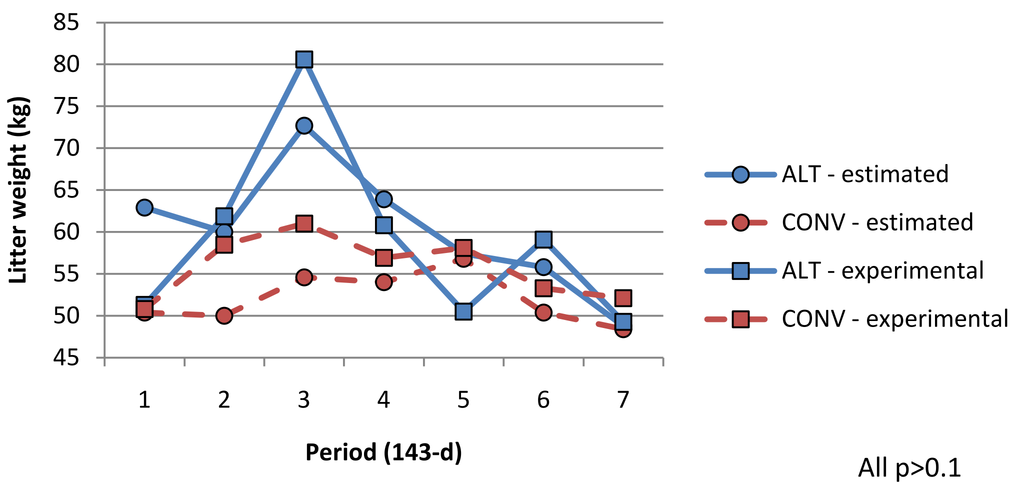


Figure 5.6. Estimated and experimental production (litter weights at weaning) per period

not statistically significant, it may have led to a wider spread in profitability between the barns than was truly present in the experimental data. This variation from experimental values can partially be attributed to imperfect estimation, but may also be credited to the simulation model using deterministic – not stochastic – values for inputs. Despite these differences, the values predicted by the individual sow simulation model for weanling production were still closely associated with the experimental values (Appendix N).

IX. Discussion of Optimal Terminal Culling

Profits were optimized in ALT when TERM occurred at the end of the 6th period (Table 5.7). This was an interior solution and roughly suggested that sows in ALT should be culled after weaning their 6th litter. CONV profits were optimized when TERM happened at the end of the 7th period. Since only 7 periods of data were available, this represented a corner solution. It is more difficult to conclude that sows in CONV should be culled following the weaning of their 7th litter; instead, these sows should be culled beyond their 7th parity. CONV contained higher risk in regards to sow replacement due to higher 2nd-period culling and fewer full-value culls; the larger SE in CONV acted as a testament to the additional risk. This likely pushed back optimality. This barn was found to be unprofitable under the current market conditions even whilst performing optimal TERM. The higher probability of early culling – especially in the 2nd period – likely overwhelmed other factors, leading to a large decrease in the present-value of accumulated net revenues (PVNR). As noted, there was a difference between the periods in which optimal TERM should occur for maximum production and optimal profitability. This finding demonstrates the importance of culling and replacement costs in the model, and how a large replacement cost pushes back the optimal time for replacement. Optimal TERM may also have been later in CONV than ALT due to reduced production, which made CONV sows take longer to recuperate their investment cost.

Using optimal TERM for each respective barn, the average parity within this sample group was 3.09 ± 0.05 in ALT and 3.42 ± 0.06 in CONV. This also coincided with an annual cull rate of 49.3 ± 3.2% in ALT and 45.2 ± 3.1% in CONV. Thus, the average herd parity was significantly lower in ALT than in CONV when managing the barns optimally. Both values of average parity fit closely with the target set by Pinilla and Lecznieski (2010) of 3.5 parities; annual cull rates also fit within the target of 45-50%.

Culling rates were not significantly different, however. Despite similar annual culling rates, ALT had lower average herd parity than CONV, likely due to the truncation of all 7^{th}-period sows caused by TERM occurring prior to the 7^{th} period. Though the early involuntary culls in CONV would increase turnover, thus decreasing average herd parity, this effect must have had as smaller effect than the removal of all late-parity sows in ALT. If sows were terminally culled at the end of period 7 in ALT instead of optimally at the end of period 6, the average herd parity and annual cull rate become 3.44 ± 0.06 and 42.6 ± 3.0%, respectively. The fact that SE chronologically increased as optimal TERM was pushed back (Table 5.7) suggests that more risk was introduced due to compounding probabilities of culling. This is the effect of the Monte Carlo simulation.

Rodriguez-Zas et al (2006) noted that there was a large variation in the literature as to when sows should be terminally culled. With similar variable values to this experiment, they found optimal TERM to be around parity 5 or 6, using the Burt (1965) approach. This approach suggests that a producer should "continue with the currently held asset until expected marginal net revenue minus expected marginal cost of planned replacement is less than the weighted average net revenue from the potential replacement." Though this method addresses the risky nature of asset replacement, it introduces a downward bias for the optimal replacement of assets. Instead of detracting the expected marginal cost of planned replacement from the current asset's value, as suggested by Burt (1965), it should be detracted from the planned replacement's value. The major difference is that the prior would suggest replacing an asset before it drops below average net revenue, at the time incurring a replacement cost. The latter sees an asset being replaced after its marginal production sinks below average production. In other words, to justify incurring a replacement cost, the marginal net revenue should be lower than the average expected net revenue. This likely was the reason Rodriguez-Zas et al (2006) found an early optimal TERM. The minor correction would push the optimal TERM back.

Some other results from Rodriguez-Zas et al (2006) seemed counter-intuitive also. For example, optimal replacement was found to be earlier when involuntary removal rates were high, and later when these rates were low. High involuntary removal rates introduce additional survival risk for future assets, thus it is more logical to retain the current asset longer if it remains productive than taking the risk on a future asset. Further, some optimal net-present values (NPV) in the sensitivity analysis were found to be negative, despite having favourable input costs; a lower replacement cost, for example, resulted in an unprofitable optimal even though the default optimal was positive (Rodriguez-Zas et al, 2006). The present research also considered one sow instead of the sow space over time. Pinilla and Lecznieski (2010) also found that the 5 parities is the optimal average for culling. Like this research, however, they suggest to not retain any sows beyond 7 parities.

Stalder et al (2003) used more appropriate methods and found a corner solution in which optimal TERM occurred after the 6th parity – a similar result to this experiment. They also found that, in order for it to recover its investment cost, a sow must remain in the herd at least 3 parities; this concurred with the result in ALT. Stalder et al (2003) also suggested that the optimal average herd parity was 3.85, and that the peak production periods were in parities 3-6, both of which coincide closely with CONV. However, average herd parity does not, in-and-of-itself, capture the optimal time for TERM; to determine optimal TERM, specific reasons for culling are necessary.

X. Sensitivity of Optimal TERM to 2nd-Period Culling Rates

As mentioned in Chapter 4, sensitivity analyses were conducted to detect the sensitivity of the optimal TERM and overall profitability (PVNR) to exogenous shocks. The sensitivity of the optimal TERM was tested by varying 2nd-period culling rates, weanling price, gilt price, and salvage values. The latter three used 5-year high and low values to determine the possibility of shifting optimal TERM. To test the effect of varying 2nd-period culling rates, the default value was used from each barn, as well as 2.5% – half the default value (5.0%) in ALT – and 25% – roughly twice the default value (12.7%) in CONV. These should provide a good range of plausible culling rates for this period. In this case, the model is considered sensitive to a variable when a change in that variable causes a shift in the optimal TERM.

Altering the overall culling rate in period 2 had no effect on when the optimal time for TERM was in either barn (Table 5.9). However, ALT became indifferent between period 6 and 7 TERM when the rate increased to 25%. Another influential change occurred when the culling rate was reduced to 5% in CONV; this occurrence caused CONV to become profitable. Other changes resulted in less dramatic changes, though slight directional shifts, observed by decreases in margins between optimal periods for TERM, were noticed. Decreasing the 2nd-period culling rate by 50% increased

PVNR in ALT by $31.61 using optimal TERM; increasing it by 154% decreased PVNR

Table 5.9. Sensitivity of optimal terminal cull to second-period cull rate, ceteris paribus, using PVNR (CDN$; mean ± SE)

Cull Rate	Barn	Sensitivity	Period 5 Terminal Cull	Period 6 Terminal Cull	Period 7 Terminal Cull
2.5%	ALT	-50%	727.39 ± 3.60	785.94 ± 3.76	757.10 ±3.93
	CONV	-80%		-147.03 ± 6.23	93.93 ± 6.66
5%	ALT	**Default**	**689.52 ± 4.43**	**754.33 ± 4.48**	**728.43 ± 4.31**
	CONV	-39%		-186.29 ± 6.85	45.83 ± 7.27
12.7%	ALT	+154%	559.68 ± 6.39	642.32 ± 6.10	623.99 ± 6.13
	CONV	**Default**		**-306.85 ± 8.51**	**-87.35 ± 9.17**
25%	ALT	+400%	337.66 ± 8.91	429.25 ± 8.58	440.71 ± 8.37
	CONV	+97%		-557.25 ± 11.19	-356.50 ± 12.35

by $112.01. This increased culling rate shrank the difference between PVNR with TERM occurring in the 6th or 7th period from around $26 to around $18 in ALT, suggesting movement towards period 7 being more optimal. Predictably, the increased rate also widened the margin between the PVNR of the 5th and 6th period TERM.

As mentioned, a culling rate of 25% led to a shift in optimality. Decreasing 2nd-period culling to the level seen in ALT (5.0%) caused CONV to become profitable. No change in this culling rate caused an influential shift in optimality in CONV. Counter-intuitively, smaller 2nd-period culling rates resulted in larger margins between 6th and 7th period TERM. This may simply be due to the magnitude of the profits or the margin. As expected, due to the introduction of more replacement risk, the SE increase with increasing culling rate. Increasing 2nd-period culling also had the expected effect of decreasing profits in both barns at optimality.

The model was more upward sensitive to changes in 2nd-period culling than downward sensitive, demonstrated by larger losses occurring from an increase than gains experienced from a decrease. Though altering the culling rates during this period did not change optimal TERM, as was observed by Rodriguez-Zas et al (2006), an increase did shrink the gap between 6^{th}-period and 7^{th}-period TERM in ALT. Counter-intuitively, a decrease widened the gap between the optimal TERM period – 6^{th} in ALT, 7^{th} in CONV – and the previous period – 5^{th} and 6^{th}, respectively – in either barn. The simulation model was likely more reliant on the whole culling profile, not just the 2^{nd} period, which attests to the model's robustness.

XI. Sensitivity of Optimal TERM to Economic Shocks

Profitability naturally changed in response to changes in discount rate, but, neither changing the discount rate to 0% nor 10% had any effect on optimal TERM in either barn, though, at a 0% discount rate, period 7 TERM in CONV became profitable (Appendix P). This is likely the case that these discount rates are just not high enough to cause significant shifts. As the discount rate increases beyond 10%, it becomes increasingly necessary to hold onto the sow longer to avoid incurring replacement costs. This occurs since a high discount rate decreases the future worth – marginal user-cost – of the current sow while the replacement cost remains quite high. With a discount rate closer to 20%, one might expect to observe a later TERM to become optimal from a profitability point-of-view.

The prices of pigs were found to have some effect on which period TERM was optimal (Table 5.10). If weanling price decreased by 60% from the default, optimal TERM shifted from period 6 to period 7 in ALT. An increase in weanling price of 100% also resulted in a shift in ALT, this time causing period 5 to become the optimal period for TERM. A decrease in gilt price of 20% – the 5-year low – made the optimal TERM indifferent between period 5 and 6 in ALT; a 20% increase – the 5-year high – caused optimal TERM to shift from period 6 to period 7. An 80% increase in salvage values shifted the optimal TERM to period 5 and an 80% decrease shifted it to period 7 in ALT.

Table 5.10. Sensitivity of optimal terminal cull to pig prices, ceteris paribus, using PVNR (CDN$; mean ± SE)

Variable & Sensitivity	**Barn**	**Period 5 Terminal Cull**	**Period 6 Terminal Cull**	**Period 7 Terminal Cull**
Weanling price, -60%	ALT		-4563.04 ± 3.65	-4479.24 ± 3.96
	CONV		-6223.84 ± 8.64	-5890.12 ± 9.47
Weanling price, +100%	ALT	12,661.53 ± 4.27	12,545.28 ± 4.32	
	CONV		9483.91 ± 9.43	9591.67 ± 9.13
Gilt price, -20%	ALT	1211.53 ± 3.58	1209.99 ± 3.64	
	CONV		158.23 ± 7.42	329.70 ± 8.08
Gilt price, +20%	ALT		290.23 ± 5.48	313.79 ± 5.33
	CONV		-794.33 ± 9.74	-520.82 ± 10.40
Salvage values, -80%	ALT		-190.81 ± 5.57	-85.61 ± 5.46
	CONV		-1231.72 ± 9.76	-872.64 ± 9.81
Salvage values, +80%	ALT	1797.61 ± 3.62	1691.86 ± 4.30	
	CONV		578.33 ± 8.99	722.44 ± 9.36

No reasonable changes in weanling price, gilt price or salvage values shifted the optimal TERM in CONV.

The ALT optimality was more sensitive to pig prices than CONV. This was likely due to ALT's production curve being more extreme across periods, with greater overall and earlier peak production than CONV. Rodriguez-Zas et al (2006) found that optimal TERM was most sensitive to sow replacement costs, followed by salvage value, and then weanling price. Specifically, optimal TERM was pushed back furthest by high replacement cost, low salvage value, and low weanling price. Shifts in gilts price also induced shifts in optimal TERM for ALT, although a decrease in gilt price simply made ALT indifferent between 5th- and 6th-period TERM. In the case where two periods yield equal profit, it would likely be optimal to cull earlier rather than later in order to increase genetic turnover – this advantage was not considered in the simulation model. Increased weanling price also shifted optimal TERM down by one parity in ALT; these results all concurred with Rodriguez-Zas et al (2006). Though salvage values were only altered within 40% of the default, an increase within this range still caused optimal TERM in ALT to decrease by one parity. Optimal TERM in CONV, however, was not sensitive to any reasonable changes in these prices, contrary to literature results (Rodriguez-Zas et al, 2006).

Optimal TERM in CONV proved to be rather insensitive to pig prices as compared to ALT; however, part of the analysis was incomplete since CONV had an upper-corner solution, which does not allow for upward shifts to be investigated. Changes in PVNR were investigated partially by using shifts in the number of SE from the base value. Percentage changes would be ineffective, as profits for a large proportion of simulation runs dropped below zero. Thus, using SE instead of percentage changes seemed to be advantageous. Though this was an objective measure of change, SE can neither be confidently used to compare PVNR in sensitivity analyses between barns nor for the sensitivity of optimal TERM. The variation of SE was too great in these cases since the risk involved in changing optimal TERM changed. However, it still effectively measured PVNR sensitivity in each respective barn.

XII. Sensitivity of PVNR to Pig Prices

The sensitivity analyses for PVNR were conducted using the values observed in

Table 4.6. Smaller variations were made to variables that PVNR was expected to be most sensitive to, e.g., weanling price, while larger variations were made to less influential variables, e.g., semen cost. For these sensitivity analyses on PVNR, the model is considered to be sensitive when a variation in a variable's value causes a housing system to either become profitable when it was unprofitable, i.e., in the case of ALT, or vice versa, i.e., in the case of CONV. The number of SE – always using the default values of $4.48 in ALT and $8.51 in CONV – will be used as a relative indicator of a shift's magnitude. Since ALT's default value lies further from the break-even point than CONV's, a larger shift is required to be considered sensitive. Using the respective default values for SE, ALT requires a negative shift of 168 SE and CONV requires a positive shift of 10 SE. This definition of sensitivity relies on the producer decision-making, i.e., if a change will not lead to a different overall decision, the barn is not sensitive to that change.

Variation in pig prices affected the PVNR for the optimal TERM in ALT substantially (Table 5.11). If weanling price increased by just 5%, it caused the PVNR to increase by $576.27, a shift of 129 SE. A decrease of 5% in weanling prices decreased PVNR by 133 SE (-$594.39), and, at $31.20 per weanling (a 10% decrease), ALT became unprofitable. Decreasing weanling price by 20% resulted in a downward shift of 527 SE (-$2359.07). With a stable price matching the 5-year high of around $70 per weanling, ALT could profit over $12,500 per farrowing space over a 20-year period. Conversely, the 5-year low of around $14 per weanling could lead to a loss of over $6300 per farrowing space. The model was less sensitive to salvage values, shifting only 52

($231.84) and 55 SE (-$247.39) in response to a 20% increase and decrease, respectively. PVNR dipped below zero when salvage values dropped by 80%. The model was slightly

Table 5.11. Sensitivity of PVNR (CDN$; mean ± SE) to pig prices in ALT with terminal cull in 6th period, ceteris paribus

Sensitivity	Weanling Price	Salvage values	Revenues[1]	Replacement price	All pig prices[2]
+20%	3115.04 ± 4.24	986.17 ± 4.43	3348.40 ± 4.38	285.93 ± 5.43	2869.93 ± 5.31
+10%	1931.78 ± 4.24	852.38 ± 4.47	2060.91 ± 4.19	516.50 ± 5.05	1813.49 ± 5.02
+5%	1330.60 ± 4.68	815.10 ± 4.29	1403.24 ± 4.36	638.61 ± 4.85	1287.20 ± 4.47
Default			**754.33 ± 4.48**		
-5%	159.94 ± 4.44	695.64 ± 4.41	105.68 ± 4.48	867.69 ± 4.27	218.87 ± 4.17
-10%	-431.90 ± 4.46	637.09 ± 4.56	-549.23 ± 4.50	981.53 ± 4.13	-317.49 ± 4.27
-20%	-1604.74 ± 4.67	506.94 ± 4.74	-1847.14 ± 4.84	1211.68 ± 3.70	-1391.45 ± 4.09

[1]Salvage values and weanling price
[2]Salvage values, weanling price, and replacement prices

more sensitive to the price of replacements than salvage values, shifting 105 (-$468.40) and 102 SE ($457.35) with a 20% increase and decrease, respectively. Increases to replacement price also resulted in greater SE. Adjusting the output prices (revenues) caused large shocks to PVNR in response to relatively small changes – 145 SE-shift (±$650) with a 5% increase or 5% decrease. Shocks to all pig prices resulted in a lesser effect on PVNR, but ALT still became unprofitable if they were decreased by 10%.

The simulation results for CONV were also quite sensitive to pig prices (Table 5.12). Despite CONV being unprofitable at the default prices, it became profitable with a 5% increase in weanling price ($36.40 per weanling) – a shift of 45 SE ($416.80). The average loss in CONV could be as high as $5882.49 ± 9.80 with the 5-year-low weanling price. PVNR for ALT, however, dropped even lower from this shock, proving that ALT was more sensitive to weanling price. For CONV to break-even, salvage values needed to increase by 10%. A 20% increase or decrease in salvage values was shown to shift PVNR by 21 SE (±$190). CONV began to break even when the price of replacements dropped

Table 5.12. Sensitivity of PVNR (CDN$; mean ± SE) to pig prices in CONV with terminal cull in 7th period, ceteris paribus

Sensitivity	Weanling Price	Salvage values	Revenues[1]	Replacement price	All pig prices[2]
+20%	1611.47 ± 10.62	105.75 ± 9.62	2062.05 ± 9.04	-507.52 ± 10.66	1611.47 ± 10.62
+10%	770.76 ± 10.03	15.58 ± 9.30	975.16 ± 9.42	-302.89 ± 9.84	770.76 ± 10.03
+5%	329.45 ± 9.74	-21.35 ± 9.00	439.42 ± 9.80	-195.96 ± 9.97	329.45 ± 9.74
Default	**-87.35 ± 9.17**				
-5%	-501.15 ± 8.83	-142.39 ± 9.63	-614.44 ± 9.47	11.28 ± 9.38	-501.15 ± 8.83
-10%	-923.86 ± 8.42	-171.06 ± 9.13	-1150.89 ± 9.22	131.12 ± 8.88	-923.86 ± 8.42
-20%	-1796.13 ± 8.41	-276.24 ± 9.88	-2221.75 ± 9.41	359.49 ± 7.78	-1796.13 ± 8.41

[1]Salvage values and weanling price
[2]Salvage values, weanling price, and replacement prices

by 5%; PVNR shifted by 46 (-$420.17) and 49 SE ($446.84) in response to a 20% increase and decrease, respectively, in replacement prices. CONV became profitable with a 5% increase in output prices (revenues) or all pig prices, with output prices causing a larger shift than all pig prices – 57 SE ($526.77) versus 45 SE ($416.80). Increases to weanling price, replacement price, and all pig prices consistently increased SE.

Salvage values had a relatively small impact on PVNR in both barns. Replacement costs had a larger impact on profits; however, even the 5-year high for replacement costs did not render ALT unprofitable when operating optimally. Weanling price had a more severe effect on profits, however, especially in ALT. This barn was equally upward and downward sensitive in response to changes in weanling price, with a 10% decrease (from $34.67 to $31.20 per weanling) resulting in a loss, on average. This sensitivity makes sense since weanling production was the main state variable of the profit model. Since weanling prices are quite volatile, pig production is very risky and producers are extremely vulnerable. CONV was less sensitive to weanling price; in fact, at the 5-year low for weanling price, CONV had fewer losses than ALT. This occurrence was likely due to CONV producing fewer weanlings than ALT. Despite being less sensitive, CONV became profitable with a 5% increase in either weanling price or all pig prices. This should be reassuring to the industry since the last five years were tumultuous with mandatory country-of-origin labeling in the U.S., H1N1 (or 'swine flu'), and the Manitoba hog moratorium battering the hog prices. Thus, it is unlikely to see such unfavourable conditions continue into the next five years.

XIII. Sensitivity of PVNR to Other Economic Shocks

Feed costs were observed to be quite impactful on profitability in ALT (Table 5.13). Increasing feed costs by 20% caused ALT to become unprofitable with a shift of 180 SE (-$805.96); PVNR also shifted by 179 SE ($800.79) with a 20% decrease in feed costs. With market-vulnerable costs containing the cost of feed, they also rendered ALT unprofitable when increased by 20%, shifting by about 265 SE (±$1190) in response to a 20% change. A 20% increase in set costs did not, however, led to ALT becoming unprofitable, only shifting PVNR by 141 SE (-$632.13). A 20% decrease to set costs

Table 5.13. Sensitivity of PVNR (CDN$; mean ± SE) to costs in ALT, ceteris paribus, with terminal cull in 6th period

Sensitivity	Feed costs	Market-vulnerable costs[1]	Set costs[2]
+20%	-51.63 ± 4.74	-436.42 ± 4.69	122.20 ± 5.47
+10%	358.51 ± 4.22	157.53 ± 4.52	439.49 ± 4.89
Default	**754.33 ± 4.48**		
-10%	1154.99 ± 4.53	1350.75 ± 4.15	1063.33 ± 3.97
-20%	1555.12 ± 4.29	1939.86 ± 4.37	1383.53 ± 3.49

[1]Straw, feed, transport and heating costs
[2]Replacement prices, semen cost, and medicine/vaccination costs

caused a similar shift in the opposite direction. These costs had similar impacts on the model in CONV (Table 5.14). A decrease of 10% to feed costs, market-vulnerable costs,

Table 5.14. Sensitivity of PVNR (CDN$; mean ± SE) to costs in CONV, ceteris paribus, with terminal cull in 7th period

Sensitivity	**Feed costs**	**Market-vulnerable costs**[1]	**Set costs**[2]
+20%	-798.22 ± 9.91	-1066.14 ± 9.53	-687.97 ± 11.09
+10%	-450.31 ± 9.70	-595.92 ± 9.77	-377.97 ± 9.85
Default		**-87.35 ± 9.17**	
-10%	285.22 ± 8.98	408.28 ± 9.05	227.97 ± 8.33
-20%	657.55 ± 8.92	912.25 ± 8.76	504.58 ± 8.22

[1] Straw, feed, transport and heating costs
[2]Replacement prices, semen cost, and medicine/vaccination costs

or set costs resulted in CONV becoming profitable. A 20% increase or decrease in feed costs caused PVNR to shift approximately 80 SE (±$720). The same adjustment to market costs shifted PVNR in CONV by about 90 SE (±$1000), while the adjustment to set costs shifted PVNR by only 65 SE (±$600) in response to an increase or decrease. Increases to any of these costs in either barn tended to increase SE.

Costs that were managed by companies – such as semen, replacement gilts, and medications – varied to a lesser extent than market-susceptible costs. This made set costs almost inconsequential in regards to profitability. This may be a market strategy by these companies, since it would not benefit them to make producers run unprofitably; producers must remain in the business to continue purchasing. Of these set costs, gilt cost appeared to be the most impactful, with semen and medication expenses being almost negligible. Profitability responded to a greater extent to varying market-driven costs, such as feed and straw. The high volatility of these costs makes hog producers very vulnerable to exogenous outputs. For example, it only takes a 20% increase in feed to make ALT unprofitable and only a 10% decrease to make CONV profitable. Morin and Theriault (2005) also found feed costs to have quite the impact on profit.

Adjusting the cost of straw was also considered for ALT, but proved to have little impact on the profitability of ALT. Doubling the cost from $12 to $24 per 1500 lb. round-bale resulted in the loss of $530 profit though, i.e., PVNR became $222.33 ± 4.56. If straw was free, ALT would make $1284.64 ± 4.46 per sow, and, if straw cost $6 per round-bale, ALT would make around $1014 per sow space over the 20-year period. Straw would likely have to increase beyond $30 per 1500lb bale to render ALT unprofitable. Since straw likely falls under the default cost of $12 per bale, especially for straw produced on-farm, ALT may be even more profitable than reported. Overall, the model was not very sensitive to the cost of straw.

XIV. Industry Standards

The CONV acted as a close approximation of most other commercial breed-to-wean operations in the Manitoba hog industry. The annual culling rate in CONV was 45%, which coincided closely with the industry standard of 50% (Stalder et al, 2003; Kemp, 2009). In the literature, most real herds had an average herd parity of between 3.1 and 3.7 parities; CONV had an average herd parity of 3.42 parities. The finding that CONV was unprofitable in current market conditions concurred with the fact that commercial pig operations were losing money, on average, in the past 5 years. Using MAFRI (2005-2009) cost-of-production data, the break-even weanling price was found to fall between the default value ($34.67 per head), which was found to be unprofitable, and the 5%-increased value ($36.40 per head), which was found to be profitable. This strongly attests to the model's validity and the application of this experiment's results to the industry.

Rodriguez-Zas et al (2006) believed that producers were acting in an optimal manner. Though this may have been the case in more favourable market conditions, this is unlikely to be the case in the current economic climate. This research discovered that optimal TERM to maximize production occurred earlier than that for optimal profitability. High replacement costs were likely to be the cause of this occurrence. Since Rodriguez-Zas et al (2006) suggested that optimal TERM should occur before the 6^{th} parity, producers are likely too production-focused, and are, in fact, performing TERM before it is financially optimal. Producers would likely benefit from performing TERM later than they would for maximum production, due primarily to the cost of replacement.

The next chapter will bring conclusion to this research by reiterating the main objectives and hypotheses of the work. It will also act to highlight the major findings. This should prove to be insightful for future research and industry direction.

CHAPTER 6. CONCLUSIONS

The last chapter presented the results of this research, including the estimations for the production and culling functions and the simulation model results. The inferences and implications that can be made from these results were then discussed. The chapter continued on to discuss the causal factors that may have induced such findings. The economic results from the simulation models were based upon the past 5 years of market data; however, the sensitivity analyses allowed the researchers to consider how the outcomes would vary with different economic inputs. They also simultaneously tested the robustness of the simulation models. This chapter aims to summarize the entire scope of the research while emphasizing the key findings.

I. Summary of Thesis

The state of the North American pork industry was first considered with emphasis on the specialization of many Manitoba pork producers in weanling production, and the dependence that these producers have on both Canadian and American pork processing. Due to both international demand and expectations from some of the larger North American pork processors, the industry is considering the adoption of group-housing systems for sows. To address the research objectives and hypotheses, a production function, culling function and discrete, dynamic simulation model were formulated. The production function considered the effect of lactation feed (LF) and non-lactating days (NLD) – as a proxy for gestation feed – as well as parity, number of semen doses (AI), and medication treatments (MEDS), on litter weights at weaning (LW). The culling function included variables for parity, body weight (WT), body condition score (BCS), backfat depth (BF), gait score (GS), number of functional teats (FT), and the number of unsuccessful breedings (MISS). Data were collected on 60 and 61 sows in ALT and CONV, respectively, over 7 parities to estimate these functions, with market data to fill in the economic costs and prices of the simulation model.

II. Fulfillment of Objectives

The primary objective of this research was to determine the optimal time in each of the respective barn systems to terminally cull a sow. No difference was expected between the barns in regards to optimal terminal culling (TERM), and both barns were expected to optimally cull beyond 6 parities, likely resulting in a corner solution of 7+ parities. Optimality in ALT was achieved by terminally culling after the 6th parity and before the 7th, while it was achieved in CONV at some point after the 7th parity.

Another main objective was to estimate a production function based on experimental data collected from both farms. This would determine whether differences existed between the alternative barn (ALT) and conventional barn (CONV) in regards to production. The production function estimation was expected to uncover that both parity and feed play a significant role in determining litter weights at weaning. Another prediction was for parity and gait score to have a significantly positive effect on culling probability, and the number of functional teats to have a negative effect. In regards to production, no difference was expected between the barns at the sow-level or the barn-level. Production was proven not to differ between barns at the sow-level, as none of the barn-interaction variables were significant in the production function. However, there was a difference observed at the barn-level, likely due to variations in culling and input usage between barns. The production function did, however, find that parity and LF were the primary determinants of LW; the LW always increased with increasing LF while it increased up to, and decreased beyond, the 3rd parity.

The research was also interested in discovering any differences in culling between ALT and CONV, and to estimate a logistic culling function from experimental data. The culling profiles were expected to vary with more involuntary culls being expected in CONV and more voluntary culls in ALT. The culling function found that parity and GS both increased the probability of culling in both barns. Increasing WT decreased the probability of culling in CONV and FT decreased the probability in ALT. This suggests a difference in culling profiles between the barns; this suggestion was confirmed when considering the periodic culling rates and the respective reasons for culling. The CONV culling occurred in a bi-modal fashion with high, early involuntary culling. The ALT had more voluntary culls with culling increasing gradually across parities. There were expected to be fewer involuntary culls in ALT as compared to CONV, as suggested by Ehlorsson et al (2002). This also proved to be true, with 21% of sows in CONV being culled for physical reasons. Reduced numbers early in CONV, coupled with higher overall culls for physical reasons, suggests a reduction in longevity and welfare.

The final objective of this research was to develop a simulation model that would use these estimations to predict the profitability of each respective housing system, and, in turn, make an economic comparison between the two. Overall, ALT was predicted to be at least as profitable as CONV. This proved to be true; the current market conditions led to ALT being more profitable than CONV, which was, in fact, unprofitable. Culling may have been the biggest contributor to this difference. The herd in CONV exhibited a 21.3% drop in sow numbers by period 4 – constituting a large loss of sows in their most productive parities – as compared to only 6.7% in ALT. The increased turnover and decreased production inevitably caused profitability to decrease. Culling in ALT, conversely, happened mostly in later parities, and lower rates of involuntary culling allowed ALT to cull for herd improvement. Avoiding early culling also enabled ALT sows to survive past their break-even point of 3 parities (Stalder et al, 2003) more often than sows in CONV.

In addition to being more profitable overall than CONV, ALT also involved less risk for purchasing replacements since more sows, on average, made it past their break-even point. The reduced risk makes this housing system better for withstanding economic hardships, thus making it more stable and sustainable. Since producers are often risk-averse (Moschini and Hennessy, 2001), they prefer to avoid high variability. The conventional system proved to be extremely risky for producers with consistent losses and a reasonable probability of extreme losses (e.g., $100 annually per farrowing space). This finding demonstrates the obvious reason as to why producers have been leaving the hog industry (Statistics Canada, 2010a).

III. Major Findings

This research aimed to economically compare two group-housing systems for breed-to-wean sow operations. In accordance, four major findings were discovered in regards to this objective. Firstly, the alternative housing system was more profitable than the conventional system. Secondly, the first finding appears to be a result of differences in culling between the two systems rather than production. Thirdly, as a result of higher production in early parities, sows in the alternative barn were optimally culled from a profitability point-of-view earlier than in the conventional barn. And, fourth and finally, these optimal decisions and the overall difference in profitability between the two barns, as determined by the simulation model, were relatively insensitive to exogenous economic shocks. Based on these findings, the alternative system seems to be the better system – for the producer and for the sow – between the two investigated.

IV. Research & Industry Suggestions

This research and the resulting simulation model could benefit from some slight adjustments. It would be advantageous for industry application to collect data on sows beyond 7 parities. This would likely capture an interior solution for optimal TERM in CONV, and would result in a more detailed suggestion for producers to follow. Another adjustment that relates to increasing the length of data collection would be to avoid culling sows for purely production reasons; this would allow the modeller to make objective culling decisions post-experiment and find optimal criteria for culling. Also, the estimation of the production function would benefit from more accurate measures of gestation feed intake that captures individual variation beyond that observed by different NLD alone. Another suggestion would be to have a more consistent weaning protocol –

with 95% of weaning events occurring within the industry standard of 18-21 days – in attempt to be able to build a production function with the dependent variable being the number of weaned pigs per litter. Considering the variation in individual weanlings would also be beneficial, valuing weanlings under 6 kg at a lesser value than those over 6 kg since it is common practice to discount low-weight weanlings (Philippe, 2009).

It would also be interesting to perform a more-complete risk analysis on the simulation model. To achieve this, all experimental variables would need to be input as stochastic variables. Further, allowing these variables to change with time, i.e., making the model dynamic, would provide more insight into producer risk. The simulation model would also benefit from better estimates of labour for these systems. The default values of labour used in the model – 12 and 14 min/sow/week in CONV and ALT, respectively – likely underestimate the true value for a 600-sow operation using these systems. The current version of the model only allows inferences on breed-to-wean operation around 600 sows in size. Due primarily to economies of scale, no direct inferences can be made on large-scale operations. The relative comparison between the two housing systems would still apply to a reasonable degree, but estimates of profitability are unlikely to be close to the true values. Collecting individual sow data from herds of various sizes would allow for the model to be adapted in order to apply to operations of all sizes. Further, this would enable a solution for optimal operation size to be uncovered. Another suggestion would be to design a simulation model that allows the researcher to find the willingness-to-pay price for better genetics, i.e., the degree of genetic improvement that makes TERM earlier optimal. Genetic improvement could be measured either simply by using litter weights as a measure or, more complexly, by using data from 'superior' sows that have survived through the first few parities.

The final suggestion for future research is to consider the economic costs of building these housing systems or converting pre-existing barns into these systems. The current research only regards the revenues and variable costs of these two systems in relative equilibrium. To get a more accurate estimate of the total true costs of establishing these housing systems, the transitory steps to bring them to these equilibrium stages need to be considered. Producers need the total economic picture before committing to alternative sow housing systems. These research suggestions could all strongly benefit the hog industry, breeders and producers alike.

Specifically concerning the hog industry, the emphasis of breeding programs has been on the efficient production of lean pork, which likely had adverse effects on sow longevity (Stalder et al, 2004). This experiment demonstrated the impact of involuntary culling, i.e., sow longevity, on profitability. New breeding programs that emphasize the selection of enduring sows would be more beneficial to the industry, especially if partial slats were going to continue to be widely used. Overcoming that early check for survivability is crucial to sows regaining their initial investment cost. Group-housing sows on straw appeared to enable sows to pass this check and become profitable investments. However, group-housing can vary greatly in more ways than just housing; housing, feeding systems, and group management can all vary (den Hartog et al, 1993). The many variations of group-housing make comparing the systems difficult. The NCLE swine facilities managed to control most aspects of group-housing except for the housing system. This research suggests that those producers looking to adopt a group-housing system should opt for the alternative system over the conventional system.

REFERENCES

Agriculture and Agri-Food Canada (AAFC). 1993. *Recommended Code of Practice for the Care and Handling of Farm Animals: Pigs.* AAFC: Ottawa, ON.

Agriculture and Agri-Food Canada (AAFC). 2010a. Canada – Exports of pork to Europe, Jan-Dec 2009. Accessed March 22, 2010: http://www.ats-sea.agr.gc.ca/stats/5352-eng.pdf

Agriculture and Agri-Food Canada (AAFC). 2010b. Canada – Exports of pork to United States, Jan-Dec 2009. Accessed March 22, 2010: http://www.ats-sea.agr.gc.ca/stats/4422-eng.pdf

Agriculture and Agri-Food Canada (AAFC). 2010c. Canada's exports to all countries. Accessed March 22, 2010: http://www.ats-sea.agr.gc.ca/stats/5022-eng.pdf

Agriculture and Agri-Food Canada (AAFC). 2010d. Canada's pork and products. Imports from all countries. Accessed March 22, 2010: http://www.ats-sea.agr.gc.ca/stats/5013-eng.pdf

Agriculture and Agri-Food Canada (AAFC). 2010e. Distribution of hog slaughtering activity 2009. Accessed August 24, 2010: http://www.agr.gc.ca/redmeat-vianderouge/rpt/09tbl31_eng.htm

Agri-Mart. 2009. Sales and Marketing. Personal Communication. December 17, 2009.

Alberta Pork. How pigs are raised. Accessed March 1, 2009: http://www.albertapork.com/industry.aspx?NavigationID=1106

Andersen, I. L. and K. E. Bøe. 1999. Straw bedding or concrete floor for loose-housed pregnant sows: Consequences for aggression, production and physical health. *Acta Agric. Scand.* **49**: 190-195.

Backus, G. B. C., H. M. Vermeer, P. F. M. M. Roelofs, P. C. Vesseur, J. A. H. N. Adams, G. P. Binnendijk, J. J. J. Smeets, C. M. C. van der Peet-Schwering, and F. J. van der Wilt. 1997. Comparison study of four housing systems for nonlactating sows. In *ASAE Proceedings of the 5th International Symposium, Livestock, Environment,* Bloomington MN.

Bank of Canada. 2010. 10-year currency converter. Accessed March 22, 2010: http://www.bankofcanada.ca/en/rates/exchform.html

Barnett, J. L., P. H. Hemsworth, G. M. Cronin, E. C. Jongman, and G. D. Hutson. 2001. A review of the welfare issues for sows and piglets in relation to housing. *Aust. J. Agric. Res.* **52**: 1-28.

Brandt, H., N. von Brevern, and P. Glodek. 1999. Factors affecting survival rate of crossbred sows in weaner production. *Livest. Prod. Sci.* **57**: 127-135.

Broom, D. M. 1986. Indicators of poor welfare. *Br. Vet. J.* **142**: 524-526.

Broom, D. M. 1991. Animal welfare: Concepts and measurement. *J. Anim. Sci.* **69**: 4167-4175.

Burt, O. R. 1965. Optimal replacement under risk. *J. Farm Econ.* **47**: 324-346.

Buyoc, M. M. A. 2007. Applied nutrition and feeding management of sows. Accessed August 24, 2010: http://www.swinepro.com/swine-articles/feed-nutrition/applied-nutrition-sows/

Canada Pork International. 2007. The Canadian Pork Story. Accessed June 13, 2010: http://www.ontariopork.on.ca/User/Docs/About/CANPORKSTORYFINAL_003%5B1%5D.pdf

Canadian Agri-Food Research Council (CARC). 2003. *Recommended Code of Practice for the Care and Handling of Farm Animals: Pigs. Addendum: Early Weaned Pigs.* CARC: Ottawa, ON.

Canadian Agri-Food Trade Alliance (CAFTA). 2008. Canada's meat processing sector. Accessed March 1, 2009: www.cafta.org/Download/meat%20processing%20facts%20-%20Jan%202008.pdf

Canadian Council on Animal Care (CCAC). 1993. *Guide to the Care and Use of Experimental Animals, Vol. 1, (2nd Ed.)* CCAC: Ottawa, ON.

Chan, M. 2009. World now at the start of 2009 influenza pandemic. Accessed March 22, 2010: http://www.who.int/mediacentre/news/statements/2009/h1n1_pandemic_phase6_20090611/en/index.html

Conrad, J. M., and C. W. Clark. 1987. *Natural Resource Economics: Notes and Problems.* Cambridge University Press: Cambridge.

Council of the European Union (CEU). 2001. Council Directive 2001/88/EC of 23 October 2001 amending Directive 91/630/EEC laying down minimum standards for the protection of pigs. *Official J. Eur. Communities.* **L316 44**: 1-4.

Crown Copyright. 2003. Statutory instrument 2003 No. 299. The welfare of farmed animals (England) (Amendment) Regulations 2003. Accessed March 22, 2010: http://www.england-legislation.hmso.gov.uk/si/si2003/20030299.htm den Hartog, L. A., G. B. C. Backus, and H. M. Vermeer. 1993. Evaluation of housing systems for sows. *J. Anim. Sci.* **71**: 1339-1344.

Dijkhuizen, A. A., R. S. Morris, and M. Morrow. 1986. Economic optimization of culling strategies in swine breeding herds, using the "PorkChop Computer Program". *Prev. Vet. Med.* **4**: 341-353.

Dourmad, J. Y., M. Etienne, A. Prunier, and J. Noblet. 1994. The effect of energy and protein intake of sows on their longevity: a review. *Livest. Prod. Sci.* **40**: 87-97.

Ehlorsson, C. J., O. Olsson, and N. Lundeheim. 2002. Inventering av klövhälsan hos suggor I olika inhysningsmiljöer [Investigations of housing and environmental factors affecting the claw health in group-housed dry sows]. *Svensk Veterinärtidning*. **54**: 297-304.

Fisher, F. M. 1970. Tests of equality between sets of coefficients in two linear regressions: An expository note. *Econometrica* **37**: 361-366.

Friendship, R. M., M. R. Wilson, G. W. Almond, I. McMillan, R. R. Hacker, R. Pieper, and S. S. Swaminathan. 1986. Sow wastage: Reasons for and effect on productivity. *J. Vet. Res.* **50**: 205-208.

Genesus Inc. 2009. Gilt pricing. Commercial documentation. December 9, 2009.

Gjein, H., and R. B. Larssen. 1995. The effect of claw lesions and claw infections on lameness in loose housing of pregnant sows. *Acta Vet. Scand.* **36**: 451-459.

Greene, W. H. 1997. *Econometric Analysis (3rd Ed.).* Prentice Hall: Upper Saddle River, NJ.

Gregory, N. G. 2007. *Animal Welfare & Meat Production. (2nd Ed..)* CABI: Oxfordshire, England.

Honey, J. 2009. Manitoba pig and pork industry 2008. Accessed March 22, 2010: http://www.umanitoba.ca/afs/agric_economics/staff/Manitobapigandporkprofile2008.pdf

Hurnik, J. F. and H. Lehman. 1988. Ethics and farm animal welfare. *J. Agr. Environ. Ethic.* **1** (4): 305-18.

Jackson, A., T. Thiessen, and G. Johnson. 2006. *Environmental and Economic Impacts of Hogs.* Stella 8 Model. University of Manitoba.

Johnson, D. G. 1950. The nature of the supply function for agricultural products. *Am. Econ. Rev.* **40**: 539-564.

Kelley, K. W., J. J. McGlone, and C. T. Gaskins. 1980. Porcine aggression: Measurement and effects of crowding and fasting. *J. Anim. Sci.* **50**: 336-341.

Kemp, R. 2009. Vice President of Genetic Programs and Research & Development. *Genesus Genetics*. Personal communication. April 10, 2009.

Kennedy, P. 2008. *A Guide to Econometrics (6th Ed.).* Wiley-Blackwell: Somerset, NJ.

Key, N. and W. McBride. 2007. The changing economics of U.S. hog production. Accessed March 1, 2009: http://www.ers.usda.gov/Publications/ERR52/ERR52.pdf

Kristensen, A. R. 1996. *Textbook Notes on Herd Management: Dynamic Programming and Markov Decision Processes*. (Dina notat No. 49). Accessed July 6, 2008: ftp://ftp.dina.kvl.dk/pub/Dina-reports/notatXX.ps

Lawlor, P. G., and P. B. Lynch. 2007. A review of factors influencing litter size in Irish sows. *Irish Vet. J.* **60**: 359-366.

Liao, T. F. 1994. *Interpreting Probability Models: Logit, Probit, and Other Generalized Linear Models*. Sage Publications, Inc.: Thousand Oaks, CA.

Link, J. E. 2009. Mandatory country of origin labeling of beef, pork, lamb, chicken, goat meat, wild and farm-raised fish and shellfish, perishable agricultural commodities, peanuts, pecans, ginseng, and macadamia nuts. *Federal Register.* **74** (10): 2658-2707.

Lucia, Jr., T., G. D. Dial, and W. E. Marsh. 2000. Lifetime reproductive performance in female pigs having distinct reasons for removal. *Livest. Prod. Sci.* **63**: 213-222.

Main, D. C. J., J. Clegg, A. Spatz, and L. E. Green. 2000. Repeatability of a lameness scoring system for finishing pigs. *Vet. Record* **147**: 574-576.

Manitoba Agriculture, Food and Rural Initiatives (MAFRI). 2005. Guidelines for Estimating Swine Farrow-Wean to 5 kg Based on 600 Sows, 13,119 Pigs Sold. Accessed December 7, 2009: http://www.gov.mb.ca/agriculture/financial/farm2005/cac32s00.html

Manitoba Agriculture, Food and Rural Initiatives (MAFRI). 2006. Guidelines for Estimating Swine Farrow-Wean to 5 kg Costs Based on 600 Sows, 13,804 Pigs Sold. Accessed December 7, 2009: http://www.gov.mb.ca/agriculture/financial/farm/pdf/copswinefarrowweanto5kgcosts600sows2006.pdf

Manitoba Agriculture, Food and Rural Initiatives (MAFRI). 2007. Guidelines for Estimating Swine Farrow-Wean to 5 kg Costs Based on 600 Sows, 13,804 Pigs Sold. Accessed December 7, 2009: http://www.gov.mb.ca/agriculture/financial/farm/pdf/copswinefarrowweanto5kgcosts600sows2007.pdf

Manitoba Agriculture, Food and Rural Initiatives (MAFRI). 2008. Guidelines for Estimating Swine Farrow-Wean to 6 kg Costs Based on 600 Sows, 12,957 Pigs Sold. Accessed December 7, 2009: http://www.gov.mb.ca/agriculture/financial/farm/pdf/copswinefarrowweanto5kgcosts600sows2008.pdf

Manitoba Agriculture, Food and Rural Initiatives (MAFRI). 2009. Guidelines for Estimating Swine Farrow-Wean to 6 kg Costs Based on 600 Sows, 12,957 Pigs Sold. Accessed October 20, 2009: http://www.gov.mb.ca/agriculture/financial/farm/pdf/copswinefarrowweancosts2009.pdf

Manitoba Agriculture, Food and Rural Initiatives (MAFRI). 2010a. Livestock Market Report Archives. Accessed January 5, 2010: http://www.gov.mb.ca/agriculture/news/markets/livestock/archive.html

Manitoba Agriculture, Food and Rural Initiatives (MAFRI). 2010b. Manitoba Hay Listing Service. Accessed January 5, 2010: http://web2.gov.mb.ca/agriculture/haysearch/

Manitoba Livestock Manure Management Initiative (MLMMI). 2008. Government legislation and programs. Accessed March 22, 2010: http://www.manure.mb.ca/legislation.php

Manitoba Pork Council (MPC). 2006. How pigs are raised. Accessed March 1, 2009: http://manitobapork.com/uploads/AnimalCare/How_Pigs_are_Raised_Mb.pdf

Maple Leaf Foods, Inc. 2007. Maple Leaf endorses U.S. industry direction on sow stalls. Accessed March 1, 2009: http://investor.mapleleaf.ca/phoenix.zhtml?c=88490&p=irol-newsArticle&ID=956262

Maple Leaf Foods, Inc. 2010. 2009 Annual Report – Financial Review. Accessed March 22, 2010: http://investor.mapleleaf.ca/phoenix.zhtml?c=88490&p=irol-reportsannual

Marchant, J. N. and D. M. Broom. 1996. Effects of dry sow housing conditions on muscle weight and bone strength. *J. Anim. Sci.* **62**: 105-113.

Martin, A. 2007. Burger King shifts policy on animals. Accessed March 22, 2010: http://www.nytimes.com/2007/03/28/business/28burger.html?_r=1

McDonald's. 2006. Animal welfare. Accessed March 22, 2010: http://www.mcdonalds.ca/en/community/animal_principles.aspx

Meat and Livestock Commission (MLC). 2002. Pig Carcase Authentication Service. Accessed March 19, 2009: http://www.mlcsl.co.uk/pdf/Pig%20Carcase%20Authentication.pdf

Mendl, M., A. J. Zanella, and D. M. Broom. Physiological and reproductive correlates of behavioural strategies in female domestic pigs. *Anim. Behav.* **44**: 1107-1121.

Microsoft Corporation. 2006. *Microsoft Office Excel 2007*. Microsoft Corporation: Redmond, WA.

Millar, C. 2009. Producer Services and Logistics Coordinator. *Manitoba Pork Marketing.* Personal communication. December 17, 2009.

Morin, M., and P. Theriault. 2005. Effect of sow longevity on profitability. *Techni-Porc.* **28**: 21-26.

Morris, J. R., J. F. Hurnik, R. M. Friendship, and N. M. Evans.1998. The effect of the Hurnik-Morris (HM) system on sow reproduction, attrition, and longevity. *J. Anim. Sci.* **76**: 2759-2762.

Moschini, G., and D. A. Hennessy. 2001. Chapter 2. Uncertainty, risk aversion, and risk management for agricultural producers. In *Handbook of Agricultural Economics Vol. 1 (1st Ed.).* B. L. Gardner, and G. C. Rausser (Eds.). Elsevier: Amsterdam, Netherlands.

Murray, W. G., D. G. Harris, G. A. Miller, and N. S. Thompson. 1983. Chapter 9. Value by capitalization. *Farm Appraisal and Valuation. (6th Ed.).* The Iowa State University Press: Ames, IA.

National Agriculture Statistics Service (NASS). 2009. Overview of the U.S. hog industry. Accessed March 22, 2010: http://www.gov.mb.ca/agriculture/statistics/pdf/nass_hogs_and_pigs.pdf

National Agriculture Statistics Service (NASS). 2010. United States and Canadian hogs. Accessed March 22, 2010: http://www.gov.mb.ca/agriculture/statistics/pdf/us-can-hogs.pdf

Oldemark LLC. 2010. Wendy's animal welfare program. Accessed March 22, 2010: http://www.wendys.com/community/animal_welfare.jsp

Patience, J. F., P. A. Thacker, and C. F. M. de Lange. 1995. *Swine Nutrition Guide (2nd Ed.).* Prairie Swine Centre, Inc.: Saskatoon, SK.

Philippe, J. 2010. Swine Unit Supervisor. *University of Manitoba, National Centre for Livestock and the Environment (NCLE).* Personal Communication. February 22, 2010.

Pinilla, J. C. and L. Lecznieski. 2010. Parity distribution, management and culling. In *Proceedings: Manitoba Swine Seminar*. **24**: 113-121.

Richmond, B. 2004. *An Introduction to Systems Thinking*. isee systems: Lebanon, NH.

Rodriguez-Zas, S. L., C. B. Davis, P. N. Ellinger, G. D. Schnitkey, N. M. Romine, J. F. Connor, R. V. Knox, and B. R. Southey. 2006. Impact of biological and economic variables on optimal parity for replacement in swine breed-to-wean herds. *J. Anim. Sci.* **84**: 2555-2565.

Rust, J. 1987. Optimal replacement of GMC bus engines: An empirical model of Harold Zurcher. *Econometrica.* **55**: 999-1033.

SAS Institute Inc. 2009. *SAS 9.2 Manual.* SAS Institute Inc.: Cary, NC.

Serenius, T. and K. J. Stalder. 2006. Selection for sow longevity. *J. Anim. Sci.* **84**: E166-E171.

Serenius, T. and K. J. Stalder. 2007. Length of productive life of crossbred sows is affected by farm management, leg conformation, sow's own prolificacy and sow's origin parity and genetics. *Animal*. **1**: 745-750.

Smithfield Foods, Inc. 2007. Landmark gestation stall policy. Accessed March 1, 2009: http://www.smithfieldfoods.com/responsibility/gestation.aspx

Smithfield Foods, Inc. 2008. 2008 Annual Report. Accessed March 22, 2010: http://www.smithfieldfoods.com/annuals.cfm

Stalder, K. J., R. C. Lacy, T. L. Cross, and G. E Conaster. 2003. Financial impact of average parity of culled females in a breed-to-wean swine operation using replacement gilt net present value analysis. *J. Swine Health Prod.* **11**: 69-74.

Stalder, K. J., M. Knauer, T. J. Baas, M. F. Rothschild, and J. W. Mabry. 2004. Sow longevity. *Pig News and Information.* **25**: 53N-74N.

Statistics Canada. 2010a. CANSIM Table 30089 – Hogs statistics, number of farms reporting and average number of hogs per farm, quarterly (Number). Accessed May 3, 2010: http://dc.chass.utoronto.ca.proxy1.lib.umanitoba.ca/cgi-bin/cansimdim/c2_subjects.pl

Statistics Canada. 2010b. Hog statistics. Fourth quarter 2009. Accessed March 22, 2010: http://www.gov.mb.ca/agriculture/statistics/pdf/hogs_stc.pdf

Stevenson, D. 2009. Operations Manager. *Genesus Genetics.* Personal communication. December 7, 2009.

Tummaruk, P., N. Lundeheim, S. Einarsson, and A. –M. Dalin. Reproductive performance of purebred Swedish Landrace and Swedish Yorkshire sows: II. Effect of mating type, weaning-to-first-service interval and lactation length. *Acta Agric. Scand.* **50**: 217-234.

U.S. Department of Agriculture Foreign Agricultural Service (USDA FAS). 2009. EU-27. Livestock and products. EU hosts global conference on trade and farm animal welfare. 2009. Accessed March 3, 2009: www.fas.usda.gov/gainfiles/200902/146327292.pdf

U.S. Department of Agriculture Foreign Agricultural Service (USDA FAS). 2010. Canada. Livestock and products semi-annual. Accessed August 24, 2010: http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Livestock%20and%20Products%20Semi-annual_Ottawa_Canada_3-2-2010.pdf

U.S. Foreign Trade Division (USFTD). 2010. HS 02 – Meat and edible meat offal. 2009 Exports to Europe. Accessed March 22, 2010: http://tse.export.gov/NTDChartDisplay.aspx

Young, L. G., G. J. King, J. Shaw, M. Quinton, J. S. Walton, and I. McMillan. 1991. Interrelationships among age, body weight, backfat and lactation feed intake with reproductive performance and longevity of sows. *Can. J. Anim. Sci.*

APPENDICES

Appendix A. Notation for theoretical equations

$f[\cdot]$ = some function

s. t. = subject to

$V[\cdot]$ = value of system

X = state variable

Y = control variable

t = time

T = terminal time

π = profit function (of entire barn)

π_i = profit

p = price of output (weanlings)

q^i = quantity of output (weanlings) for sow i

c^h = costs of variable input h

x^h = vector of variable inputs

c^j = cost of fixed input j

x^j = vector of fixed inputs

n = number of productive animals in operation

n_0 = initial number of productive animals in operation (i.e., at time 0)

N = capacity of farrowing spaces

σ^i = salvage value of sow i

c^g = cost of replacement gilt and expenses up to breeding weight

δ = discount rate (continuous model)

β^t = discount factor (discrete model) = $1/(1+r)^t$

r = discount rate (discrete model

I = expected income stream from replacement gilt

κ = market capitalization rate

x_p^i = parity of sow i

k^i = binary culling variable for sow i

cd^i = vector of condition variables for sow i

c^{ir} = total cost of sow replacement = $c^g - \sigma^i$

$\mathcal{L}[\cdot]$ = Lagrangian

λ = co-state (auxiliary) variable in Lagrangian and Hamiltonian equations

$F[\cdot]$ = state (movement) equation

$\mathcal{H}[\cdot]$ = continuous-value Hamiltonian

$\widetilde{\mathcal{H}}[\cdot]$ = current-value Hamiltonian

μ = current-value costate variable = $e^{-\delta t} \cdot \lambda$

Burt's model (1965):

$\widetilde{R}$ = conditional expected value of net revenues of asset

c^{Vr} = voluntary replacement cost of asset

c^{Ir} = involuntary replacement cost of asset

φ = probability that asset survives to next period with normal production

w = weighted (compounded) probability of involuntary replacement

θ = net revenue from sow without event of involuntary culling

Appendix B. Stacked time-series data for production function and culling function

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
29	0	1	0	170	3.50	17.0	0.0	5	126	16	70	0	42.9	11	0
31	0	1	0	164	3.50	16.3	0.0	6	129	15	61	0	47.4	10	0
51	0	1	0	178	3.50	16.1	0.0	5	128	15	73	0	34.3	8	0
55	0	1	0	159	3.25	14.4	2.0	3	127	14	81	0	66.7	12	0
57	0	1	0	168	3.13	12.3	0.0	5	127	16	76	0	60.6	11	0
63	0	1	0	190	3.50	15.5	0.7	5	125	14	92	0	57.8	11	0
72	0	1	0	175	3.38	15.3	0.3	5	126	15	78	1	41.6	10	0
81	0	1	0	181	3.25	14.3	0.0	4	127	14	71	0	61.4	11	0
84	0	1	0	170	3.44	16.0	0.0	6	126	13	58	1	55.0	11	0
86	0	1	0	174	3.25	16.3	0.0	5	124	15	74	1	65.5	11	0
94	0	1	0	156	3.44	12.0	0.0	5	125	14	87	0	51.8	11	0
98	0	1	0	175	3.50	15.9	0.0	5	128	14	68	0	53.7	15	0
99	0	1	0	150	3.31	22.2	0.0	5	129	14	65	0	51.7	11	0
102	0	1	0	174	3.38	15.1	0.0	6	129	13	65	0	42.3	10	0
105	0	1	0	156	3.38	12.4	0.0	5	127	14	76	0	53.2	12	0
106	0	1	0	161	3.44	13.1	0.0	5	123	14	104	0	56.4	9	0
115	0	1	0	144	3.13	10.2	2.0	5	126	15	63	0	41.5	10	0
119	0	1	0	154	3.44	13.3	0.0	5	123	14	100	0	66.5	12	0
120	0	1	0	155	3.25	13.0	0.0	5	125	14	67	0	40.6	5	0
121	0	1	0	163	3.50	15.9	0.0	5	127	14	70	0	45.4	9	0
122	0	1	0	149	3.42	16.2	0.0	3	115	15	168	0	0.0	0	0
123	0	1	0	169	3.13	12.7	1.0	5	126	15	89	0	59.5	12	0
125	0	1	0	164	3.44	15.2	0.0	5	125	16	88	1	53.6	9	0
126	0	1	0	146	3.17	12.3	0.0	3	118	15	152	0	0.0	0	0
127	0	1	0	160	3.50	17.5	0.0	5	126	15	81	0	50.5	9	0
128	0	1	0	178	3.44	13.0	0.0	5	124	16	102	0	58.6	12	0
129	0	1	0	172	3.25	11.6	0.0	6	126	14	79	0	44.3	10	0
132	0	1	0	160	3.44	15.1	0.0	5	126	16	78	0	53.2	12	0
133	0	1	0	159	3.17	13.3	0.0	6	125	15	84	0	52.9	10	0
134	0	1	0	164	3.31	13.4	0.0	6	127	16	80	0	58.1	13	0
135	0	1	0	167	3.50	17.1	1.0	3	122	15	87	0	30.5	4	0
136	0	1	0	157	3.44	13.3	0.0	5	124	14	92	0	60.3	11	0
137	0	1	0	159	3.38	14.2	0.3	5	127	14	71	0	50.6	8	0
138	0	1	0	170	3.44	15.1	0.0	5	132	14	38	0	0.0	0	0
139	0	1	0	162	3.31	15.1	0.7	6	128	14	71	1	57.9	10	0
140	0	1	0	149	3.25	14.1	0.0	3	119	13	135	0	0.0	0	0
142	0	1	0	164	3.31	9.8	0.0	5	125	14	90	0	52.5	11	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
144	0	1	0	173	3.38	13.8	0.0	6	125	14	86	0	56.7	10	0
145	0	1	0	163	3.44	12.6	0.7	5	127	15	60	2	47.0	10	0
146	0	1	0	164	3.31	11.2	0.0	5	124	15	96	0	58.4	9	0
149	0	1	0	175	3.38	17.8	1.0	6	125	16	86	0	69.9	10	0
271	0	1	0	170	3.33	15.4	0.0	3	121	15	116	0	76.8	11	0
272	0	1	0	166	3.42	20.6	0.0	3	118	17	128	0	68.5	10	0
273	0	1	0	174	3.44	14.2	0.0	5	123	15	101	0	58.0	9	0
276	0	1	0	146	3.38	16.9	0.7	5	124	14	93	0	43.4	9	0
277	0	1	0	159	3.50	16.1	0.0	3	118	16	139	0	73.4	10	0
279	0	1	0	168	3.33	14.6	0.0	3	128	15	66	0	50.8	10	0
280	0	1	0	150	3.38	20.6	0.0	5	124	15	93	0	41.4	9	0
281	0	1	0	175	3.44	16.4	0.0	5	128	15	66	1	44.0	10	0
283	0	1	0	171	3.42	15.9	0.0	3	121	15	116	0	74.0	11	0
284	0	1	0	161	3.33	15.8	0.0	3	116	16	135	0	80.9	10	0
285	0	1	0	161	3.25	12.9	0.0	5	128	14	71	0	55.3	10	0
286	0	1	0	163	3.50	16.6	0.0	5	128	14	65	0	33.8	9	0
288	0	1	0	178	3.50	19.6	0.0	3	119	16	126	0	48.4	9	0
289	0	1	0	159	3.44	14.7	0.0	5	120	15	119	1	56.5	8	0
294	0	1	0	171	3.44	15.4	0.0	5	121	16	116	0	51.4	8	0
295	0	1	0	167	3.42	14.1	0.0	3	120	15	127	0	57.0	9	0
296	0	1	0	161	3.42	14.6	0.0	3	119	16	126	1	53.4	8	0
297	0	1	0	161	3.38	13.8	0.0	4	122	14	108	0	42.0	8	0
298	0	1	0	154	3.25	11.9	0.0	3	118	14	145	0	74.8	11	0
300	0	1	0	159	3.33	12.9	0.0	3	121	15	122	1	64.3	8	0
29	0	2	1	202	3.33	12.2	0.0	2	123	16	99	0	57.3	10	0
31	0	2	1	208	3.33	14.0	0.5	2	131	15	111	0	53.1	9	0
51	0	2	1	216	3.58	17.1	0.0	2	123	15	127	0	76.5	11	0
55	0	2	1	172	3.50	11.3	0.0	0	35	14	0	0	0.0	0	1
57	0	2	1	209	3.25	12.3	1.3	2	124	15	119	0	69.7	11	0
63	0	2	1	228	3.33	12.9	0.0	3	123	12	138	0	72.1	11	0
72	0	2	1	217	3.25	15.2	0.0	3	123	16	129	0	62.2	11	0
81	0	2	1	212	3.50	16.2	0.3	2	143	14	0	0	0.0	0	0
84	0	2	1	205	3.42	17.2	0.0	0	121	13	92	1	66.7	10	1
86	0	2	1	215	3.25	19.4	0.0	2	125	15	121	0	74.9	11	0
94	0	2	1	184	3.50	13.2	0.0	2	143	14	0	1	0.0	0	0
98	0	2	1	208	3.50	15.2	0.0	2	123	14	125	0	66.6	11	0
99	0	2	1	195	3.50	23.6	0.0	2	124	15	109	0	66.2	10	0
102	0	2	1	212	3.50	13.3	0.0	2	122	13	130	0	59.6	9	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
105	0	2	1	202	3.33	12.4	0.0	2	122	14	147	0	67.0	10	0
106	0	2	1	203	3.42	19.4	0.0	2	123	14	134	0	78.4	11	0
115	0	2	1	188	3.25	12.9	2.0	3	123	15	104	0	54.7	11	0
119	0	2	1	198	3.42	14.1	0.0	2	127	14	100	0	54.6	11	0
120	0	2	1	207	3.25	14.1	0.0	2	125	14	106	0	77.1	11	0
121	0	2	1	218	3.50	15.6	0.0	2	119	14	157	0	91.6	11	0
122	0	2	0	198	3.33	16.1	0.0	2	123	15	117	0	159.3	18	0
123	0	2	1	183	3.00	13.1	3.0	0	60	15	0	0	0.0	0	1
125	0	2	1	180	3.19	14.4	0.5	2	112	16	0	1	0.0	0	1
126	0	2	0	165	3.25	9.0	0.0	0	43	15	39	1	111.9	13	1
127	0	2	1	215	3.42	20.1	0.0	2	119	15	149	0	85.0	10	0
128	0	2	1	217	3.44	14.9	0.0	2	124	16	120	1	66.3	10	0
129	0	2	1	204	3.25	12.3	1.0	2	143	14	0	3	0.0	0	0
132	0	2	1	206	3.33	16.0	0.0	2	127	14	74	0	53.3	10	0
133	0	2	1	219	3.17	15.1	0.0	2	125	15	101	0	55.4	10	0
134	0	2	1	216	3.25	16.1	0.0	2	124	16	113	0	65.9	10	0
135	0	2	1	194	3.44	20.5	0.5	2	143	15	0	1	0.0	0	0
136	0	2	1	205	3.42	16.8	0.0	2	125	14	117	1	55.1	8	0
137	0	2	1	210	3.33	14.3	0.0	3	125	14	107	0	74.2	10	0
138	0	2	1	228	3.50	19.7	0.0	0	126	14	87	0	48.2	8	0
139	0	2	1	214	3.25	16.7	0.0	3	124	14	116	0	65.3	8	0
140	0	2	0	171	3.25	11.0	0.0	3	140	13	28	0	107.5	11	0
142	0	2	1	228	3.33	14.2	0.0	2	126	15	124	0	68.8	11	0
144	0	2	1	229	3.42	14.2	0.0	2	126	12	157	0	67.5	11	0
145	0	2	1	194	3.17	9.9	2.0	2	124	15	106	2	63.9	10	0
146	0	2	1	211	3.25	14.1	0.0	2	118	15	151	0	80.4	10	0
149	0	2	1	224	3.42	18.4	0.0	2	124	16	126	0	76.9	11	0
271	0	2	1	200	3.33	15.1	0.0	2	127	15	85	0	62.6	10	0
272	0	2	1	208	3.44	18.1	0.0	6	123	17	116	0	71.4	11	0
273	0	2	1	225	3.33	17.3	0.0	2	124	15	123	0	77.0	10	0
276	0	2	1	183	3.38	21.4	0.0	2	123	14	123	0	79.8	11	0
277	0	2	1	194	3.33	18.0	0.0	2	125	16	112	1	47.7	7	0
279	0	2	1	192	3.50	14.6	0.0	0	33	15	0	0	0.0	0	1
280	0	2	1	216	3.63	24.4	0.0	0	125	15	114	0	65.8	10	0
281	0	2	1	230	3.33	20.4	0.0	3	124	15	131	0	77.4	11	0
283	0	2	1	212	3.44	18.0	0.0	4	127	14	95	0	48.4	10	0
284	0	2	1	189	3.50	16.4	0.0	0	42	16	0	0	0.0	0	1
285	0	2	1	208	3.42	15.4	0.0	2	124	13	127	0	80.5	11	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
286	0	2	1	221	3.50	22.0	0.0	2	121	13	135	0	72.8	10	0
288	0	2	1	189	3.50	14.6	0.0	2	109	16	0	1	0.0	0	1
289	0	2	1	193	3.50	17.3	0.0	3	127	14	100	0	60.6	10	0
294	0	2	1	214	3.38	17.3	0.0	2	124	14	130	0	71.4	10	0
295	0	2	1	208	3.50	14.7	0.0	4	122	15	139	0	73.0	11	0
296	0	2	1	214	3.50	18.2	0.0	4	123	14	121	0	72.9	11	0
297	0	2	1	217	3.42	18.3	0.5	2	123	14	136	0	75.5	11	0
298	0	2	1	177	3.25	10.7	3.0	0	41	14	0	1	0.0	0	1
300	0	2	1	202	3.31	13.6	0.0	4	124	15	129	0	76.5	10	0
29	0	3	2	241	3.38	20.3	0.0	0	125	16	118	0	56.3	10	0
31	0	3	2	238	3.50	18.8	0.5	2	123	15	137	1	66.3	8	0
51	0	3	2	255	3.50	21.9	0.0	2	124	15	100	0	51.0	6	0
57	0	3	2	216	3.42	14.1	1.0	2	143	15	0	1	0.0	0	1
63	0	3	2	268	3.42	19.0	0.0	2	126	13	95	0	73.0	12	0
72	0	3	2	259	3.42	23.1	0.5	2	122	16	133	0	82.4	12	0
81	0	3	1	256	3.42	19.4	0.0	3	127	12	114	1	83.9	12	0
86	0	3	2	264	3.50	35.5	0.0	2	125	15	112	0	83.6	12	0
94	0	3	1	212	3.38	11.3	0.3	2	125	14	103	0	66.9	11	0
98	0	3	2	248	3.58	21.2	0.0	2	125	14	121	0	70.0	10	0
99	0	3	2	240	3.63	31.6	0.0	0	124	15	111	1	68.3	10	0
102	0	3	2	257	3.33	20.0	0.0	2	125	13	101	0	52.8	10	0
105	0	3	2	241	3.42	20.4	0.0	3	125	14	116	0	57.7	10	0
106	0	3	2	253	3.50	29.6	0.0	1	126	14	106	0	68.9	10	0
115	0	3	2	224	3.42	15.8	2.0	2	124	15	86	1	57.3	10	0
119	0	3	2	244	3.50	22.6	0.0	3	122	14	142	0	74.5	10	0
120	0	3	2	244	3.42	23.2	0.0	1	125	14	102	0	76.8	10	0
121	0	3	2	261	3.50	27.8	0.5	2	126	14	98	0	72.6	11	0
122	0	3	2	229	3.25	22.0	0.0	2	122	15	118	0	85.2	10	0
127	0	3	2	259	3.50	28.5	0.0	0	124	15	98	0	83.3	11	0
128	0	3	2	249	3.50	26.2	0.0	3	143	16	0	0	0.0	0	0
129	0	3	1	288	3.25	15.1	.	0	127	14	102	2	59.3	11	0
132	0	3	2	240	3.42	26.7	0.5	2	125	16	57	1	54.4	10	0
133	0	3	2	242	3.25	13.6	2.0	2	139	15	0	1	0.0	0	1
134	0	3	2	250	3.42	22.5	0.5	3	119	16	112	0	69.7	12	0
135	0	3	1	255	3.42	21.9	1.5	2	122	15	109	2	64.9	10	0
136	0	3	2	250	3.50	23.9	0.0	3	124	14	97	1	57.1	9	0
137	0	3	2	239	3.42	21.7	0.0	2	123	14	107	0	83.7	11	0
138	0	3	2	.	3.25	18.5	0.0	0	32	14	0	0	0.0	0	1

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
139	0	3	2	241	3.33	21.2	0.0	0	113	14	0	3	52.8	8	1
140	0	3	1	266	3.50	18.0	0.0	3	142	13	4	0	0.0	0	0
142	0	3	2	270	3.33	17.7	0.0	3	124	16	117	0	68.6	11	0
144	0	3	2	289	3.42	22.9	0.0	2	124	14	104	0	67.8	9	0
145	0	3	2	209	3.17	13.0	1.0	3	123	16	115	0	69.2	11	0
146	0	3	2	260	3.50	19.3	0.0	2	118	15	141	0	71.2	12	0
149	0	3	2	277	3.50	26.4	0.5	2	126	16	101	0	70.9	11	0
271	0	3	2	227	3.38	20.5	0.3	4	143	15	0	0	0.0	0	0
272	0	3	2	248	3.42	24.0	0.0	3	123	17	102	0	69.8	12	0
273	0	3	2	269	3.42	21.7	0.5	3	123	14	91	0	68.0	9	0
276	0	3	2	217	3.50	25.5	1.5	2	121	14	122	0	77.6	10	0
277	0	3	2	252	3.58	28.6	0.5	3	122	16	98	2	90.2	12	0
280	0	3	2	221	3.42	31.7	0.5	2	125	15	99	0	63.2	12	0
281	0	3	2	268	3.42	28.0	0.0	2	124	15	113	0	80.0	12	0
283	0	3	2	269	3.58	26.6	0.0	2	124	14	109	0	76.2	10	0
285	0	3	2	246	3.50	23.3	0.0	2	123	13	125	0	72.4	10	0
286	0	3	2	230	3.50	25.3	0.0	2	143	13	0	0	0.0	0	0
289	0	3	2	227	3.38	22.5	0.0	3	123	15	120	0	83.6	11	0
294	0	3	2	272	3.50	27.0	0.5	2	123	14	121	0	65.1	9	0
295	0	3	2	262	3.42	20.3	1.0	3	124	15	105	0	67.8	12	0
296	0	3	2	275	3.67	25.9	0.0	3	123	14	110	0	76.6	13	0
297	0	3	2	238	3.50	22.0	0.0	3	122	14	133	0	79.8	12	0
300	0	3	2	269	3.42	22.0	0.0	2	124	15	108	0	81.2	13	0
29	0	4	3	267	3.42	18.8	0.0	2	124	16	109	0	58.7	11	0
31	0	4	3	268	3.25	19.9	0.0	2	118	15	144	0	93.1	10	0
51	0	4	3	284	3.42	25.5	0.0	3	118	15	99	1	81.5	11	0
63	0	4	3	257	3.38	22.9	1.5	0	111	13	0	3	0.0	0	1
72	0	4	3	280	3.50	22.1	0.0	3	119	14	131	0	80.5	11	0
81	0	4	2	281	3.42	23.1	0.5	3	124	12	113	0	72.3	11	0
86	0	4	3	288	3.58	41.0	0.0	3	123	15	109	0	76.9	11	0
94	0	4	2	252	3.50	14.5	0.0	2	126	14	85	0	59.7	11	0
98	0	4	3	283	3.50	26.2	0.0	2	125	14	73	0	97.6	18	0
99	0	4	3	237	3.50	31.1	0.0	0	17	15	0	0	0.0	0	1
102	0	4	3	284	3.33	23.3	0.0	3	124	13	75	1	54.4	12	0
105	0	4	3	275	3.33	20.1	0.0	3	123	14	117	0	70.2	11	0
106	0	4	3	291	3.58	37.0	0.0	3	124	14	101	0	70.3	10	0
115	0	4	3	240	3.17	18.1	2.5	3	124	15	80	0	64.2	12	0
119	0	4	3	290	3.58	29.5	0.0	3	121	14	127	0	75.2	10	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
120	0	4	3	267	3.50	26.8	0.0	2	143	14	0	0	0.0	0	0
121	0	4	3	291	3.58	28.1	0.0	2	123	14	79	0	74.3	10	0
122	0	4	3	264	3.50	27.1	0.0	2	125	15	95	1	88.2	11	0
127	0	4	3	262	3.58	26.4	0.0	2	128	15	75	0	0.0	0	0
128	0	4	2	283	3.58	23.9	0.0	2	127	16	71	0	60.0	12	0
129	0	4	2	279	3.50	19.4	2.0	0	14	14	0	2	0.0	0	1
132	0	4	3	258	3.42	25.1	1.0	2	123	16	109	0	66.0	10	0
134	0	4	3	277	3.42	24.4	0.0	2	123	16	107	0	76.2	11	0
135	0	4	2	237	3.25	21.4	1.0	0	102	15	81	3	67.8	10	1
136	0	4	3	282	3.58	28.4	0.0	2	124	14	75	1	65.8	10	0
137	0	4	3	271	3.33	20.5	0.0	3	122	14	119	0	94.7	10	0
140	0	4	1	263	3.50	15.9	1.0	2	118	11	143	1	69.3	12	0
142	0	4	3	325	3.50	21.2	0.0	0	124	15	103	0	39.4	8	0
144	0	4	3	321	3.58	25.4	0.0	3	123	14	109	0	74.7	11	0
145	0	4	3	243	3.25	.	0.0	0	120	16	143	1	85.6	10	0
146	0	4	3	282	3.33	23.3	1.5	3	124	15	93	0	78.7	11	0
149	0	4	3	299	3.58	28.7	0.0	2	121	16	87	0	88.4	10	0
271	0	4	2	269	3.33	22.6	0.5	2	123	15	120	0	62.1	9	0
272	0	4	3	257	3.33	23.6	0.0	2	124	16	102	0	63.6	8	0
273	0	4	3	286	3.50	25.4	0.0	2	125	15	85	1	62.3	8	0
276	0	4	3	261	3.50	29.9	0.0	2	121	14	121	0	61.0	9	0
277	0	4	3	253	3.33	21.7	0.0	3	139	16	12	0	0.0	0	0
280	0	4	3	249	3.50	25.8	0.0	5	143	15	0	0	0.0	0	0
281	0	4	3	298	3.58	31.3	0.0	2	123	15	111	0	55.9	9	0
283	0	4	3	290	3.58	28.0	0.0	2	125	15	94	0	54.7	8	0
285	0	4	3	267	3.50	24.6	0.0	2	126	14	88	0	58.4	10	0
286	0	4	2	267	3.58	24.8	0.0	2	121	14	128	0	68.8	11	0
289	0	4	3	271	3.50	27.1	0.0	2	123	15	86	1	61.6	8	0
294	0	4	3	293	3.50	26.8	0.0	2	123	14	107	0	58.7	8	0
295	0	4	3	271	3.50	23.8	0.0	3	125	15	86	0	67.8	9	0
296	0	4	3	285	3.67	27.5	0.0	2	143	14	0	0	0.0	0	0
297	0	4	3	267	3.50	27.5	0.0	3	143	14	0	0	0.0	0	0
300	0	4	3	290	3.33	25.8	0.0	3	124	15	103	0	71.2	8	0
29	0	5	4	288	3.50	20.0	0.0	2	125	16	91	0	50.3	9	0
31	0	5	4	266	3.25	21.2	0.0	3	126	15	88	0	75.6	12	0
51	0	5	4	289	3.42	25.2	0.0	3	126	15	70	0	71.8	12	0
72	0	5	4	265	3.25	19.9	0.0	3	122	15	99	0	54.3	9	0
81	0	5	3	230	2.88	18.8	0.0	3	122	12	85	1	50.9	9	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
86	0	5	4	290	3.58	43.0	0.0	0	107	15	80	0	61.0	10	1
94	0	5	3	257	3.17	15.6	0.0	2	124	14	103	0	70.4	11	0
98	0	5	4	306	3.63	25.5	0.0	0	125	14	71	0	61.8	12	0
102	0	5	4	285	3.50	19.0	0.0	2	126	13	88	0	40.4	10	0
105	0	5	4	289	3.38	26.1	0.0	2	126	14	88	0	62.4	12	0
106	0	5	4	293	3.50	35.9	0.0	0	36	14	0	2	0.0	0	1
115	0	5	4	247	3.25	16.8	2.0	3	123	15	94	0	51.5	9	0
119	0	5	4	287	3.50	28.7	0.0	2	122	14	81	0	65.6	12	0
120	0	5	3	274	3.25	27.1	0.0	2	124	14	101	0	76.9	12	0
121	0	5	4	274	3.50	25.1	0.0	2	124	14	81	0	68.7	10	0
122	0	5	4	274	3.50	31.2	0.0	5	125	15	95	0	62.6	10	0
127	0	5	3	273	3.50	28.2	0.0	2	122	15	114	1	79.5	11	0
128	0	5	3	269	3.50	24.2	0.0	2	143	16	0	0	0.0	0	0
132	0	5	4	254	3.33	23.8	0.0	3	126	16	69	3	45.7	9	0
134	0	5	4	299	3.50	29.4	0.0	0	124	16	72	1	71.7	11	0
136	0	5	4	290	3.58	30.6	0.0	3	122	14	86	0	63.2	9	0
137	0	5	4	281	3.33	22.0	0.0	3	124	14	87	0	57.3	7	0
140	0	5	2	287	3.50	23.5	0.0	2	120	11	134	0	65.5	9	0
142	0	5	4	306	3.33	22.1	0.0	3	126	15	88	0	0.0	0	0
144	0	5	4	325	3.58	24.8	0.0	3	124	12	82	0	45.1	8	0
145	0	5	4	234	3.00	13.3	0.0	0	21	16	0	0	0.0	0	1
146	0	5	4	290	3.42	18.0	0.5	3	124	14	104	0	79.5	11	0
149	0	5	4	287	3.50	29.5	0.0	2	143	16	0	0	0.0	0	0
271	0	5	3	162	3.42	18.8	0.0	3	125	15	97	0	72.4	11	0
272	0	5	4	267	3.42	27.8	0.0	2	132	16	49	0	0.0	0	0
273	0	5	4	293	3.33	25.0	0.0	3	122	15	98	0	81.5	11	0
276	0	5	4	249	3.38	25.1	1.5	2	121	14	112	0	70.6	11	0
277	0	5	3	243	3.33	31.8	0.0	3	118	16	131	1	58.0	10	0
280	0	5	3	287	3.58	33.8	0.0	2	122	15	90	0	77.3	10	0
281	0	5	4	305	3.50	28.3	0.0	2	119	15	145	0	88.1	11	0
283	0	5	4	293	3.50	28.9	0.0	2	125	15	76	0	67.8	11	0
285	0	5	4	269	3.42	26.7	0.0	3	121	14	131	0	83.4	11	0
286	0	5	3	272	3.50	25.8	0.0	2	124	13	77	0	53.0	10	0
289	0	5	4	276	3.42	28.5	0.0	3	119	15	115	0	109.1	12	0
294	0	5	4	308	3.42	26.1	0.0	3	121	14	102	0	60.1	9	0
295	0	5	4	274	3.50	19.7	0.0	3	121	15	127	0	83.4	12	0
296	0	5	3	288	3.50	27.2	0.0	2	123	14	110	0	79.5	12	0
297	0	5	3	284	3.58	27.4	0.0	3	125	14	95	0	63.9	9	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
300	0	5	4	294	3.42	25.9	0.0	3	123	15	114	1	73.0	11	0
29	0	6	5	276	3.50	22.8	0.0	5	143	16	0	0	0.0	0	0
31	0	6	5	282	3.58	23.5	1.0	5	125	15	95	0	62.0	9	0
51	0	6	5	293	3.50	22.4	0.0	2	123	15	90	0	68.5	11	0
72	0	6	5	293	3.44	29.3	0.7	3	143	15	7	0	0.0	0	0
81	0	6	4	269	3.25	19.9	0.0	3	126	12	88	0	55.6	9	0
94	0	6	4	267	3.42	18.1	0.0	3	121	14	123	1	67.3	10	0
98	0	6	5	271	3.50	25.9	0.0	4	143	14	0	1	0.0	0	0
102	0	6	5	283	3.42	19.3	1.5	3	125	13	87	0	51.3	11	0
105	0	6	5	291	3.42	24.2	0.0	3	121	14	127	0	84.6	13	0
115	0	6	5	244	3.33	15.4	1.5	0	109	15	86	1	62.9	12	1
119	0	6	5	274	3.42	27.7	0.0	2	70	14	0	0	0.0	0	1
120	0	6	4	291	3.33	29.5	0.0	3	121	14	127	0	83.4	10	0
121	0	6	5	304	3.67	30.0	0.0	2	120	14	90	0	66.5	9	0
122	0	6	5	270	3.50	33.5	0.0	2	128	15	71	0	57.0	11	0
127	0	6	4	287	3.58	32.4	0.0	2	121	15	98	1	80.2	11	0
128	0	6	3	301	3.42	25.9	0.0	3	124	16	112	0	63.7	12	0
132	0	6	5	275	3.33	30.0	1.5	2	120	16	98	0	54.3	9	0
134	0	6	5	294	3.33	25.2	1.0	3	125	16	68	1	67.0	12	0
136	0	6	5	290	3.50	29.1	0.0	3	121	14	89	1	48.6	8	0
137	0	6	5	285	3.42	21.1	0.0	3	124	14	129	0	76.1	10	0
140	0	6	3	303	3.42	20.6	0.5	3	120	11	91	0	53.0	9	0
142	0	6	4	281	3.50	18.1	0.0	0	1	15	31	0	50.5	8	1
144	0	6	5	332	3.50	29.2	0.0	3	120	12	122	0	87.0	12	0
146	0	6	5	289	3.33	19.9	0.5	3	119	14	115	0	65.6	10	0
149	0	6	4	327	3.50	30.1	0.0	2	125	16	71	0	53.8	10	0
271	0	6	4	264	3.50	21.8	0.0	2	143	15	0	0	0.0	0	0
272	0	6	4	269	3.50	27.1	0.0	3	121	16	113	0	80.1	12	0
273	0	6	5	311	3.42	26.5	0.0	3	128	15	53	0	52.7	9	0
276	0	6	5	263	3.38	23.3	0.0	3	119	14	71	0	82.4	12	0
277	0	6	4	264	3.31	25.6	0.0	2	107	16	143	1	69.6	11	1
280	0	6	4	286	3.50	33.6	1.3	2	143	15	0	0	0.0	0	0
281	0	6	5	323	3.50	30.8	1.0	3	143	15	65	1	57.5	10	0
283	0	6	5	311	3.58	30.0	0.0	0	107	15	63	1	50.2	10	1
285	0	6	5	292	3.42	29.0	0.0	3	125	14	95	0	46.5	7	0
286	0	6	4	289	3.67	27.8	0.0	2	117	13	102	0	46.3	11	0
289	0	6	5	290	3.33	25.6	0.0	0	101	15	63	0	40.0	7	1
294	0	6	5	323	3.58	27.1	0.0	3	125	14	72	0	52.4	8	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
295	0	6	5	285	3.42	23.6	0.0	3	124	15	94	0	48.8	9	0
296	0	6	4	299	3.50	25.7	0.0	2	122	14	91	0	59.8	10	0
297	0	6	4	294	3.50	27.0	0.0	2	121	14	115	0	70.7	11	0
300	0	6	5	310	3.42	27.7	0.0	3	124	15	75	0	70.0	10	0
29	0	7	5	317	3.63	24.6	0.0	0	74	16	69	0	47.1	7	1
31	0	7	6	282	3.50	26.4	0.0	0	116	15	0	0	0.0	0	1
51	0	7	6	279	3.50	21.2	0.0	0	31	15	0	0	0.0	0	1
72	0	7	5	311	3.50	27.2	0.0	0	82	15	64	0	50.5	9	1
81	0	7	5	295	3.38	20.8	0.0	0	80	12	67	1	53.5	10	1
94	0	7	5	289	3.58	21.6	0.0	2	122	14	107	0	61.4	10	0
98	0	7	5	301	3.58	25.1	0.0	2	124	14	75	0	57.3	10	0
102	0	7	6	258	3.25	17.2	3.0	0	40	13	0	5	0.0	0	1
105	0	7	6	307	3.50	26.2	0.0	0	82	14	121	2	65.2	10	1
120	0	7	5	299	3.50	29.9	0.0	1	120	14	97	0	83.9	10	0
121	0	7	6	287	3.50	30.7	0.7	2	143	14	0	0	0.0	0	0
122	0	7	6	313	3.58	37.5	0.0	0	109	15	72	0	71.5	11	1
127	0	7	6	286	3.50	32.2	0.0	5	91	15	0	0	58.3	8	1
128	0	7	4	318	3.50	26.8	0.0	3	126	16	64	0	56.2	10	0
132	0	7	6	292	3.42	28.3	2.0	0	106	16	76	1	55.1	10	1
134	0	7	6	297	3.44	22.5	0.0	3	118	16	69	1	53.3	9	1
136	0	7	6	307	3.58	33.0	0.0	0	104	14	71	1	29.1	5	1
137	0	7	6	290	3.50	22.2	0.0	0	94	14	90	1	56.2	7	1
140	0	7	4	304	3.50	21.4	0.0	3	137	11	108	0	102.0	18	1
144	0	7	6	343	3.50	26.1	0.5	0	101	12	63	0	64.4	11	1
146	0	7	6	300	3.42	21.7	1.0	0	103	14	79	0	62.0	10	1
149	0	7	5	332	3.63	30.5	0.0	0	81	16	73	0	74.2	10	1
271	0	7	4	301	3.38	22.1	0.0	0	39	15	110	0	62.5	8	1
272	0	7	5	249	3.25	22.5	1.0	5	42	16	36	1	67.8	10	1
273	0	7	6	300	3.50	25.4	0.0	0	95	15	75	0	42.4	8	1
276	0	7	6	268	3.50	27.1	0.5	0	93	14	73	0	61.7	11	1
280	0	7	4	321	3.63	29.4	2.0	0	38	15	70	0	53.5	10	1
281	0	7	6	317	3.50	27.2	0.0	0	93	15	93	0	46.1	6	1
285	0	7	6	289	3.42	24.3	0.0	0	99	14	96	2	76.9	10	1
286	0	7	5	310	3.75	29.0	0.0	0	11	13	48	0	0.0	0	1
294	0	7	6	307	3.58	28.4	0.0	0	94	14	83	0	41.8	8	1
295	0	7	6	298	3.50	20.8	0.0	0	106	15	92	0	56.8	9	1
296	0	7	5	303	3.50	20.9	0.0	0	70	14	85	0	63.1	11	1
297	0	7	5	271	3.38	26.0	0.0	0	77	14	83	0	78.8	11	1

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
300	0	7	6	308	3.50	24.8	0.0	0	103	15	97	0	72.2	8	1
94	0	8	6	292.5	3.63	21.7	0.0	0	61	14	108	0	67.5	11	1
98	0	8	6	315	3.63	25.1	0.0	0	41	14	67	1	69.6	13	1
120	0	8	6	318.5	3.50	29.1	0.0	0	55	14	122	0	62.5	10	1
121	0	8	6	290	3.50	32.0	0.0	0	12	14	0	0	0.0	0	1
128	0	8	5	294	3.50	23.8	0.0	0	1	16	72	0	50.3	8	1
2	1	1	0	180	3.50	24.9	0.0	3	127	15	75	0	53.5	12	0
5	1	1	0	183	3.50	17.8	0.0	4	124	14	97	0	79.8	14	0
14	1	1	0	166	3.44	14.3	0.0	5	124	14	93	0	52.2	9	0
23	1	1	0	173	3.31	16.7	0.0	5	125	14	86	0	64.2	12	0
25	1	1	0	175	3.38	16.5	0.0	5	127	13	64	0	37.7	9	0
68	1	1	0	154	3.38	12.6	0.0	5	124	14	93	0	46.9	9	0
70	1	1	0	153	3.31	16.9	0.0	5	125	16	90	0	53.1	14	0
76	1	1	0	157	3.31	18.5	0.0	5	123	14	103	0	69.8	12	0
89	1	1	0	165	3.31	13.9	0.0	6	126	16	79	0	43.1	8	0
151	1	1	0	153	3.50	16.8	0.0	5	125	13	85	0	45.5	6	0
153	1	1	0	146	3.42	15.1	0.0	3	117	14	147	0	0.0	0	0
155	1	1	0	142	3.38	12.5	0.0	6	125	16	86	0	59.2	10	0
157	1	1	0	115	3.25	12.9	0.0	3	119	15	127	0	64.4	9	0
158	1	1	0	150	3.33	17.4	0.0	3	123	15	105	0	70.6	12	0
159	1	1	0	153	3.38	11.2	1.3	5	125	14	83	0	62.4	11	0
160	1	1	0	165	3.42	17.8	0.0	5	128	14	61	0	51.7	10	0
162	1	1	0	152	3.33	14.2	0.0	3	116	13	133	0	0.0	0	0
163	1	1	0	160	3.31	11.0	0.0	6	124	14	113	0	56.4	9	0
165	1	1	0	162	3.31	16.8	0.0	5	127	14	70	0	18.9	3	0
166	1	1	0	161	3.38	14.2	0.0	6	126	14	71	0	69.4	12	0
167	1	1	0	147	3.31	11.1	2.0	5	125	15	81	1	56.3	10	0
168	1	1	0	151	3.25	13.4	0.0	6	124	13	94	0	35.3	6	0
169	1	1	0	134	3.25	13.8	0.0	3	117	14	138	0	0.0	0	0
170	1	1	0	153	3.38	15.4	1.0	6	126	15	81	0	57.6	11	0
171	1	1	0	149	3.33	12.5	0.0	4	117	16	134	0	0.0	0	0
174	1	1	0	176	3.38	15.3	0.0	5	125	16	83	0	61.8	11	0
175	1	1	0	157	3.44	20.2	0.0	6	123	15	108	0	62.1	10	0
176	1	1	0	138	3.33	14.6	0.0	3	118	13	131	0	0.0	0	0
178	1	1	0	160	3.38	16.7	0.0	6	127	15	72	0	52.9	10	0
179	1	1	0	150	3.33	21.8	0.0	3	127	15	75	0	55.9	12	0
180	1	1	0	164	3.33	13.8	0.0	3	116	14	138	0	0.0	0	0
181	1	1	0	169	3.33	15.2	0.5	3	122	16	111	0	77.3	12	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
182	1	1	0	173	3.44	17.4	0.0	5	123	17	95	0	41.3	9	0
185	1	1	0	162	3.31	16.3	0.0	6	122	14	103	0	54.4	8	0
192	1	1	0	167	3.50	16.6	0.0	6	121	15	114	0	65.1	9	0
201	1	1	0	162	3.38	16.9	0.0	5	122	15	107	0	44.5	7	0
203	1	1	0	149	3.38	14.2	0.0	6	122	14	103	0	57.4	12	0
204	1	1	0	165	3.44	15.4	0.3	6	125	14	84	0	56.4	11	0
207	1	1	0	151	3.33	15.5	0.0	3	122	14	108	0	77.5	12	0
209	1	1	0	148	3.25	14.3	0.0	3	123	14	99	0	45.0	8	0
241	1	1	0	183	3.44	17.5	0.0	6	123	14	104	0	71.4	11	0
242	1	1	0	169	3.42	16.4	0.0	3	119	14	126	0	50.9	6	0
246	1	1	0	140	3.33	13.5	0.0	3	120	16	141	0	79.6	11	0
247	1	1	0	174	3.42	15.7	0.0	3	123	16	101	0	65.8	11	0
248	1	1	0	168	3.31	17.5	0.0	5	127	14	73	0	42.9	10	0
249	1	1	0	144	3.31	15.9	0.0	5	125	14	87	0	50.2	8	0
250	1	1	0	169	3.19	13.8	0.7	5	122	14	111	0	82.9	12	0
251	1	1	0	171	3.25	14.7	0.0	6	122	14	108	0	58.9	11	0
252	1	1	0	157	3.42	25.1	0.0	3	121	16	109	0	65.3	10	0
254	1	1	0	163	3.44	17.1	0.0	5	125	16	74	0	44.0	8	0
255	1	1	0	174	3.50	22.5	1.0	3	123	14	99	0	55.0	10	0
256	1	1	0	159	3.25	15.6	0.0	3	120	16	119	0	42.6	5	0
257	1	1	0	146	3.33	13.8	0.0	3	120	14	126	0	72.6	10	0
258	1	1	0	168	3.44	17.9	0.0	6	127	15	73	0	55.4	10	0
259	1	1	0	172	3.50	18.4	0.7	5	127	16	73	0	49.6	10	0
261	1	1	0	170	3.38	14.5	0.0	5	127	14	73	0	49.9	9	0
263	1	1	0	177	3.50	17.0	0.0	3	121	14	104	0	70.6	11	0
264	1	1	0	166	3.25	15.4	0.0	5	123	16	105	0	70.6	11	0
268	1	1	0	162	3.25	16.2	0.0	5	127	15	74	0	44.5	10	0
270	1	1	0	143	3.25	13.5	0.0	5	123	15	105	0	53.5	11	0
2	1	2	1	229	3.58	27.5	0.0	1	125	15	98	0	0.0	0	0
5	1	2	1	224	3.50	20.1	0.0	2	122	14	119	0	81.3	10	0
14	1	2	1	226	3.38	17.4	0.0	0	123	14	139	0	81.6	11	0
23	1	2	1	200	3.50	.	0.0	0	130	16	0	1	0.0	0	1
25	1	2	1	227	3.42	20.7	0.0	2	124	15	120	0	68.2	10	0
68	1	2	1	209	3.50	18.2	0.0	0	123	14	142	0	78.0	12	0
70	1	2	1	205	3.50	21.7	0.0	2	125	15	126	0	63.8	10	0
76	1	2	1	220	3.42	19.1	0.0	2	124	15	121	0	86.1	13	0
89	1	2	1	232	3.42	18.6	0.0	2	123	16	134	0	69.1	11	0
151	1	2	1	216	3.50	20.7	0.0	2	123	14	116	0	83.8	12	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
153	1	2	0	188	3.50	17.8	0.0	3	124	14	104	0	144.2	19	0
155	1	2	1	200	3.42	16.1	0.0	3	123	16	115	0	72.3	11	0
157	1	2	1	165	3.25	13.0	0.0	5	121	15	137	0	80.7	10	0
158	1	2	1	195	3.50	19.9	0.0	0	36	15	0	0	0.0	0	1
159	1	2	1	216	3.25	13.4	0.0	3	125	14	99	0	66.1	8	0
160	1	2	1	205	3.50	24.7	0.0	2	124	14	103	0	52.7	7	0
162	1	2	0	190	3.42	16.5	0.0	2	120	13	137	0	78.3	8	0
163	1	2	1	224	3.33	18.7	0.0	3	124	13	115	0	87.9	10	0
165	1	2	1	234	3.42	23.9	0.0	3	117	14	168	0	98.7	9	0
166	1	2	1	213	3.25	16.8	0.0	2	125	13	103	0	80.0	11	0
167	1	2	1	203	3.25	16.3	2.5	3	120	13	98	1	49.9	5	0
168	1	2	1	224	3.50	18.6	0.0	2	123	14	111	0	71.3	10	0
169	1	2	0	188	3.33	15.7	1.5	1	121	14	132	0	97.6	8	0
170	1	2	1	230	3.50	21.8	0.0	3	121	15	136	0	77.4	9	0
171	1	2	0	193	3.33	14.4	0.0	1	121	16	100	0	93.5	9	0
174	1	2	1	232	3.42	18.2	0.0	3	125	16	103	0	58.8	9	0
175	1	2	1	212	3.50	25.1	0.0	3	121	15	128	0	82.3	11	0
176	1	2	0	178	3.25	14.4	0.0	0	43	13	13	0	94.1	10	1
178	1	2	1	220	3.50	19.4	0.0	3	123	13	115	0	95.5	12	0
179	1	2	1	176	3.50	19.4	0.0	2	119	16	158	0	93.2	10	0
180	1	2	0	201	3.33	13.9	0.0	3	124	14	105	0	126.7	18	0
181	1	2	1	196	3.17	16.4	0.5	3	119	15	151	0	86.3	10	0
182	1	2	1	238	3.50	19.4	0.0	2	123	16	113	0	71.4	11	0
185	1	2	1	219	3.42	23.3	0.0	2	122	14	119	0	79.4	10	0
192	1	2	1	182	3.50	14.0	0.0	0	30	15	0	0	0.0	0	1
201	1	2	1	234	3.42	21.3	0.0	2	120	16	137	0	88.8	11	0
203	1	2	1	190	3.50	15.9	1.5	5	143	14	0	1	0.0	0	0
204	1	2	1	232	3.50	20.1	0.0	2	121	14	128	0	84.9	11	0
207	1	2	1	182	3.33	17.0	0.0	2	122	13	128	0	76.1	8	0
209	1	2	1	203	3.42	20.5	1.0	2	122	14	125	0	71.3	12	0
241	1	2	1	245	3.42	19.7	1.5	2	128	14	74	1	86.8	12	0
242	1	2	1	224	3.44	21.9	0.0	5	125	15	87	0	26.3	4	0
246	1	2	1	208	3.25	15.5	0.0	5	128	14	79	0	68.7	10	0
247	1	2	1	219	3.42	19.2	0.0	4	143	16	0	0	0.0	0	0
248	1	2	1	237	3.50	24.5	0.0	3	122	12	118	0	70.8	11	0
249	1	2	1	212	3.42	22.4	0.0	2	121	14	119	0	52.9	6	0
250	1	2	1	233	3.25	20.6	0.0	3	124	14	114	1	85.7	10	0
251	1	2	1	234	3.25	18.9	0.0	3	125	14	103	0	62.6	11	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
252	1	2	1	206	3.50	20.4	0.0	2	138	16	20	0	0.0	0	0
254	1	2	1	216	3.50	21.8	0.0	2	123	15	109	0	63.1	10	0
255	1	2	1	214	3.50	22.5	0.0	4	143	14	0	0	0.0	0	0
256	1	2	1	209	3.50	16.9	0.0	2	131	16	54	0	0.0	0	0
257	1	2	1	192	3.38	11.9	0.0	2	132	16	49	0	0.0	0	0
258	1	2	1	234	3.50	24.6	0.0	2	125	15	95	0	62.5	10	0
259	1	2	1	242	3.50	25.5	0.0	2	124	16	99	0	66.3	11	0
261	1	2	1	240	3.42	17.5	0.0	2	124	14	113	0	67.8	9	0
263	1	2	1	224	3.42	21.1	0.0	2	137	14	24	0	0.0	0	0
264	1	2	1	229	3.17	22.5	0.0	2	123	15	137	0	68.3	10	0
268	1	2	1	228	3.50	23.7	0.0	2	143	15	0	0	0.0	0	0
270	1	2	1	207	3.33	19.7	0.0	2	122	14	122	0	61.9	10	0
2	1	3	1	240	3.50	25.3	0.0	2	122	16	106	0	133.8	21	0
5	1	3	2	251	3.50	23.5	0.0	2	125	14	108	0	85.2	13	0
14	1	3	2	240	3.50	17.8	0.0	3	129	14	67	0	0.0	0	0
25	1	3	2	262	3.42	23.2	0.5	2	123	15	111	0	76.6	11	0
68	1	3	2	240	3.50	22.8	0.0	2	131	14	57	0	0.0	0	0
70	1	3	2	242	3.42	22.8	0.0	3	124	15	104	0	81.0	15	0
76	1	3	2	255	3.50	22.8	0.0	2	122	15	119	0	80.6	10	0
89	1	3	2	263	3.33	27.7	0.0	2	123	16	111	0	89.1	14	0
151	1	3	2	246	3.50	27.2	0.0	2	124	14	115	0	83.9	12	0
153	1	3	2	225	3.44	22.8	0.0	6	127	14	89	0	58.0	11	0
155	1	3	2	235	3.42	17.9	0.0	3	123	16	123	0	86.9	13	0
157	1	3	2	226	3.25	13.8	0.0	3	127	15	85	0	67.2	12	0
159	1	3	2	258	3.33	14.9	0.0	3	124	14	122	0	89.9	12	0
160	1	3	2	234	3.50	21.9	0.0	3	123	14	92	1	84.3	10	0
162	1	3	1	225	3.38	17.9	0.0	4	127	14	84	0	152.7	21	0
163	1	3	2	264	3.33	18.4	0.0	3	121	13	144	0	80.8	10	0
165	1	3	2	256	3.33	25.8	0.0	3	123	14	116	0	96.5	11	0
166	1	3	2	256	3.25	20.5	0.0	2	122	14	117	1	92.7	12	0
167	1	3	2	235	3.33	16.7	0.5	3	121	14	141	0	106.7	12	0
168	1	3	2	269	3.42	23.0	0.0	2	122	14	141	0	79.6	11	0
169	1	3	1	229	3.33	19.1	0.0	2	142	14	109	0	171.2	24	0
170	1	3	2	260	3.50	25.2	0.0	3	121	14	137	0	91.3	12	0
171	1	3	1	237	3.38	15.9	0.0	5	124	16	91	0	136.7	21	0
174	1	3	2	260	3.50	19.4	0.0	3	124	16	121	0	82.1	11	0
175	1	3	2	245	3.42	26.0	0.0	3	124	15	109	0	73.8	11	0
178	1	3	2	243	3.25	20.4	1.0	3	122	14	130	0	95.5	12	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
179	1	3	2	224	3.50	22.8	0.0	2	122	14	119	0	78.4	11	0
180	1	3	2	268	3.42	18.8	0.0	6	127	14	84	0	66.8	11	0
181	1	3	2	240	3.17	19.2	1.0	6	143	15	0	0	0.0	0	0
182	1	3	2	277	3.50	21.9	0.0	2	123	16	111	0	62.0	9	0
185	1	3	2	245	3.50	21.1	0.0	3	121	14	118	0	79.5	11	0
201	1	3	2	276	3.42	23.6	0.0	3	124	16	111	0	66.1	10	0
203	1	3	1	255	3.50	22.9	0.0	3	121	14	119	0	96.3	13	0
204	1	3	2	286	3.58	24.2	1.0	2	124	14	82	0	63.9	10	0
207	1	3	2	243	3.33	23.2	0.0	2	121	14	99	0	82.1	13	0
209	1	3	2	240	3.38	22.4	1.7	5	124	14	79	2	48.2	8	0
241	1	3	2	260	3.42	18.7	0.0	3	121	14	127	0	84.5	12	0
242	1	3	2	260	3.50	19.9	0.0	3	121	15	121	0	94.1	11	0
246	1	3	2	262	3.42	21.9	0.0	2	125	16	95	0	64.0	10	0
247	1	3	1	294	3.50	25.3	0.0	3	121	16	119	0	86.1	11	0
248	1	3	2	276	3.33	30.5	0.0	3	122	13	119	0	86.6	11	0
249	1	3	2	231	3.50	26.1	0.0	3	122	15	105	0	70.7	13	0
250	1	3	2	268	3.33	22.9	0.0	2	122	14	120	1	58.9	7	0
251	1	3	2	264	3.25	19.2	0.0	2	123	14	112	0	83.7	13	0
252	1	3	1	239	3.42	23.6	0.0	3	125	16	119	0	77.3	11	0
254	1	3	2	250	3.50	22.8	0.0	3	122	15	84	0	81.6	13	0
255	1	3	1	295	3.50	32.5	0.0	3	124	15	103	0	68.6	13	0
256	1	3	1	267	3.17	23.2	0.0	3	128	16	115	0	103.6	12	0
257	1	3	1	255	3.42	16.1	0.0	3	129	14	105	0	84.3	10	0
258	1	3	2	273	3.50	27.3	0.0	2	120	15	136	0	99.8	12	0
259	1	3	2	275	3.50	33.9	0.0	2	123	16	79	0	70.0	11	0
261	1	3	2	273	3.33	17.8	0.0	2	122	14	116	0	63.0	10	0
263	1	3	1	263	3.33	23.3	0.0	3	121	14	137	0	85.0	11	0
264	1	3	2	273	3.42	25.9	0.0	3	124	13	105	0	85.1	12	0
268	1	3	1	291	3.58	27.1	1.0	3	121	14	125	0	65.3	11	0
270	1	3	2	257	3.42	23.6	0.0	2	122	14	103	0	75.9	11	0
2	1	4	3	279	3.50	29.3	0.0	2	125	16	92	0	64.2	11	0
5	1	4	3	252	3.25	23.8	0.0	3	124	14	103	0	82.0	13	0
14	1	4	2	276	3.38	21.9	1.5	3	119	14	134	1	70.3	12	0
25	1	4	3	291	3.50	27.8	0.0	2	143	15	0	0	0.0	0	0
68	1	4	2	269	3.50	22.1	1.0	3	137	14	139	0	123.0	23	0
70	1	4	3	277	3.50	30.3	0.0	0	123	15	115	0	57.7	10	0
76	1	4	3	297	3.38	28.3	0.0	2	123	14	108	0	75.9	12	0
89	1	4	3	271	3.38	24.4	0.0	2	123	16	115	0	78.2	13	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
151	1	4	3	288	3.58	27.4	0.0	0	104	14	121	0	69.7	10	1
153	1	4	3	246	3.50	20.7	2.0	0	118	14	0	0	0.0	0	1
155	1	4	3	257	3.42	19.2	0.0	3	122	16	124	0	84.5	12	0
157	1	4	3	236	3.33	16.9	0.0	2	122	15	119	0	52.1	8	0
159	1	4	3	278	3.33	14.8	0.0	3	124	14	103	0	79.9	11	0
160	1	4	3	277	3.33	24.8	0.0	0	95	14	118	0	97.7	12	1
162	1	4	3	270	3.50	29.9	0.0	0	124	14	101	0	70.8	9	0
163	1	4	3	290	3.25	21.8	0.0	3	124	13	110	0	71.7	9	0
165	1	4	3	284	3.25	24.3	0.0	0	111	14	115	0	83.0	11	1
166	1	4	3	278	3.42	21.3	0.0	2	123	14	111	0	62.8	9	0
167	1	4	3	260	3.33	18.0	1.0	3	122	14	119	0	76.3	10	0
168	1	4	3	272	3.42	26.8	0.5	3	122	14	110	0	60.3	9	0
169	1	4	3	257	3.31	21.1	0.0	5	125	14	99	0	78.1	12	0
170	1	4	3	262	3.42	27.8	0.0	3	125	15	99	0	78.9	14	0
171	1	4	3	243	3.25	14.4	0.0	0	117	16	0	0	0.0	0	1
174	1	4	3	300	3.50	25.0	0.0	3	123	16	120	0	80.4	11	0
175	1	4	3	253	3.50	33.9	0.0	3	124	15	101	0	75.2	12	0
178	1	4	3	269	3.42	21.5	0.0	3	121	12	128	0	80.6	11	0
179	1	4	3	288	3.58	39.0	0.0	2	120	14	136	0	94.5	12	0
180	1	4	3	280	3.50	23.2	0.0	3	143	14	0	0	0.0	0	0
181	1	4	2	312	3.33	29.6	1.5	3	123	15	111	1	68.1	9	0
182	1	4	3	304	3.50	24.2	0.0	0	123	16	111	0	54.0	10	0
185	1	4	3	284	3.42	26.4	1.5	3	124	14	103	1	72.8	10	0
201	1	4	3	302	3.42	23.5	0.0	0	110	16	111	0	63.7	8	1
203	1	4	2	247	3.50	24.6	0.0	3	122	14	113	1	69.8	11	0
204	1	4	3	286	3.50	24.1	0.0	0	115	14	0	0	0.0	0	1
207	1	4	3	265	3.42	24.2	0.0	2	125	14	99	0	66.1	11	0
209	1	4	3	244	3.25	23.2	3.0	0	82	14	0	4	0.0	0	1
241	1	4	3	276	3.33	23.2	0.0	3	125	14	95	0	70.1	8	0
242	1	4	3	294	3.42	21.3	0.0	0	107	15	95	0	87.7	12	1
246	1	4	3	297	3.33	19.7	0.0	0	114	15	88	0	61.5	9	1
247	1	4	2	311	3.50	23.5	0.0	3	124	16	103	0	65.7	11	0
248	1	4	3	285	3.25	21.4	0.0	2	123	12	103	0	65.3	9	0
249	1	4	3	269	3.50	29.3	0.0	3	143	15	0	0	0.0	0	0
250	1	4	3	305	3.33	25.0	0.0	2	126	14	89	1	66.5	9	0
251	1	4	3	287	3.17	19.1	0.0	3	123	14	111	0	66.7	11	0
252	1	4	2	248	3.50	21.5	0.0	3	124	16	107	0	70.1	11	0
254	1	4	3	280	3.50	24.1	0.0	2	123	15	109	0	56.6	10	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
255	1	4	2	314	3.63	28.2	0.0	3	143	15	0	0	0.0	0	0
256	1	4	2	277	3.33	22.5	0.0	2	111	16	172	0	78.9	11	0
257	1	4	2	283	3.42	15.1	0.0	2	109	14	183	0	66.9	9	0
258	1	4	3	298	3.50	36.1	0.0	0	113	15	84	0	63.0	11	1
259	1	4	3	307	3.50	31.5	0.0	2	123	16	97	0	57.8	10	0
261	1	4	3	312	3.50	22.8	0.0	0	123	13	108	1	57.3	9	0
263	1	4	2	275	3.50	23.4	0.0	3	126	14	113	0	81.0	11	0
264	1	4	3	290	3.50	26.1	0.0	0	119	13	105	0	85.1	12	0
268	1	4	2	302	3.50	29.4	0.0	0	77	14	0	0	0.0	0	1
270	1	4	3	277	3.42	26.1	0.0	2	125	13	98	1	63.7	9	0
2	1	5	4	277	3.50	29.9	0.0	2	122	16	119	0	79.3	10	0
5	1	5	4	281	3.50	24.4	0.0	3	143	14	0	0	0.0	0	0
14	1	5	3	279	3.31	19.3	0.0	5	126	14	88	0	137.4	21	0
25	1	5	3	338	3.58	35.0	0.0	2	124	15	100	0	54.3	8	0
68	1	5	4	291	3.42	22.5	1.0	3	123	14	107	0	67.6	10	0
70	1	5	4	292	3.67	28.9	0.0	2	126	15	88	0	0.0	0	0
76	1	5	4	308	3.33	25.7	0.5	3	122	14	119	0	76.1	10	0
89	1	5	4	308	3.63	28.2	0.0	0	125	16	95	0	56.8	10	0
155	1	5	4	270	3.38	16.5	0.0	3	124	16	111	0	61.4	9	0
157	1	5	4	260	3.17	16.4	0.0	3	123	15	110	0	86.0	14	0
159	1	5	4	298	3.25	14.4	.	0	126	14	88	0	56.7	9	0
162	1	5	4	236	3.25	18.6	1.0	0	1	14	0	0	0.0	0	1
163	1	5	4	301	3.25	20.4	1.0	2	123	13	113	0	81.6	11	0
166	1	5	4	292	3.50	24.1	0.0	2	125	14	95	0	79.3	10	0
167	1	5	4	291	3.38	19.9	0.0	0	128	14	73	0	0.0	0	0
168	1	5	4	204	3.58	27.0	0.0	2	125	14	95	0	38.6	6	0
169	1	5	4	286	3.38	25.7	0.0	0	124	14	100	0	90.2	12	0
170	1	5	4	296	3.33	25.8	0.0	2	124	15	103	0	58.9	10	0
174	1	5	4	309	3.50	20.1	0.0	2	125	16	95	0	74.4	12	0
175	1	5	4	286	3.50	28.4	0.0	3	123	15	111	0	73.8	12	0
178	1	5	4	267	3.50	20.3	0.0	3	124	12	111	0	72.4	8	0
179	1	5	4	290	3.56	33.9	0.0	6	123	14	111	0	88.9	12	0
180	1	5	3	308	3.50	21.0	0.0	3	126	14	88	0	60.4	11	0
181	1	5	3	305	3.33	27.5	0.0	2	118	15	148	0	65.8	8	0
182	1	5	4	303	3.50	21.7	0.0	2	126	16	91	0	0.0	0	0
185	1	5	4	303	3.50	25.7	0.0	3	124	14	99	0	57.7	9	0
203	1	5	3	283	3.56	23.3	0.0	2	124	14	103	0	69.9	9	0
207	1	5	4	279	3.50	28.2	0.0	0	36	14	0	0	0.0	0	1

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
241	1	5	4	263	3.42	21.1	0.0	3	143	14	0	0	0.0	0	0
247	1	5	3	305	3.42	23.6	1.0	3	123	16	106	0	83.1	11	0
248	1	5	4	293	3.33	22.0	0.0	2	123	12	111	0	77.3	10	0
249	1	5	3	307	3.50	32.4	0.0	3	124	15	82	1	71.3	10	0
250	1	5	4	289	3.33	28.8	0.0	2	125	14	86	2	73.9	11	0
251	1	5	4	304	3.25	16.1	0.0	0	124	14	105	1	71.0	12	0
252	1	5	3	279	3.50	28.8	0.0	3	143	16	0	0	0.0	0	0
254	1	5	4	287	3.50	29.5	0.7	2	143	15	0	1	0.0	0	0
255	1	5	2	342	3.50	35.1	0.0	0	35	15	0	0	0.0	0	1
256	1	5	3	309	3.50	23.5	0.0	3	120	16	128	0	65.0	11	0
257	1	5	3	290	3.33	16.3	0.0	3	120	14	130	0	76.6	12	0
259	1	5	4	327	3.67	35.4	0.0	2	126	16	51	0	45.2	8	0
261	1	5	4	318	3.50	22.8	0.0	0	23	13	0	0	0.0	0	1
263	1	5	3	312	3.50	28.4	0.0	3	143	14	0	0	0.0	0	0
264	1	5	4	268	3.50	33.8	0.0	2	143	13	0	0	0.0	0	0
270	1	5	4	294	3.58	30.1	0.0	2	124	13	74	0	71.9	10	0
2	1	6	5	269	3.31	23.1	0.0	5	123	16	89	0	74.8	10	0
5	1	6	4	299	3.50	29.5	0.0	0	86	14	0	0	0.0	0	1
14	1	6	5	286	3.42	18.2	0.0	4	121	14	109	0	68.2	9	0
25	1	6	4	336	3.58	30.7	1.0	3	120	14	103	0	85.9	10	0
68	1	6	5	278	3.42	21.7	1.3	5	143	14	0	0	0.0	0	0
70	1	6	4	295	3.58	29.3	0.0	3	124	15	73	0	126.9	23	0
76	1	6	5	308	3.42	29.1	1.0	3	123	14	87	0	61.7	9	0
89	1	6	5	312	3.50	27.2	0.0	0	22	16	0	0	0.0	0	1
155	1	6	5	270	3.42	15.8	0.0	3	123	16	79	0	86.7	12	0
157	1	6	5	253	3.33	14.1	1.5	3	124	15	94	0	79.0	10	0
159	1	6	5	273	3.25	13.6	0.0	5	143	14	0	0	0.0	0	0
163	1	6	5	298	3.42	17.6	0.0	3	124	13	102	0	86.3	12	0
166	1	6	5	294	3.42	22.5	0.0	2	123	14	81	0	84.8	11	0
167	1	6	4	262	3.25	12.2	0.0	2	119	14	154	1	99.8	12	0
168	1	6	5	305	3.50	25.3	0.0	3	123	14	80	0	60.5	11	0
169	1	6	5	259	3.25	20.3	0.0	0	32	14	0	0	0.0	0	1
170	1	6	5	297	3.50	24.0	0.0	2	122	15	88	0	85.0	12	0
174	1	6	5	299	3.50	18.6	0.0	3	121	16	116	0	76.3	9	0
175	1	6	5	281	3.58	29.7	0.0	2	121	15	91	0	72.6	11	0
178	1	6	5	288	3.50	21.5	0.0	0	97	12	92	0	72.3	12	1
179	1	6	5	287	3.50	34.3	0.0	3	125	14	67	0	58.9	9	0
180	1	6	4	315	3.50	20.4	0.0	3	127	14	63	0	52.4	9	0

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
181	1	6	4	301	3.33	23.5	0.0	2	126	15	82	0	61.5	10	0
182	1	6	4	291	3.31	21.3	1.0	5	127	16	71	0	126.5	23	0
185	1	6	5	302	3.50	26.4	0.0	2	121	14	92	0	64.0	8	0
203	1	6	4	290	3.50	24.7	0.0	3	127	13	57	0	0.0	0	0
241	1	6	4	300	3.50	19.3	0.0	3	74	14	91	2	61.9	9	1
247	1	6	4	298	3.42	18.4	0.0	1	127	16	69	0	54.9	9	0
248	1	6	5	285	3.33	18.0	0.0	3	123	12	88	0	71.3	10	0
249	1	6	4	288	3.42	24.4	0.0	1	124	15	99	0	70.4	10	0
250	1	6	5	299	3.33	20.0	0.0	2	123	14	100	0	67.8	9	0
251	1	6	5	294	3.25	19.5	0.0	5	143	14	0	0	0.0	0	0
252	1	6	3	289	3.50	26.4	0.0	3	126	16	67	0	57.9	11	0
254	1	6	4	289	3.50	28.6	0.0	0	89	15	0	0	0.0	0	1
256	1	6	4	305	3.42	21.5	0.0	3	120	16	105	0	69.0	11	0
257	1	6	4	283	3.50	16.5	0.0	3	119	14	129	0	64.9	11	0
259	1	6	5	327	3.58	32.4	0.5	3	123	16	70	0	50.2	9	0
263	1	6	3	325	3.56	25.8	0.0	3	124	14	72	0	70.8	11	0
264	1	6	4	304	3.75	29.0	0.0	0	25	13	73	0	70.5	9	1
270	1	6	5	282	3.42	22.6	0.0	2	123	13	86	0	72.0	12	0
2	1	7	6	274	3.33	22.7	0.0	0	118	16	121	0	83.5	12	1
14	1	7	6	274	3.33	17.5	0.0	0	116	14	114	0	77.7	12	1
25	1	7	5	312	3.42	22.7	0.0	0	91	14	118	0	65.9	10	1
68	1	7	5	275	3.50	23.4	2.0	0	81	14	0	2	0.0	0	1
70	1	7	6	279	3.50	28.2	0.0	3	118	15	89	0	55.5	9	1
76	1	7	6	306	3.42	23.6	2.0	0	98	14	128	1	78.8	11	1
155	1	7	6	260	3.50	17.6	0.0	0	93	16	0	0	0.0	0	1
157	1	7	6	249	3.25	15.7	0.0	0	101	15	112	0	73.8	11	1
159	1	7	5	285	3.50	26.9	0.0	0	92	14	0	0	0.0	0	1
163	1	7	6	279	3.25	20.3	0.0	0	88	13	0	0	0.0	0	1
166	1	7	6	283	3.50	18.6	0.0	0	90	14	149	0	75.0	9	1
167	1	7	5	264	3.33	15.3	0.0	2	121	14	140	0	69.5	11	0
168	1	7	6	287	3.38	24.9	0.0	0	90	14	0	0	0.0	0	1
170	1	7	6	291	3.50	21.1	0.0	0	110	15	83	1	51.7	8	1
174	1	7	6	303	3.42	17.6	0.0	0	107	16	83	0	64.8	9	1
175	1	7	6	269	3.42	29.2	0.0	0	110	15	123	0	84.3	13	1
179	1	7	6	298	3.50	30.9	0.0	0	108	14	99	0	67.0	9	1
180	1	7	5	288	3.50	19.3	0.0	3	143	14	0	0	0.0	0	0
181	1	7	5	295	3.25	25.3	0.0	2	29	15	0	0	0.0	0	1
182	1	7	6	293	3.25	17.7	0.0	0	117	16	102	0	57.8	11	1

Dam ID	Barn	Per-iod	Par-ity	Avg Wt	Avg BCS	Avg BF	Avg GS	AI	NLD	FT	LF	Med	LW	Wean	Cull
185	1	7	6	297	3.50	24.6	0.0	0	102	14	109	0	64.8	9	1
203	1	7	4	279	3.50	20.6	0.0	3	107	13	90	0	110.2	20	1
247	1	7	5	298	3.50	19.3	0.0	0	92	16	0	0	0.0	0	1
248	1	7	6	265	3.25	22.2	0.0	0	89	12	0	0	0.0	0	1
249	1	7	5	275	3.50	24.9	0.0	0	103	15	96	1	71.6	9	1
250	1	7	6	304	3.25	18.4	0.0	0	93	14	139	1	65.8	8	1
251	1	7	5	315	3.25	17.2	0.0	0	29	14	101	0	58.0	11	1
252	1	7	4	279	3.50	22.0	0.0	0	5	16	57	0	64.9	9	1
256	1	7	5	301	3.42	18.1	0.0	3	116	16	158	1	55.1	7	0
257	1	7	5	289	3.50	15.8	0.0	3	110	14	193	0	59.1	7	0
259	1	7	6	326	3.58	28.5	0.0	0	90	16	80	0	49.8	9	1
263	1	7	4	292	3.50	24.0	0.0	3	128	0	64	0	50.4	8	1
270	1	7	6	283	3.50	20.4	0.0	0	107	13	106	1	70.4	10	1
167	1	8	6	251	3.25	11.5	2.0	0	1	14	41	0	91.4	11	1
180	1	8	5	292	3.50	21.1	0.0	0	14	14	0	0	0.0	0	1
256	1	8	6	297	3.50	16.9	0.0	0	1	.	49	0	82.1	9	1
257	1	8	6	300	3.50	13.6	0.0	0	1	.	57	0	73.2	8	1

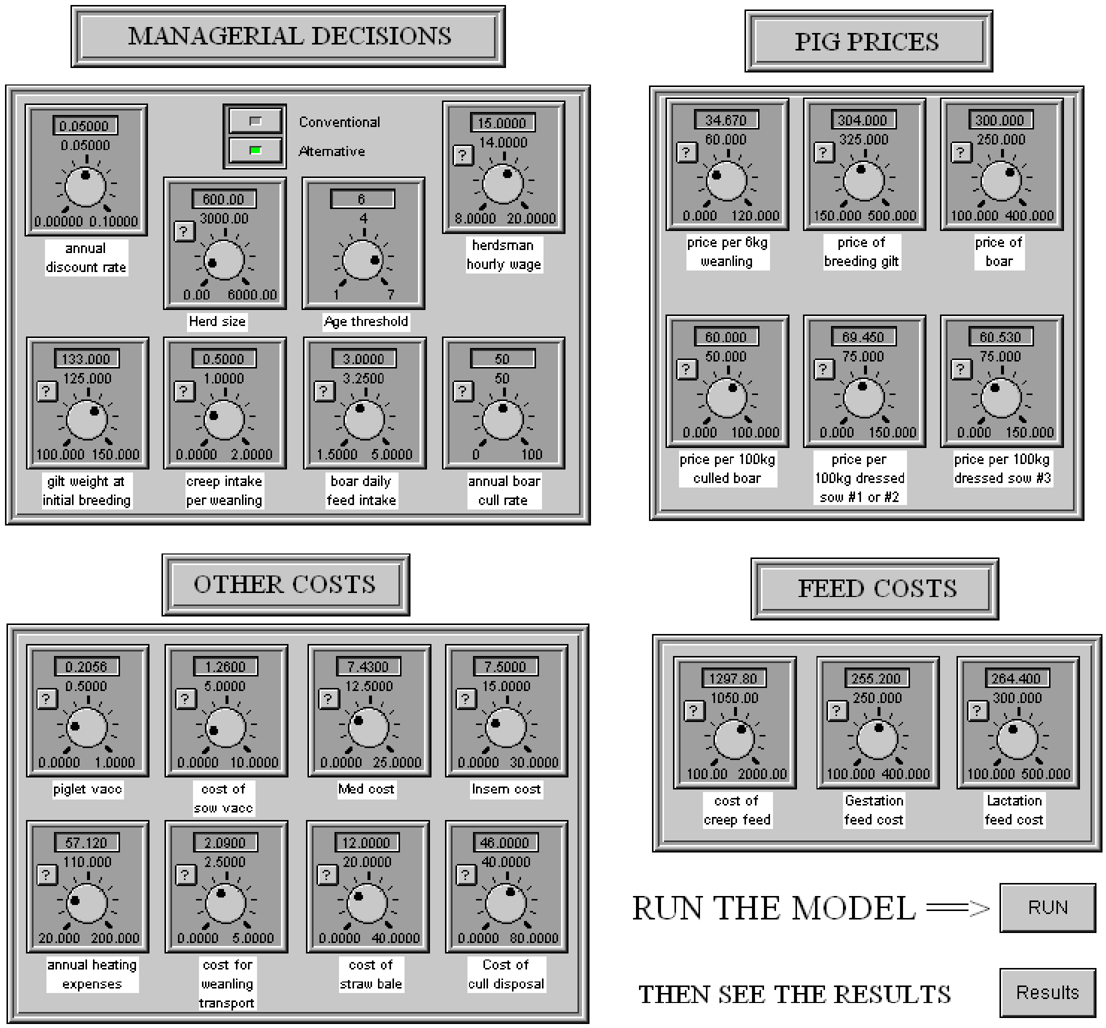
Appendix C. Average periodic values – mean ± standard deviation (min; max) – for production input variables in ALT

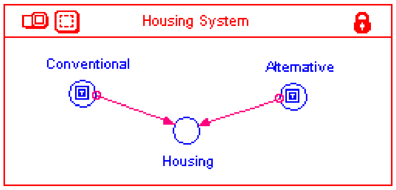
Period	1	2	3	4	5	6	7
Parity	0	0.9±0.3 (0;1)	1.8±0.4 (1;2)	2.8±0.4 (2;3)	3.7±0.5 (2;4)	4.5±0.6 (3;5)	5.5±0.7 (4;6)
AI	4.5±1.2 (3;6)	2.3±1.2 (0;5)	2.9±1.0 (2;6)	1.9±1.3 (0;5)	2.1±1.3 (0;6)	2.5±1.4 (0;5)	0.7±1.2 (0;3)
NLD	123.2±3.1 (116;128)	120.8±20.5 (30;143)	124.1±4.3 (120;143)	120.6±11.8 (77;143)	117.4±31.0 (1;143)	113.8±28.5 (22;143)	96.7±28.0 (5;143)
LF	98.4±21.5 (61;147)	96.9±46.2 (0;168)	107.4±23.7 (0;144)	93.7±44.7 (0;183)	78.1±45.6 (0;148)	72.7±38.5 (0;154)	80.4±56.4 (0;193)
Meds	0.02±0.13 (0;1)	0.08±0.28 (0;1)	0.09±0.35 (0;2)	0.2±0.6 (0;4)	0.1±0.4 (0;2)	0.08±0.35 (0;2)	0.2±0.5 (0;2)

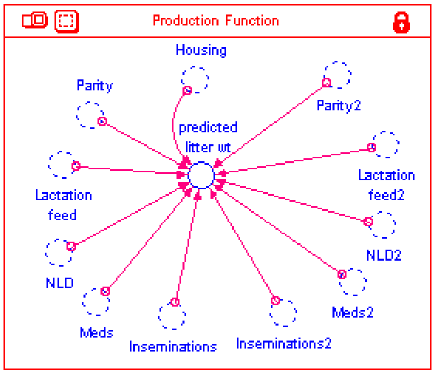
Appendix D. Average periodic values – mean ± standard deviation (min; max) – for production input variables in CONV

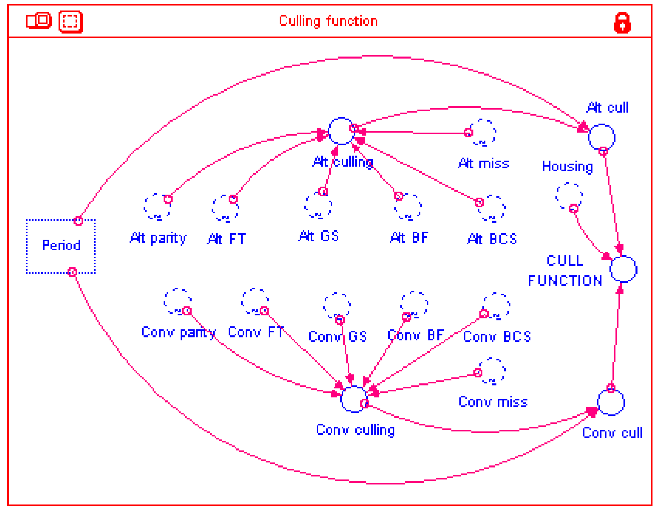
Period	1	2	3	4	5	6	7
Parity	0	1.0±0.2 (0;1)	1.9±0.3 (1;2)	2.8±0.4 (1;3)	3.7±0.5 (2;4)	4.6±0.6 (3;5)	5.5±0.7 (4;6)
AI	4.6±1.0 (3;6)	2.0±1.1 (0;6)	2.1±0.9 (0;4)	2.2±1.0 (0;5)	2.3±1.0 (0;5)	2.5±1.1 (0;5)	0.7±1.4 (0;5)
NLD	124.3±3.7 (115;132)	117.0±25.7 (33;143)	123.9±14.5 (32;143)	119.9±23.2 (14;143)	119.6±20.9 (21;143)	119.7±22.9 (1;143)	89.8±31.4 (11;143)
LF	91.6±27.0 (38;168)	95.0±50.2 (0;157)	92.9±42.2 (0;142)	85.3±42.2 (0;144)	86.8±33.8 (0;145)	78.6±39.7 (0;143)	68.7±33.2 (0;121)
Meds	0.2±0.4 (0;2)	0.2±0.6 (0;3)	0.3±0.7 (0;3)	0.3±0.7 (0;3)	0.2±0.6 (0;3)	0.2±0.4 (0;1)	0.4±1.0 (0;5)

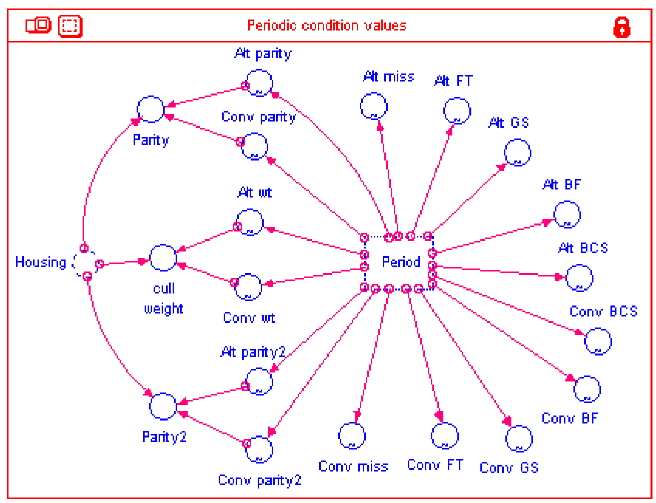
Appendix E. Screenshots of barn simulation model

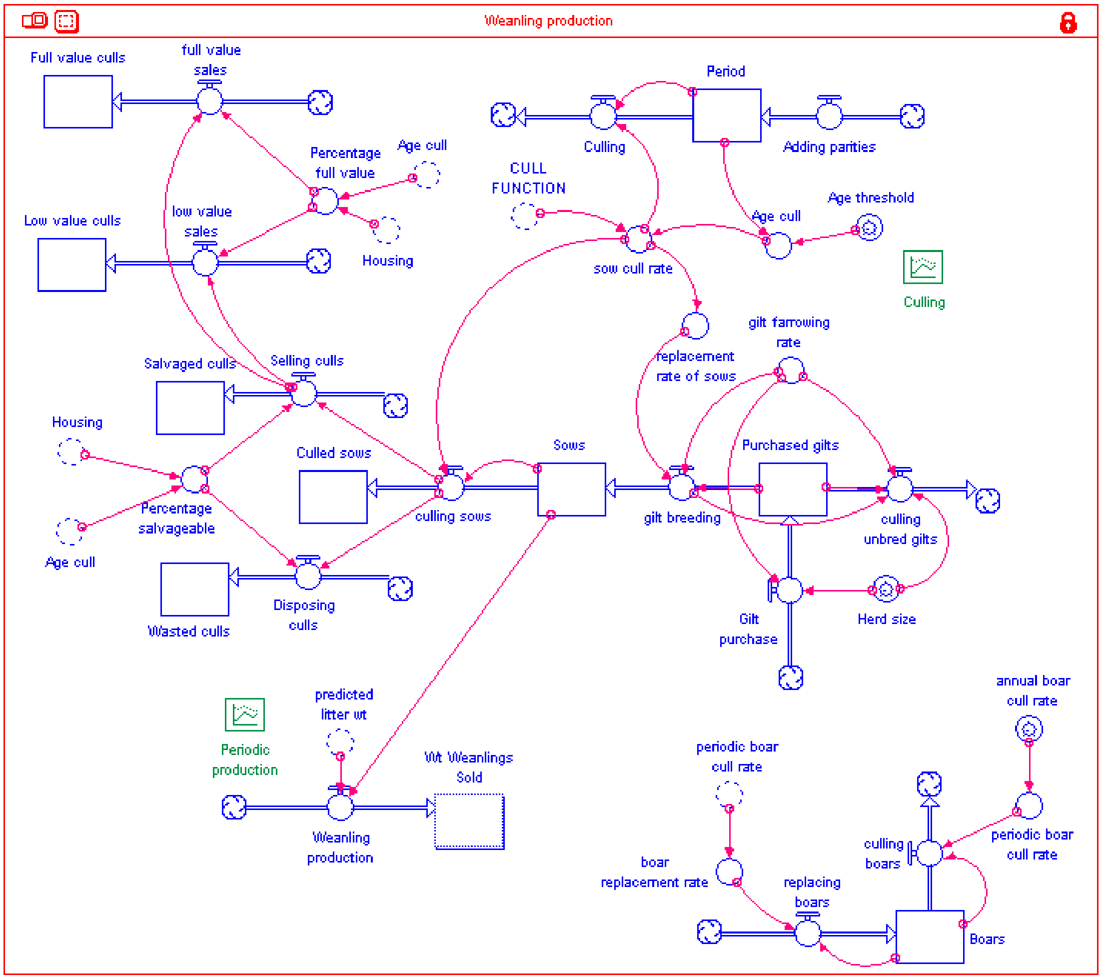



Housing System
Conventional
Alternative
Housing

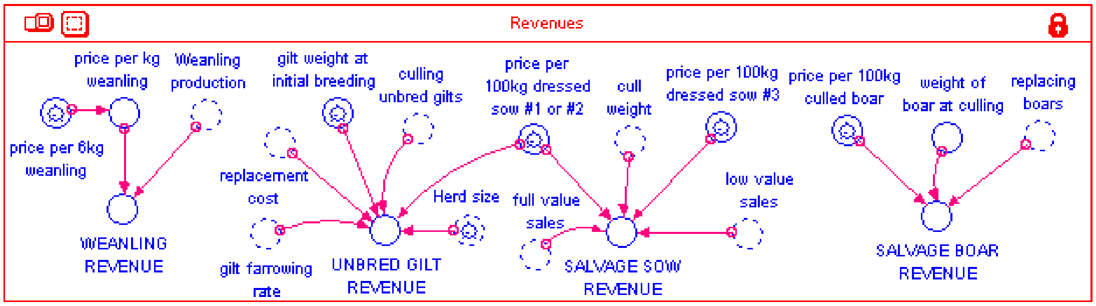

Production Function
Housing
Parity
Parity2
predicted
litter wt
Lactation
feed
Lactation
feed2
NLD
NLD2
Meds
Meds2
Inseminations
Inseminations2

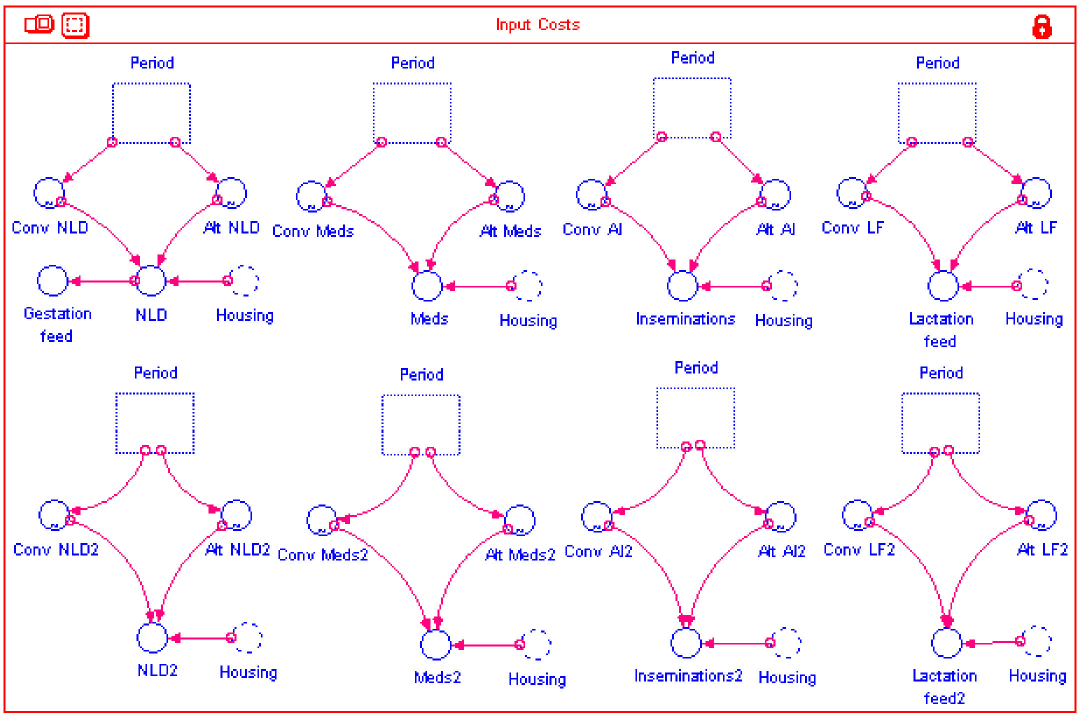

Culling function
Alt cull
Alt culling
Alt miss
Housing
Period
Alt parity
Alt FT
Alt GS
Alt BF
Alt BCS
CULL
FUNCTION
Conv parity
Conv FT
Conv GS
Conv BF
Conv BCS
Conv miss
Conv culling
Conv cull

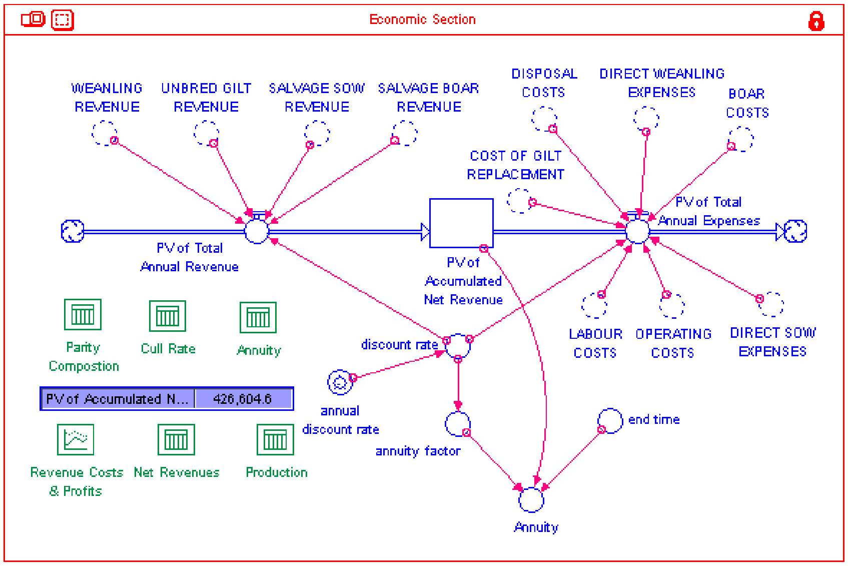

Periodic condition values
Alt parity
Alt miss
Alt FT
Conv parity
Parity
Alt GS
Alt BF
Alt wt
Alt BCS
Housing
Period
cull
weight
Conv wt
Conv BCS
Alt parity2
Conv BF
Parity2
Conv miss
Conv FT
Conv GS
Conv parity2



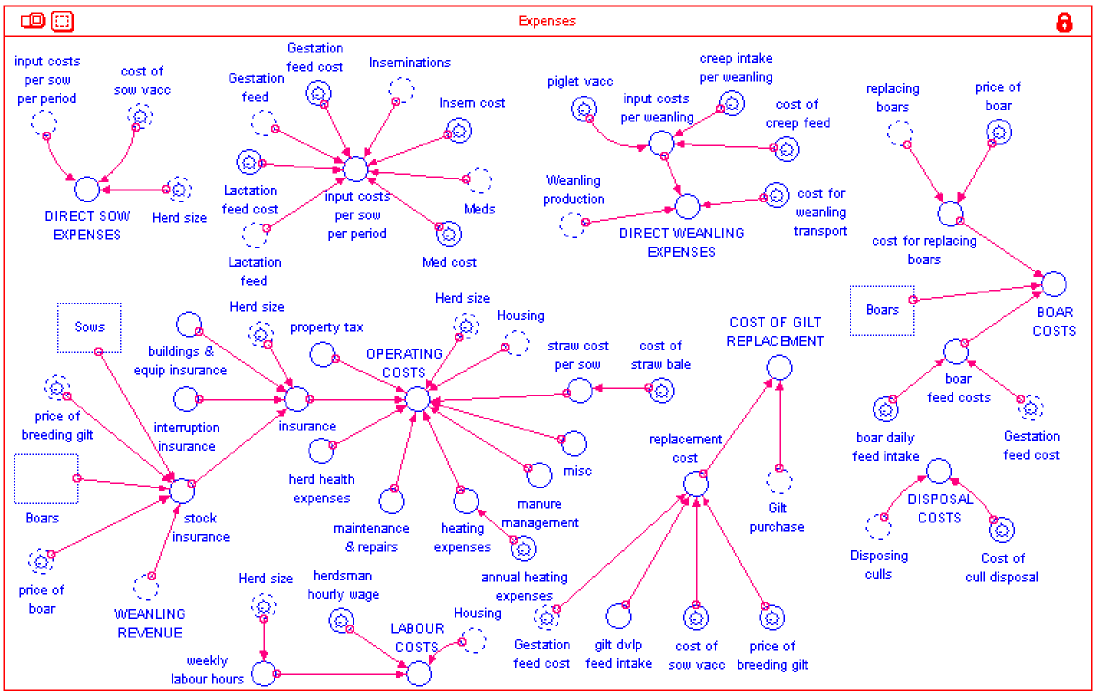
Weanling production
Full value culls
full value sales
Percentage full value
Age cull
Housing
low value sales
Low value culls
Salvaged culls
Selling culls
Housing
Percentage salvageable
Age cull
Culled sows
culling sows
Disposing culls
Wasted culls
Period
Culling
Adding parities
CULL FUNCTION
Age cull
Age threshold
sow cull rate
Culling
replacement rate of sows
gilt farrowing rate
Sows
Purchased gilts
gilt breeding
culling unbred gilts
Gilt purchase
Herd size
Periodic production
predicted litter wt
Wt Weanlings Sold
Weanling production
periodic boar cull rate
annual boar cull rate
boar replacement rate
replacing boars
culling boars
periodic boar cull rate
Boars


Revenues
price per kg weanling
Weanling production
price per 6kg weanling
WEANLING REVENUE
gilt weight at initial breeding
culling unbred gilts
replacement cost
Herd size
gilt farrowing rate
UNBRED GILT REVENUE
price per 100kg dressed sow #1 or #2
cull weight
price per 100kg dressed sow #3
full value sales
low value sales
SALVAGE SOW REVENUE
price per 100kg culled boar
weight of boar at culling
replacing boars
SALVAGE BOAR REVENUE


Input Costs
Period
Conv NLD
Alt NLD
Gestation feed
NLD
Housing
Period
Conv Meds
Alt Meds
Meds
Housing
Period
Conv AI
Alt AI
Inseminations
Housing
Period
Conv LF
Alt LF
Lactation feed
Housing
Period
Conv NLD2
Alt NLD2
NLD2
Housing
Period
Conv Meds2
Alt Meds2
Meds2
Housing
Period
Conv AI2
Alt AI2
Inseminations2
Housing
Period
Conv LF2
Alt LF2
Lactation feed2
Housing



Economic Section
WEANLING REVENUE
UNBRED GILT REVENUE
SALVAGE SOW REVENUE
SALVAGE BOAR REVENUE
DISPOSAL COSTS
DIRECT WEANLING EXPENSES
BOAR COSTS
COST OF GILT REPLACEMENT
PV of Total Annual Expenses
PV of Total Annual Revenue
PV of Accumulated Net Revenue
Parity Compostion
Cull Rate
Annuity
discount rate
LABOUR COSTS
OPERATING COSTS
DIRECT SOW EXPENSES
PV of Accumulated N... 426,604.6
annual discount rate
end time
annuity factor
Revenue Costs & Profits
Net Revenues
Production
Annuity



Expenses
input costs per sow per period
cost of sow vacc
DIRECT SOW EXPENSES
Herd size
Gestation feed cost
Gestation feed
Inseminations
Insem cost
Lactation feed cost
input costs per sow per period
Meds
Lactation feed
Med cost
piglet vacc
creep intake per weanling
input costs per weanling
cost of creep feed
Weanling production
cost for weanling transport
DIRECT WEANLING EXPENSES
replacing boars
price of boar
cost for replacing boars
Boars
BOAR COSTS
boar feed costs
boar daily feed intake
Gestation feed cost
DISPOSAL COSTS
Disposing culls
Cost of cull disposal
Sows
buildings & equip insurance
Herd size
property tax
Herd size
Housing
OPERATING COSTS
straw cost per sow
cost of straw bale
COST OF GILT REPLACEMENT
price of breeding gilt
interruption insurance
insurance
herd health expenses
misc
replacement cost
Boars
stock insurance
maintenance & repairs
heating expenses
manure management
Gilt purchase
price of boar
WEANLING REVENUE
Herd size
herdsman hourly wage
annual heating expenses
Housing
LABOUR COSTS
weekly labour hours
Gestation feed cost
gilt dvlp feed intake
cost of sow vacc
price of breeding gilt

Appendix F. Equations for barn simulation model

Culling function
Alt_cull = IF Period=1 THEN 0 ELSE (EXP(Alt_culling))/(1+EXP(Alt_culling))
Alt_culling = -4.7510+(0.2260+0.1688)*Alt_parity+(0.2901+0.5061)*Alt_BCS-(0.1059-0.1209)*Alt_BF+(0.6745-0.2969)*Alt_GS+(0.2062-0.3343)*Alt_FT+(0.2747+0.1927)*Alt_miss
Conv_cull = IF Period=1 THEN 0 ELSE (EXP(Conv_culling))/(1+EXP(Conv_culling))
Conv_culling = -4.7510+(0.2260)*Conv_parity+(0.2901)*Conv_BCS-(0.1059)*Conv_BF+(0.6745)*Conv_GS+(0.2062)*Conv_FT+(0.2747)*Conv_miss
CULL_FUNCTION = IF Housing=0 THEN MONTECARLO(100*Conv_cull) ELSE MONTECARLO(100*Alt_cull)

Economic Section
PV_of_Accumulated_Net_Revenue(t) = PV_of_Accumulated_Net_Revenue(t - dt) + (PV_of_Total_Annual_Revenue - PV_of_Total_Annual_Expenses) * dt
INIT PV_of_Accumulated_Net_Revenue = 0

INFLOWS:
PV_of_Total_Annual_Revenue = (WEANLING_REVENUE+SALVAGE_SOW_REVENUE+UNBRED_GILT_REVENUE+SALVAGE_BOAR_REVENUE)*(1/(1+discount_rate)^TIME)
OUTFLOWS:
PV_of_Total_Annual_Expenses = (DIRECT_SOW_EXPENSES+DIRECT_WEANLING_EXPENSES+COST_OF_GILT_REPLACEMENT+BOAR_COSTS+LABOUR_COSTS+OPERATING_COSTS+DISPOSAL_COSTS)*(1/(1+discount_rate)^TIME)
annual_discount_rate = 0.05
Annuity = IF (TIME=end_time) THEN (PV_of_Accumulated_Net_Revenue/annuity_factor) ELSE (0)
annuity_factor = IF (discount_rate=0) THEN (TIME) ELSE ((1-(1/((1+discount_rate)^TIME)))/discount_rate)
discount_rate = (1+annual_discount_rate)^(143/365)-1
end_time = STOPTIME

Expenses
annual_heating_expenses = 57.12
BOAR_COSTS = Boars*boar_feed_costs+cost_for_replacing_boars
boar_daily_feed_intake = 3
boar_feed_costs = boar_daily_feed_intake*143*Gestation_feed_cost/1000
buildings_&_equip_insurance = 888577.20/600*0.0078*(143/365)
cost_for_replacing_boars = replacing_boars*price_of_boar
cost_for_weanling_transport = 2.09
cost_of_creep_feed = 1297.8

Cost_of_cull_disposal = 46
COST_OF_GILT_REPLACEMENT = replacement_cost*Gilt_purchase
cost_of_sow_vacc = 1.26
cost_of_straw_bale = 12
creep_intake_per_weanling = 0.5
DIRECT_SOW_EXPENSES =
  (input_costs_per_sow_per_period+cost_of_sow_vacc)*Herd_size
DIRECT_WEANLING_EXPENSES =
  (input_costs_per_weanling+cost_for_weanling_transport)*Weanling_production/6
DISPOSAL_COSTS = Disposing_culls*Cost_of_cull_disposal
Gestation_feed_cost = 255.2
gilt_dvlp_feed_intake = 180
heating_expenses = annual_heating_expenses*(143/365)
herd_health_expenses = 7.25*(143/365)
herdsman_hourly_wage = 15
input_costs_per_sow_per_period =
  (Gestation_feed*Gestation_feed_cost/1000)+(Lactation_feed*Lactation_feed_cost/1000)+(Meds*Med_cost)+(Inseminations*Insem_cost)
input_costs_per_weanling =
  creep_intake_per_weanling*cost_of_creep_feed/1000+piglet_vacc
Insem_cost = 7.5
insurance =
  Herd_size*(buildings_&_equip_insurance+interruption_insurance)+stock_insurance
interruption_insurance = 9.36*(143/365)
LABOUR_COSTS =
  (weekly_labour_hours*herdsman_hourly_wage)*(1+Housing*(20/120))/7*143
Lactation_feed_cost = 264.4
maintenance_&_repairs = 8.15*(143/365)
manure_management = 21*0.002*143+3000/600*(143/365)
Med_cost = 7.43
misc = 2*(143/365)
OPERATING_COSTS = IF Housing=0 THEN
  (insurance+(property_tax+herd_health_expenses+heating_expenses+maintenance_&_repairs+manure_management+misc)*Herd_size) ELSE
  (insurance+(property_tax+herd_health_expenses+0.904*heating_expenses+maintenance_&_repairs+manure_management+misc+straw_cost_per_sow)*Herd_size)
piglet_vacc = 0.20555
price_of_boar = 300
price_of_breeding_gilt = 304
property_tax = 4500/600*(143/365)
replacement_cost =
  price_of_breeding_gilt+cost_of_sow_vacc*2+(gilt_dvlp_feed_intake*Gestation_feed_cost/1000)
stock_insurance =

((price_of_breeding_gilt*Sows+price_of_boar*Boars)*(143/365)+WEANLING_REVENUE)*(0.88/100)
straw_cost_per_sow = cost_of_straw_bale*500/144*143/365
weekly_labour_hours = 120*Herd_size/600

Housing System
Alternative = 1
Conventional = 1
Housing = IF (Conventional=1 AND Alternative=0) THEN 0 ELSE 1

Input Costs
Gestation_feed = 2.6*NLD
Inseminations = IF (Housing=0) THEN Conv_AI ELSE Alt_AI
Inseminations2 = IF (Housing=0) THEN Conv_AI2 ELSE Alt_AI2
Lactation_feed = IF (Housing=0) THEN Conv_LF ELSE Alt_LF
Lactation_feed2 = IF (Housing=0) THEN Conv_LF2 ELSE Alt_LF2
Meds = IF (Housing=0) THEN Conv_Meds ELSE Alt_Meds
Meds2 = IF (Housing=0) THEN Conv_Meds2 ELSE Alt_Meds2
NLD = IF Housing=0 THEN Conv_NLD ELSE Alt_NLD
NLD2 = IF (Housing=0) THEN 1.3*Conv_NLD2 ELSE 1.3*Alt_NLD2
Alt_AI = GRAPH(Period)
(1.00, 4.55), (2.00, 2.27), (3.00, 2.88), (4.00, 1.86), (5.00, 2.11), (6.00, 2.52), (7.00, 0.667), (8.00, 0.00)
Alt_AI2 = GRAPH(Period)
(1.00, 22.1), (2.00, 6.50), (3.00, 9.27), (4.00, 5.21), (5.00, 6.21), (6.00, 8.43), (7.00, 1.88), (8.00, 0.00)
Alt_LF = GRAPH(Period)
(1.00, 98.4), (2.00, 96.9), (3.00, 107), (4.00, 93.7), (5.00, 78.0), (6.00, 72.7), (7.00, 80.4), (8.00, 36.7)
Alt_LF2 = GRAPH(Period)
(1.00, 10140), (2.00, 11486), (3.00, 12094), (4.00, 10745), (5.00, 8127), (6.00, 6732), (7.00, 9553), (8.00, 1827)
Alt_Meds = GRAPH(Period)
(1.00, 0.017), (2.00, 0.083), (3.00, 0.089), (4.00, 0.196), (5.00, 0.114), (6.00, 0.075), (7.00, 0.242), (8.00, 0.00)
Alt_Meds2 = GRAPH(Period)
(1.00, 0.017), (2.00, 0.083), (3.00, 0.125), (4.00, 0.411), (5.00, 0.159), (6.00, 0.125), (7.00, 0.303), (8.00, 0.00)
Alt_NLD = GRAPH(Period)
(1.00, 123), (2.00, 121), (3.00, 124), (4.00, 121), (5.00, 117), (6.00, 114), (7.00, 96.7), (8.00, 4.25)
Alt_NLD2 = GRAPH(Period)
(1.00, 15188), (2.00, 14993), (3.00, 15412), (4.00, 14671), (5.00, 14720), (6.00, 13730), (7.00, 10115), (8.00, 49.8)

Conv_AI = GRAPH(Period)
(1.00, 4.59), (2.00, 2.03), (3.00, 2.08), (4.00, 2.15), (5.00, 2.29), (6.00, 2.51), (7.00, 0.743), (8.00, 0.00)
Conv_AI2 = GRAPH(Period)
(1.00, 22.1), (2.00, 5.38), (3.00, 5.19), (4.00, 5.60), (5.00, 6.29), (6.00, 7.49), (7.00, 2.57), (8.00, 0.00)
Conv_LF = GRAPH(Period)
(1.00, 91.6), (2.00, 95.0), (3.00, 92.9), (4.00, 85.3), (5.00, 86.8), (6.00, 78.6), (7.00, 68.7), (8.00, 73.4)
Conv_LF2 = GRAPH(Period)
(1.00, 9114), (2.00, 11509), (3.00, 10385), (4.00, 9021), (5.00, 8655), (6.00, 7711), (7.00, 5798), (8.00, 7171)
Conv_Meds = GRAPH(Period)
(1.00, 0.18), (2.00, 0.246), (3.00, 0.327), (4.00, 0.333), (5.00, 0.227), (6.00, 0.22), (7.00, 0.429), (8.00, 0.2)
Conv_Meds2 = GRAPH(Period)
(1.00, 0.213), (2.00, 0.377), (3.00, 0.558), (4.00, 0.625), (5.00, 0.409), (6.00, 0.22), (7.00, 1.11), (8.00, 0.2)
Conv_NLD = GRAPH(Period)
(0.00, 124), (1.00, 117), (2.00, 124), (3.00, 120), (4.00, 120), (5.00, 120), (6.00, 89.8), (7.00, 34.0)
Conv_NLD2 = GRAPH(Period)
(1.00, 15454), (2.00, 14329), (3.00, 15554), (4.00, 14907), (5.00, 14734), (6.00, 14844), (7.00, 9026), (8.00, 1714)

Periodic condition values
cull_weight = IF Housing=0 THEN Conv_wt ELSE Alt_wt
Parity = IF Housing=0 THEN Conv_parity ELSE Alt_parity
Parity2 = IF Housing=0 THEN Conv_parity2 ELSE Alt_parity2
Alt_BCS = GRAPH(Period)
(1.00, 3.12), (2.00, 3.43), (3.00, 3.39), (4.00, 3.42), (5.00, 3.45), (6.00, 3.44), (7.00, 3.42), (8.00, 3.44)
Alt_BF = GRAPH(Period)
(1.00, 15.9), (2.00, 19.4), (3.00, 22.4), (4.00, 24.4), (5.00, 25.0), (6.00, 22.9), (7.00, 21.6), (8.00, 15.8)
Alt_FT = GRAPH(Period)
(1.00, 14.6), (2.00, 14.5), (3.00, 14.6), (4.00, 14.5), (5.00, 14.4), (6.00, 14.4), (7.00, 14.1), (8.00, 14.0)
Alt_GS = GRAPH(Period)
(1.00, 0.125), (2.00, 0.183), (3.00, 0.143), (4.00, 0.214), (5.00, 0.12), (6.00, 0.158), (7.00, 0.121), (8.00, 0.5)
Alt_miss = GRAPH(Period)
(1.00, 0.00), (2.00, 0.1), (3.00, 0.214), (4.00, 0.196), (5.00, 0.295), (6.00, 0.475), (7.00, 0.515), (8.00, 1.25)

Alt_parity = GRAPH(Period)
(1.00, 0.00), (2.00, 0.9), (3.00, 1.79), (4.00, 2.80), (5.00, 3.71), (6.00, 4.53), (7.00, 5.49), (8.00, 5.75)
Alt_parity2 = GRAPH(Period)
(1.00, 0.00), (2.00, 0.9), (3.00, 3.36), (4.00, 8.02), (5.00, 14.0), (6.00, 20.8), (7.00, 30.5), (8.00, 33.3)
Alt_wt = GRAPH(Period)
(1.00, 159), (2.00, 213), (3.00, 255), (4.00, 279), (5.00, 292), (6.00, 293), (7.00, 287), (8.00, 285)
Conv_BCS = GRAPH(Period)
(1.00, 3.18), (2.00, 3.28), (3.00, 3.42), (4.00, 3.46), (5.00, 3.42), (6.00, 3.46), (7.00, 3.50), (8.00, 3.55)
Conv_BF = GRAPH(Period)
(1.00, 14.8), (2.00, 15.7), (3.00, 22.6), (4.00, 25.0), (5.00, 25.4), (6.00, 25.7), (7.00, 25.7), (8.00, 26.3)
Conv_FT = GRAPH(Period)
(1.00, 14.8), (2.00, 14.6), (3.00, 14.6), (4.00, 14.6), (5.00, 14.5), (6.00, 14.5), (7.00, 14.4), (8.00, 14.4)
Conv_GS = GRAPH(Period)
(1.00, 0.17), (2.00, 0.262), (3.00, 0.412), (4.00, 0.24), (5.00, 0.091), (6.00, 0.48), (7.00, 0.305), (8.00, 0.00)
Conv_miss = GRAPH(Period)
(1.00, 0.00), (2.00, 0.049), (3.00, 0.096), (4.00, 0.188), (5.00, 0.295), (6.00, 0.415), (7.00, 0.543), (8.00, 1.20)
Conv_parity = GRAPH(Period)
(1.00, 0.00), (2.00, 0.951), (3.00, 1.90), (4.00, 2.81), (5.00, 3.71), (6.00, 4.59), (7.00, 5.46), (8.00, 5.80)
Conv_parity2 = GRAPH(Period)
(1.00, 0.00), (2.00, 0.951), (3.00, 3.71), (4.00, 8.10), (5.00, 14.0), (6.00, 21.4), (7.00, 30.3), (8.00, 33.8)
Conv_wt = GRAPH(Period)
(1.00, 164), (2.00, 205), (3.00, 249), (4.00, 274), (5.00, 277), (6.00, 289), (7.00, 299), (8.00, 302)

Production Function
predicted_litter_wt = 6.303516*Parity-0.98179*Parity2+0.651518*Inseminations+0.46765*Housing*Inseminations-0.05123*Inseminations2-0.06461*Housing*Inseminations2+0.079408*NLD-0.20599*Housing*NLD-0.00093*NLD2+0.001255*Housing*NLD2+0.991781*Lactation_feed+0.132621*Housing*Lactation_feed-0.00371*Lactation_feed2-0.00034*Housing*Lactation_feed2+1.943581*Meds-2.2953*Housing*Meds-0.34982*Meds2+0.175995*Housing*Meds2

Revenues
gilt_weight_at_initial_breeding = 133
price_per_100kg_culled_boar = 60
price_per_100kg_dressed_sow_#1_or_#2 = 69.45
price_per_100kg_dressed_sow_#3 = 60.53
price_per_6kg_weanling = 34.67
price_per_kg_weanling = price_per_6kg_weanling/6
SALVAGE_BOAR_REVENUE =
replacing_boars*weight_of_boar_at_culling*price_per_100kg_culled_boar/100
SALVAGE_SOW_REVENUE =
price_per_100kg_dressed_sow_#1_or_#2/100*cull_weight*full_value_sales+price_per _100kg_dressed_sow_#3/100*cull_weight*low_value_sales
UNBRED_GILT_REVENUE = IF TIME=0 THEN ((Herd_size/gilt_farrowing_rate)-Herd_size)*gilt_weight_at_initial_breeding*price_per_100kg_dressed_sow_#1_or_#2/100 ELSE IF culling_unbred_gilts<Herd_size THEN culling_unbred_gilts*gilt_weight_at_initial_breeding*price_per_100kg_dressed_sow_#1_or_#2/100 ELSE culling_unbred_gilts*replacement_cost
WEANLING_REVENUE = price_per_kg_weanling*Weanling_production
weight_of_boar_at_culling = 225

Weanling production
Boars(t) = Boars(t - dt) + (replacing_boars - culling_boars) * dt
INIT Boars = Sows/200

INFLOWS:
replacing_boars = Boars*boar_replacement_rate
OUTFLOWS:
culling_boars = Boars*periodic_boar_cull_rate
Culled_sows(t) = Culled_sows(t - dt) + (culling_sows) * dt
INIT Culled_sows = 0

INFLOWS:
culling_sows = Sows*sow_cull_rate
Full_value_culls(t) = Full_value_culls(t - dt) + (full_value_sales) * dt
INIT Full_value_culls = 0

INFLOWS:
full_value_sales = Selling_culls*Percentage_full_value
Low_value_culls(t) = Low_value_culls(t - dt) + (low_value_sales) * dt
INIT Low_value_culls = 0

INFLOWS:
low_value_sales = Selling_culls*(1-Percentage_full_value)
Period(t) = Period(t - dt) + (Adding_parities - Culling) * dt

INIT Period = 1

INFLOWS:
Adding_parities = 1
OUTFLOWS:
Culling = IF (sow_cull_rate=1) THEN (Period) ELSE 0
Purchased_gilts(t) = Purchased_gilts(t - dt) + (Gilt_purchase - culling_unbred_gilts - gilt_breeding) * dt
INIT Purchased_gilts = 0

INFLOWS:
Gilt_purchase = Herd_size/gilt_farrowing_rate
OUTFLOWS:
culling_unbred_gilts = IF gilt_breeding=0 THEN Purchased_gilts ELSE (Herd_size/gilt_farrowing_rate)-Herd_size
gilt_breeding = replacement_rate_of_sows*Purchased_gilts*gilt_farrowing_rate
Salvaged_culls(t) = Salvaged_culls(t - dt) + (Selling_culls) * dt
INIT Salvaged_culls = 0

INFLOWS:
Selling_culls = culling_sows*Percentage_salvageable
Sows(t) = Sows(t - dt) + (gilt_breeding - culling_sows) * dt
INIT Sows = Herd_size

INFLOWS:
gilt_breeding = replacement_rate_of_sows*Purchased_gilts*gilt_farrowing_rate
OUTFLOWS:
culling_sows = Sows*sow_cull_rate
Wasted_culls(t) = Wasted_culls(t - dt) + (Disposing_culls) * dt
INIT Wasted_culls = 0

INFLOWS:
Disposing_culls = culling_sows*(1-Percentage_salvageable)
Wt_Weanlings_Sold(t) = Wt_Weanlings_Sold(t - dt) + (Weanling_production) * dt
INIT Wt_Weanlings_Sold = 0

INFLOWS:
Weanling_production = Sows*predicted_litter_wt
Age_cull = IF (Period=(Age_threshold)) THEN 1 ELSE 0
Age_threshold = 6
annual_boar_cull_rate = 50
boar_replacement_rate = periodic_boar_cull_rate
gilt_farrowing_rate = 0.895
Herd_size = 600

Percentage_full_value = IF Age_cull=1 THEN 1 ELSE IF Housing=0 THEN MONTECARLO(71.4) ELSE MONTECARLO(92.3)
Percentage_salvageable = IF Age_cull=1 THEN 1 ELSE IF Housing=0 THEN MONTECARLO(75) ELSE MONTECARLO(92.9)
periodic_boar_cull_rate = annual_boar_cull_rate/100*143/365
replacement_rate_of_sows = sow_cull_rate
sow_cull_rate = IF ((Age_cull+CULL_FUNCTION)>=1) THEN 1 ELSE 0

Appendix G. Mean, median and skewness of culling function variables

Variable	**Mean**	**Median**	**Skewness**
Parity	2.59	3	0.21
Barn x Parity	1.3	0	0.89
WT	258.8	267.0	-0.39
Barn x WT	134.2	188.0	0.06
BCS	3.41	3.42	0.39
Barn x BCS	1.75	3	0
BF	22.53	22.55	0.25
Barn x BF	11.57	13.8	0.24
GS	0.21	0	2.82
Barn x GS	0.085	0	4.94
FT	14.52	14	-0.33
Barn x FT	7.39	12	-0.011
MISS	0.22	0	1.86
Barn x MISS	0.12	0	2.75

Appendix H. Reasons for culling experimental sows in ALT (using terminology from Table 4.3)

Sow	Reason for cull	Herd life (days)	Period of cull	Parity at cull	Reported reason of cull
2	Finished on trial	999	7	7	TERM
5	Reproductive problems	801	6	4	REPRO
14	Finished on trial	993	7	7	TERM
23	Destroyed following sickness	273	2	2	PHYS
25	Finished on trial	970	7	6	TERM
68	Lame (repro issues?)	939	7	5	PHYS
70	Finished on trial	996	7	7	TERM
76	Finished on trial	977	7	7	TERM
89	Open; reproductive problems	737	6	5	REPRO
151	Low production	554	4	4	PROD
153	Open (low births)	547	4	3	REPRO
155	Finished on trial (open)	951	7	6	REPRO
157	Finished on trial	976	7	7	TERM
158	Open; reproductive problems	179	2	1	REPRO
159	Finished on trial (open)	950	7	5	REPRO
160	Low weaned	545	4	4	PROD
162	Reproductive problems	573	5	4	REPRO
163	Finished on trial (open)	946	7	6	REPRO
165	Low production	560	4	4	PROD
166	Finished on trial	972	7	7	TERM
167	Finished on trial	1007	8	7	TERM
168	Finished on trial (open)	948	7	6	REPRO
169	Open; reproductive problems	747	6	5	REPRO
170	Finished on trial	985	7	7	TERM
171	Open, low births	546	4	3	REPRO
174	Finished on trial	983	7	7	TERM
175	Finished on trial	990	7	7	TERM
176	Open; reproductive problems	189	2	1	REPRO
178	Finished on trial (open)	832	6	6	REPRO
179	Finished on trial	989	7	7	TERM
180	Returns to service	1015	8	5	REPRO
181	Reproductive problems	887	7	5	REPRO
182	Finished on trial	994	7	7	TERM
185	Low production	983	7	7	PROD

Sow	Reason for cull	Herd life (days)	Period of cull	Parity at cull	Reported reason of cull
192	Reproductive problems	173	2	1	REPRO
201	Low production, open	559	4	4	PROD
203	Finished on trial	999	7	6	TERM
204	Open; reproductive issues	544	4	3	REPRO
207	Open; reproductive problems	608	5	4	REPRO
209	Lame	511	4	3	PHYS
241	Finished on trial (open)	809	6	5	REPRO
242	Low production	554	4	4	PROD
246	Low production	560	4	4	PROD
247	Finished on trial (open)	950	7	5	REPRO
248	Finished on trial (open)	947	7	6	REPRO
249	Finished on trial	982	7	6	TERM
250	Poor (milk) production	973	7	7	PROD
251	Finished on trial	904	7	6	TERM
252	Non-productive/low production	879	7	5	PROD
254	Reproductive problems	804	6	4	REPRO
255	Returns to service	607	5	2	REPRO
256	Finished on trial	1009	8	7	TERM
257	Finished on trial	1008	8	7	TERM
258	Low production	558	4	4	PROD
259	Poor (milk) production	968	7	7	PROD
261	Open; reproductive problems	595	5	4	REPRO
263	Finished on trial (open)	874	7	5	REPRO
264	Size	764	6	4	PHYS
268	Reproductive problems	506	4	2	REPRO
270	Finished on trial	986	7	7	TERM

Appendix J. Reasons for culling experimental sows in CONV (using terminology from Table 4.3)

Sow	Reason for cull	Herd life (days)	Period of cull	Parity at cull	Reported reason of cull
29	Low production	950	7	6	PROD
31	Finished on trial (open)	974	7	6	REPRO
51	Uterine infection	889	7	6	PHYS
55	Open; reproductive problems	178	2	1	REPRO
57	Reproductive problems	372	3	2	REPRO
63	Lame	541	4	3	PHYS
72	Finished on trial	958	7	7	TERM
81	Finished on trial	938	7	6	TERM
84	Prolapsed	281	2	2	PHYS
86	Low production	695	5	5	PROD
94	Finished on trial	1091	8	7	TERM
98	Finished on trial	1059	8	7	TERM
99	Mastitis	446	4	3	PHYS
102	Foot infection (RH)	898	7	6	PHYS
105	Finished on trial	962	7	7	TERM
106	Leg and shoulder Injury	608	5	4	PHYS
115	Poor structure	841	6	6	PHYS
119	Reproductive problems	785	6	5	REPRO
120	Finished on trial	1091	8	7	TERM
121	Returns to service	1013	8	6	REPRO
122	Finished on trial	985	7	7	TERM
123	Broken hip	203	2	1	PHYS
125	Returns to service	255	2	1	REPRO
126	Open; reproductive problems	190	2	1	REPRO
127	Finished on trial (open)	949	7	6	REPRO
128	Finished on trial	1020	8	6	TERM
129	Weak hind end	443	4	2	PHYS
132	Finished on trial	984	7	7	TERM
133	Spinal injury/defect	425	3	2	PHYS
134	Finished on trial	997	7	7	TERM
135	Poor structure	553	4	3	PHYS
136	Poor (milk) production	980	7	7	PROD
137	Finished on trial	971	7	7	TERM
138	Open; reproductive problems	318	3	2	REPRO

Sow	Reason for cull	Herd life (days)	Period of cull	Parity at cull	Reported reason of cull
139	Died; complications w/ farrowing	399	3	3	PHYS
140	Finished on trial	1001	7	6	TERM
142	Poor (milk) production	720	6	5	PROD
144	Finished on trial	975	7	7	TERM
145	Open; reproductive problems	593	5	4	REPRO
146	Finished on trial	977	7	7	TERM
149	Finished on trial	957	7	6	TERM
271	Finished on trial	917	7	5	TERM
272	Finished on trial (open)	908	7	6	REPRO
273	Finished on trial	972	7	7	TERM
276	Finished on trial	972	7	7	TERM
277	Farrowing difficulties	850	6	6	PROD
279	Open; reproductive problems	176	2	1	REPRO
280	Poor udder condition	912	7	5	PROD
281	Poor (milk) production	972	7	7	PROD
283	Finished on trial (open)	839	6	6	REPRO
284	Open; reproductive problems	185	2	5	REPRO
285	Finished on trial	979	7	7	TERM
286	Poor (milk) production	881	7	6	PROD
288	Died in farrowing crate	252	2	1	PHYS
289	Low production	832	6	6	PROD
294	Poor (milk) production	973	7	7	PROD
295	Finished on trial	987	7	7	TERM
296	Finished on trial	949	7	6	TERM
297	Finished on trial	956	7	6	TERM
298	Open; reproductive problems	184	2	6	REPRO
300	Finished on trial	983	7	7	TERM

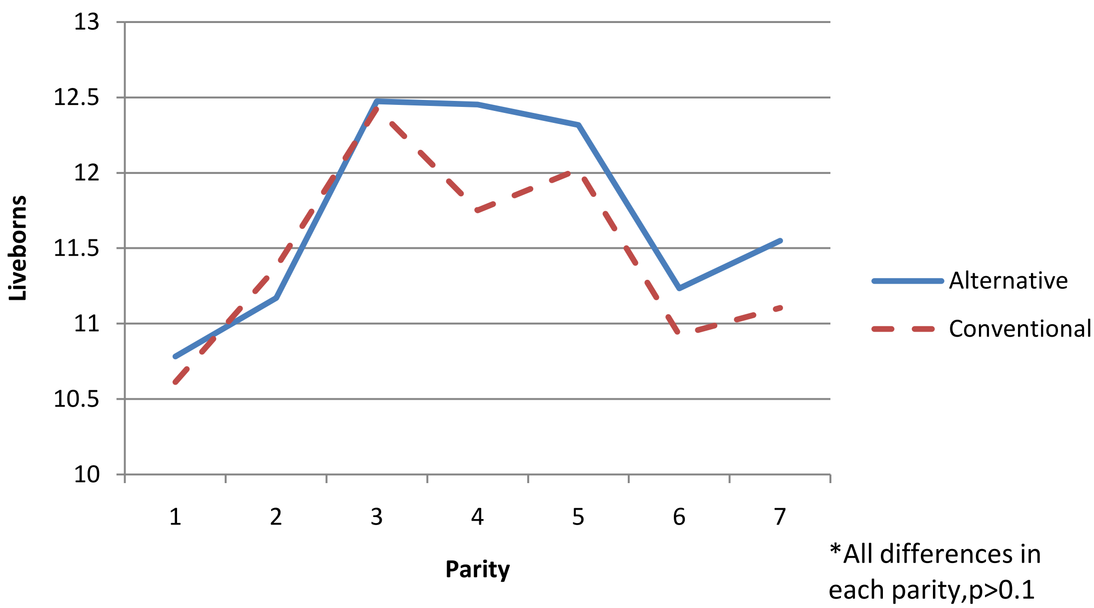
Appendix K. Reasons for culling in ALT per period (derived from Appendix H)

Period	1	2	3	4	5	6	7	8	
Sows (n) at start of period	**60**	**60**	**56**	**56**	**44**	**40**	**33**	**4**	**TOTAL**
Low production	0	0	0	7	0	0	4	0	**11**
Reproductive issues	0	3	0	4	4	6	8	1	**25**
Physical issues	0	1	0	1	0	1	1	0	**4**
TOTAL NON-TERMINAL CULLS	**0**	**4**	**0**	**12**	**4**	**7**	**13**	**1**	**41**
Terminal culls	0	0	0	0	0	0	16	3	**19**
TOTAL CULLS	**0**	**4**	**0**	**12**	**4**	**7**	**29**	**4**	**60**

Appendix L. Reasons for culling in CONV per period (derived from Appendix J)

Period	1	2	3	4	5	6	7	8	
Sows (n) at start of period	**61**	**61**	**52**	**48**	**44**	**41**	**35**	**5**	**TOTAL**
Low production	0	0	0	0	1	4	5	0	**10**
Reproductive issues	0	6	2	0	1	1	3	1	**14**
Physical issues	0	3	2	4	1	1	2	0	**13**
TOTAL NON-TERMINAL CULLS	**0**	**9**	**4**	**4**	**3**	**6**	**10**	**1**	**37**
Terminal culls	0	0	0	0	0	0	20	4	**24**
TOTAL CULLS	**0**	**9**	**4**	**4**	**3**	**6**	**30**	**5**	**61**

Appendix M. Average number of piglets born alive (liveborns)



Appendix N. Experimental and model-predicted weanling production (kg) per period

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**
ALT – experimental (kg)	51.3	61.9	80.6	60.8	50.5	59.1	49.3
ALT - model (kg)	62.9	60.0	72.7	63.9	57.4	55.8	48.8
% difference	**22.7**	**-3.1**	**-9.8**	**5.1**	**13.7**	**-5.6**	**-1.1**
CONV - experimental (kg)	50.8	58.5	61.0	56.9	58.0	53.3	52.1
CONV - model (kg)	50.4	50.0	54.6	54.0	56.8	50.4	48.4
% difference	**-0.8**	**-14.6**	**-10.6**	**-5.2**	**-2.1**	**-5.4**	**-7.2**

Appendix O. Experimental and simulation model-predicted culling rates (%)

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**
ALT – experimental (%)	0	6.7	0	21.4	9.1	17.5	87.9
ALT - model (%)	0	5.0	6.0	9.3	12.6	17.4	100
CONV - experimental (%)	0	14.8	7.7	8.3	6.8	14.6	85.7
CONV - model (%)	0	12.7	7.4	5.6	7.4	9.7	100

Appendix P. Sensitivity of optimal terminal cull to discount rate

Variable & Value	**Barn**	**Period 5 Terminal Cull**	**Period 6 Terminal Cull**	**Period 7 Terminal Cull**
Discount rate, 0%	ALT	1240.57 ± 6.81	1335.29 ± 6.61	1290.27 ± 7.07
Discount rate, 5%	ALT	689.52 ± 4.43	754.33 ± 4.48	728.43 ± 4.31
Discount rate, 10%	ALT	393.33 ± 3.41	437.17 ± 3.49	425.68 ± 3.50
Discount rate, 0%	CONV		-302.08 ± 13.10	35.02 ± 13.75
Discount rate, 5%	CONV		-306.85 ± 8.51	-87.35 ± 9.17
Discount rate, 10%	CONV		-322.66 ± 6.57	-158.14 ± 7.13

Appendix Q. Sensitivity of PVNR (CDN$; mean ± SE) to minor costs

	ALTERNATIVE		**CONVENTIONAL**	
Sensitivity	**Medicine/ vaccination cost**	**Semen cost**	**Medicine/ vaccination cost**	**Semen cost**
+40%	691.76 ± 4.55	480.98 ± 4.40	-173.71 ± 10.07	-326.49 ± 9.53
+20%	721.76 ± 4.42	614.55 ± 4.47	-122.24 ± 9.44	-222.43 ± 9.70
Default	**754.33 ± 4.48**		**-87.35 ± 9.17**	
-20%	773.94 ± 4.60	890.28 ± 4.38	-45.07 ± 9.56	23.26 ± 9.57
-40%	812.03 ± 4.47	1030.73 ± 4.27	-15.15 ± 9.35	163.07 ± 9.12