Title: Strategies to optimize sow longevity **NPB #03-110**

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Abstract: Sow longevity and production records of 148,568 sows in 32 Central Illinois commercial herds from January 1995 to May 2001 were analyzed using survival and repeatability models respectively, to characterize sow performance and profitability. The largest difference in longevity between the major genetic lines was approximately one parity. The significant differences in sow removal rate or hazard among genetic lines constitute evidence that sow longevity could be improved by using replacements from specific genetic lines. Assuming a zero discount rate per parity, genetic lines with longer herd life resulted in greater profit than genetic lines with shorter herd life, however this difference was reduced with increasing discount rates.

A dynamic programming model was used to find the optimal parity for voluntary replacement in sow breeding herds and the associated economic value while accounting for involuntary culling. Results from the sensitivity analysis showed that sow replacement cost and salvage value had the highest impact on the optimal parity at replacement followed by the returns per piglet. In comparison, the discount rate and number of parities per year generally had smaller influence on the optimal parity. The optimal replacement age was 6 parities under the default or average biological and economical conditions and this is higher than three to four parities, the average age at removal in US breeding herds. Our study demonstrated that genetic lines and minimization of voluntary culling in early parities can provide producers with more opportunities to maximize profitability through effective voluntary culling.

Introduction: The investment in sow replacement constitutes a major budget decision for many producers. Forty to fifty percent of the sows are removed by parity three or four, an age when most replacements barely recover their initial cost. Incentives to increase sow longevity include larger litters with heavier pigs in older parities; fewer non-productive days; acquired immunity to herd diseases; higher sow salvage value, and lower replacements cost. Sow longevity is an example of survival data and is most adequately studied using survival analysis. However, few studies have used models appropriate to describe sow longevity in US commercial breeding herds.

Replacement decision-making is a continual and complex decision process that is based on biological and economic reasons. It is important to assess the impact of replacing a sow at different ages in economical terms while accounting for involuntary replacement. A model for optimal replacement of assets has been applied for dairy cattle replacements. This informative approach has not been applied to sow replacement in US herds. In addition, sensitivity analyses are required to identify the optimal replacement parity for a wide range of biological and economic conditions relevant to the US swine industry.

Objectives: The long term goal is to provide guidelines to maximize pork production efficiency and animal well-being. The objective of this research was to address the pork industry concerns about the deteriorating sow longevity statistics through a comprehensive characterization of the major factors and accurate portrait of the biological and financial aspects of sow longevity and lifetime production. The central hypothesis is that longevity is the result of a complex interplay of involuntary (e.g. mortality, disease) and voluntary (e.g. number and weight of pigs weaned) culling practices, genetics, environmental and financial factors. These factors must be studied simultaneously to identify the optimal longevity structures within different contexts. To accomplish this, the specific aims are: a) to identify the factors influencing sow longevity while accounting for removal reason using appropriate statistical methods, and b) to compare alternative practices (e.g. genetic line selection, culling scheme) to optimize sow longevity using financial indicators. All these objectives were successfully accomplished.

Materials & Methods: Records from 32 herds from Central Illinois in the US Midwest were obtained from January 1995 to May 2001(Rodriguez-Zas et al., 2003). A total of 148,568 sows that farrowed on average 2.2 times per year with an average of 10.4 live piglets per litter during this period were analyzed. The average replacement rate, culling rate and death rate were 59.8%, 41.6% and 9.7%, respectively. Eight genetic lines were frequently present in multiple herds. Two indicators of sow longevity, herd life (total number of days from first service until removal from the herd) and productive days (total number of days the sow gestated and lactated until removal from the herd), were analyzed. The measurements of sow productivity studied were the total number of piglets born, the number of piglets born alive, litter size at weaning, total weight of litter at birth and total weight of litter at weaning.

Survival and repeated measures analyses

Longevity was characterized with a hazard function that represents the instantaneous removal rate for a sow remaining in the herd to a particular time point using survival analysis. The hazard function for a sow at any particular time was described with a linear fixed effects proportional hazards model with Cox and Weibull models using the Phreg and Lifereg procedures of SAS (SAS Inst. Inc., Cary, NC), respectively. Measurements of sow productivity were analyzed using repeated models and accounted for the correlation among measurements from the same sow. The analysis was conducted using the Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). The final explanatory variables included in the models were herd-year of entry, genetic line, month of farrowing and parity A detailed description of the models is presented in Rodriguez-Zas et al. (2003).

Comparison of genetic lines

The economic comparison of the genetic lines requires the simultaneous consideration of longevity and performance because lines differ in the longevity and performance ranking. The net present value (NPV) analysis combines the length and amount of investment, the time necessary for an investment to be profitable and the cost adjusted by a discount (a combination of inflation and interest rates and risk) rate per parity. The net present value per sow was computed using the median longevity of the genetic line of interest, different discount rates and net income per litter values. For this comparison, each parity was assumed to have the same net income (either $10 or $50 per parity sow) and this income was pro-rated for partial parities. All genetic lines had the same net gilt replacement cost ($250) and salvage cost ($150). A detailed description of the computations is provided in Rodriguez-Zas et al. (2003).

Optimum parity at replacement

A dynamic programming approach was used to compute the capitalization of the weighted average of expected net revenues into perpetuity for an infinite planning horizon, V(T) and identify the optimal parity at replacement. This economic indicator is a function of the probability that a sow in any one parity will survival to the following parity with normal productivity, the discount rate, the voluntary replacement of a sow after parity T, the net revenue of a sow in absence of replacement costs due to involuntary culling in parity t, and the replacement cost of a sow due to involuntary culling in parity t.

Input variable values and sensitivity analysis

The calculations in this study were based on a breed-to-wean swine operation. The biological inputs used in the model were the sow survival per parity, litter size at weaning, number of parities per year and rate of involuntary culling. The default or standard values for the biological indicators were obtained from Rodriguez-Zas et al. (2003). Records from the first ten parities were considered because only a small proportion of herds reported parities greater than ten. Survival rates per parity only considered the proportion of sow reported dead in terms of the involuntary culling criterion. Sensitivity analysis was performed for all the input variables with respect to the expected net revenues to identify changes in the optimal parity at replacement. The default values for the inputs are given in Table 1 in US dollars and taxation was not considered, the default and sensitivity values for involuntary culling rate across parities are given in Table 2 and the default and sensitivity values for litter size at weaning across parities are given in Table 3. These descriptors are available in Southey et al. (2004, submitted).

Table 1 Default values.

Parameter	Value
Parity per year:	2.2
Discount rate:	10%
Yearly costs:	$500
Returns per piglet:	$35
Sow cost:	$250
Salvage value:	$150
Building per sow:	$1100
Yearly interest for buildings:	$50

Table 2 Involuntary culling rate (%) scenarios

Parity	Default	A	B	C	D	E
1	1.54	0	0.05	0.1	2.00	2.00
2	3.57	0	0.05	0.1	3.00	5.00
3	3.22	0	0.05	0.1	4.00	8.00
4	3.56	0	0.05	0.1	5.00	11.00
5	3.88	0	0.05	0.1	6.00	14.00
6	3.94	0	0.05	0.1	7.00	17.00
7	3.61	0	0.05	0.1	8.00	20.00
8	3.81	0	0.05	0.1	9.00	23.00
9	3.75	0	0.05	0.1	10.00	26.00
10	4.10	0	0.05	0.1	11.00	29.00

Table 3 Litter size at weaning scenarios.

Parity	Default	A	B	C	D
1	8.96	8	10	9.85	8.06
2	9.42	8	10	10.36	8.47
3	9.29	8	10	10.22	8.36
4	9.12	8	10	10.03	8.21
5	8.85	8	10	9.74	7.97
6	8.59	8	10	9.44	7.73
7	8.35	8	10	9.18	7.51
8	8.11	8	10	8.92	7.29
9	7.90	8	10	8.69	7.11
10	7.92	8	10	8.69	7.13

Economic output measurements

The net present value of sales, costs and net returns were obtained for purchasing an average sow that enters the herd as gilt and exits after the optimum parity. This included the initial cost of the gilt at the start and the discounted sales and costs per parity weighted by the probability of surviving that parity until the optimal parity was reached. In addition to the regular costs and income, the costs of replacing the proportion of sows that failed at each parity were included. Annuity equivalent was computed on the cumulative net present value of returns adjusted for the number of parities per year. Internal rate of returns (IRR) and marginal or modified internal rate of returns (MIRR) were computed on the net present value of the net returns assuming that the finance discount rate was equal to the refinance discount rate.

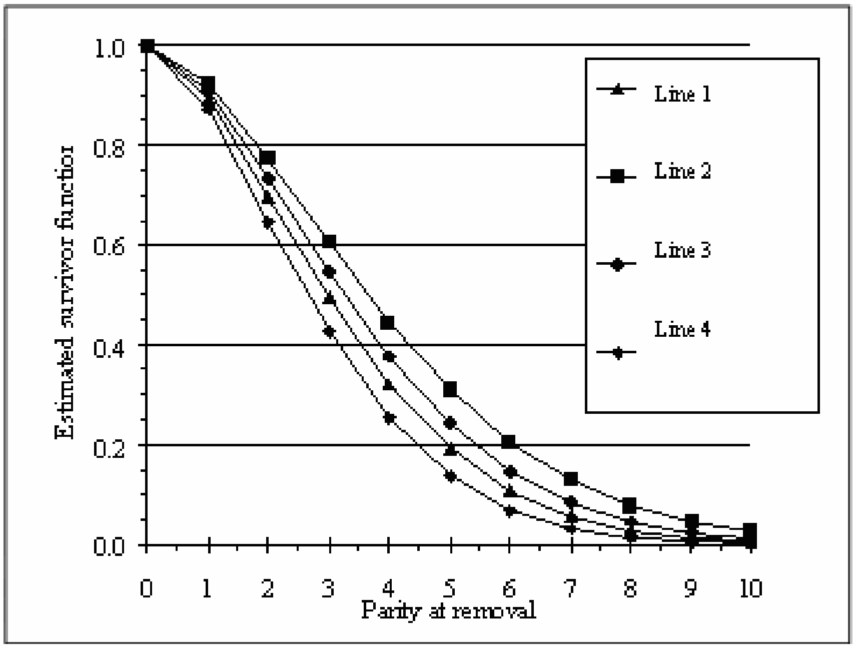
The investment indicators of the sow enterprise were computed assuming a fixed enterprise costs. The return on income was equal to the sum of net present value of the net revenue until the optimum parity divided by the sum of the sow cost and building and equipment costs. The return on assets was equal to the sum of net present value of the net return until the optimum parity plus the interest on buildings divided by the cost of buildings. The return on sales was equal to the net present value of sales divided by the net value of revenue (Southey et al., 2004 submitted).

Results:

Sow longevity and performance

The maximum predicted herd life after adjustment for genetic line ranged between 700 and 900 d while minimum predicted herd life after adjustment for genetic line ranged between 150 and 300 d. The survival for four genetic lines is presented in Figure 1. The herd-year effect had a significant ($P < 0.0001$) influence on sow longevity with no clear trend across the period studied (Rodriguez-Zas et al., 2003). The interaction between year of entry or herd and genetic line was not significant ($P < 0.1$). The estimated hazard ratios for herd life corresponding to the major genetic lines were computed relative to the most frequent line termed reference line. Sows from the best line had a 22% less probability of being removed than sows from the reference genetic line. Sows from the worst genetic line had a 20% greater chance of being removed than sows from the reference genetic line. The best four genetic lines formed a group that was significantly less likely ($P < 0.05$) to be culled than the group formed from by the worse three genetic lines ($P < 0.05$) while the reference line was intermediate (Rodriguez-Zas et al., 2003). A reference line sow has a 89% probability to remain in the herd for one parity and this probability drops to 32% and 3% by the fourth and eighth parities, respectively. Over 50% of sows in the worse genetic line in terms of herd life were removed by the end of the third parity. In contrast, four parities would be necessary to remove 50% of sows from the other genetic lines. The probability of a sow reaching 600 d (approximately four parities) of herd life ranged from 29% to 48%. The most extreme genetic lines differed in herd life by 158 d or approximately one parity. The estimated hazard ratios for productive days corresponding to each genetic line are summarized in Rodriguez-Zas et al. (2003).

Figure 1. Survival function for four genetic lines.



The total number of piglets born and the number of piglets born alive were similar among genetic lines (Rodriguez-Zas et al., 2003). Although genetic line was significant, the difference in total born and weaned between the most extreme genetic lines was 0.46 and 0.64 of a piglet respectively. The genetic lines had very similar litter weights at birth and at weaning when unadjusted for litter size. The genetic lines with larger litters at birth tended to have higher weights but this difference was not present at weaning. This discrepancy may be due to cross-fostering or other management practices. Litter size and weight at birth and weaning generally increased from the first to the fourth parity and decreased in subsequent parities.

Economic comparison of genetic lines

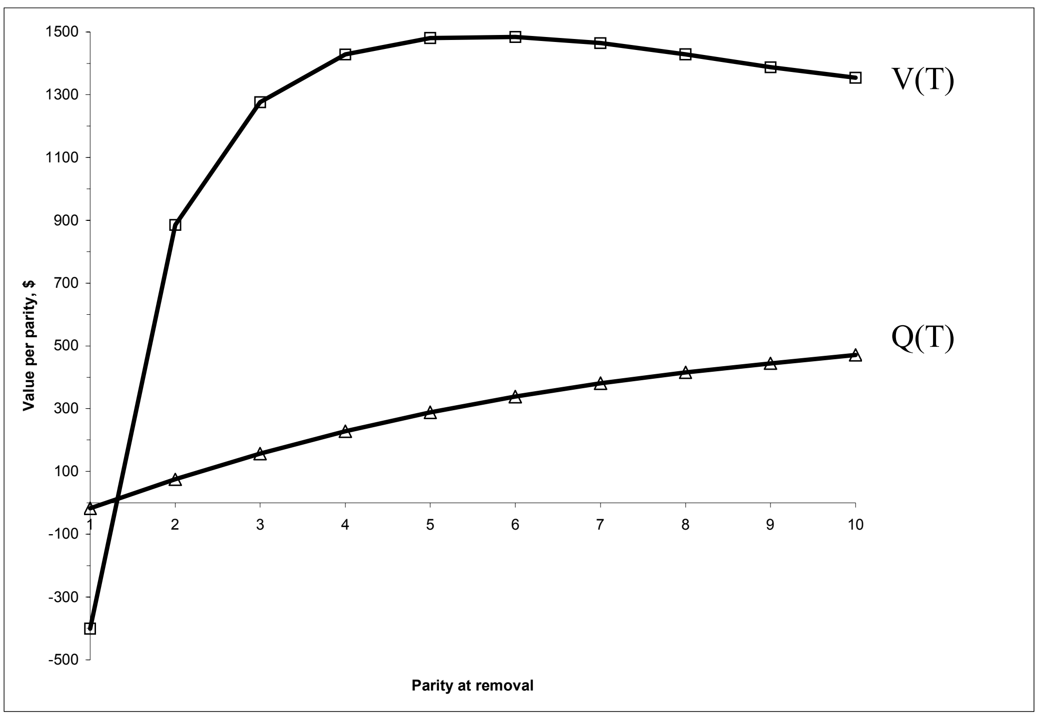
For a net income of $50 per parity, 2.0 and 3.68 parities are required to recuperate the initial investment (replacement) cost of the gilt under zero and 10% discount rates, respectively. Whereas 10 parities are required to recuperate the investment cost if the net income is $10 per litter and the discount rate is zero. Consequently, maximizing the net income per litter is important, not only to the overall profitability but also to maximize the benefit of longevity. Assuming a discount rate of zero, the difference between genetic lines was reduced to the difference in longevity multiplied by the net income per litter. Considering a $50 net income per litter, the difference between the best and worst longevity lines was $52.39 and the difference between the best two longevity lines was $13.94. Considering a $10 net income per litter, the difference between the best and worst longevity lines was $10.48 and the difference between the best two longevity lines was $2.79. The relative value of the high longevity line decreased with increasing interest rates because the value of income decreases with increasing time (Rodriguez-Zas et al., 2003)

Optimum parity at replacement

The weighted average of expected net revenues (V(T)) and the net present value of net revenue (Q(T)) increases from parity one to an optimum at parity six and gradually decreases after parity six (Figure 2).

Number of parities per year had no substantial effect on the optimal parity at removal. For the default values, the breakeven number of parities was between 1.8 and 2.0 parities. Increasing the number of parities per year from 2.0 to 2.2 and 2.5 increased the net revenue by $117 and $262, respectively. For the default discount rate of 10%, investment on a sow herd with 2.2 or more parities per year would be favored over some alternative investment with a 10% return (Southey et al., 2004 submitted).

Figure 2. The net present value of net revenue, Q(T) and V(T) by parity



The assumption of a constant involuntary replacement rate resulted in an optimal parity of six. The optimal parity at replacement was lower in the scenarios with increasing rate of involuntary replacement across parities, than in the default scenario or constant replacement rates scenarios (Southey et al., 2004 submitted). When the default litter sizes per parity were increased by 10% then the optimal parity was reduced by one parity. Reducing the default litter size by 10% did not change the optimal parity but resulted in a small loss. Simultaneous changes in litter size and replacement rate had little or no impact on the optimal parity. However, these changes had an impact on the economic indicators (Table 4).

Table 4. Optimal parity, NPV, annuity equivalent and (marginal) internal rate of return ((M)IRR) for the default litter size at weaning and different involuntary replacement rate scenarios.

Involuntary culling rate	Optimal parity	NPV at optimum	Annuity equivalent	IRR	MIRR
Default	6	$154.39	$67.45	17.46%	12.09%
A	6	$210.94	$92.15	22.69%	13.50%
B	6	$123.52	$53.96	13.98%	11.16%
C	6	$36.09	$15.77	4.37%	8.26%
D	5	$96.29	$49.44	12.93%	10.75%
E	4	$10.36	$6.51	1.79%	8.12%

The discount rate had minor influence of the optimal parity. At a discount rate of 10% or higher, the optimal parity was six and decreased to five with a discount rate of 5% or lower. A 10% discount rate provided the best net present value of net revenue. The 1% and 10% discount rates provided the best economic indicators and discount rates greater than 10% showed the worse indicators. The yearly fixed costs had a minimal impact of optimum parity. Costs less than $300 resulted in an optimal age at replacement of five parities and greater than $300 resulted in six parities. Costs per year greater than $500 resulted in a non-profitable enterprise. The optimum parity changed from seven to five parities by changing the returns per piglet from $25 to $40. Large increases in the returns per piglet were required to lower the optimal parity. Minimum returns of $66 per piglet weaned would be required to reduce the optimal parity to four with the other values remaining the same. With higher returns per piglet, the indicators clearly support the current investment on a sow breeding herd with optimal age at replacement.

Sow replacement cost and salvage value had a substantial impact on the average optimal parity at replacement (Southey et al, 2004 submitted). The lowest optimal parity was three and occurred when the net replacement value was zero and when the sow cost was $150 or $100. Increasing the net replacement value to $50, and $100 caused the optimal parity to increase to five and seven, respectively. The salvage value has similar effect to sow cost in that reducing the salvage value by $50 typically increased the optimal parity by one. The combination of sow cost, salvage value, and returns per piglet weaned also had an impact on optimal parity. An increase in the returns per piglet weaned was often sufficient to overcome the differential between sow cost and salvage value or reduce the optimal parity (Table 5).

Under the default scenario, the return of sales and investment were 9.78% and 11.44%, respectively. Under increasing sow replacement costs and the same salvage value, the net present value of sales and costs increased due to the increase in the optimal parity. The highest returns on sales occurred with a sow cost of $150 that was 1.1% higher than the default scenario. Increasing the litter size by 1.1% per parity increased the net returns by $91 over the default scenario even though the optimal parity was smaller. This also resulted in higher rates of returns on investment, assets and sales. Litter returns had the highest impact on these indicators.

Table 5. Influence of sow replacement cost, salvage value and returns per piglet on optimal parity.

Sow cost	Salvage value	Returns per piglet $20	$25	$30	$35	$40	$45	$50
$100	$0	7	7	6	6	5	5	5
$50	6	5	5	5	4	4	4	
$100	3	3	3	3	3	3	3	
$150	$0	10	8	7	7	6	6	6
$50	7	7	6	6	5	5	5	
$100	5	5	5	4	4	4	4	
$150	3	3	3	3	3	3	3	
$200	$0	10	10	10	8	7	7	7
$50	10	8	7	7	6	6	6	
$100	7	7	6	6	5	5	5	
$150	5	5	5	4	4	4	4	
$250	$0	10	10	10	10	8	8	7
$50	10	10	9	8	7	7	7	
$100	10	8	7	7	6	6	6	
$150	7	7	6	6	5	5	5	

Discussion: The highest difference in herd life among genetic lines (approximately one parity) suggests that sow longevity can be improved by replacing a low longevity genetic line with another genetic line with higher expected longevity. The variation in longevity between herd and years is likely to be primarily related to management and economic factors and changes in genetic line composition of a herd.

Assuming an average of 2.35 parities per year and that four parities are required to recuperate the investment cost, a sow must remain in the herd for approximately 600 d. The probabilities to reach this age ranged between 0.31 and 0.48. This range suggests that most sows are likely to be culled before recuperating the investment cost. Considering two 1,000-sow herds using the highest and lowest lines for herd life in Table 4, 170 more sows from the highest line for herd life than the lowest line for herd life are expected to recuperate their initial purchase costs. These results exemplify the potential impact of genetic line decisions on profitability through the major impact on sow longevity and limited impact on performance. The net present value analysis allowed the simultaneous consideration of longevity and productivity indicators. Higher interest rates reduced the additional value of genetic lines with high longevity. The reduction depended on the net income per litter since the high longevity genetic lines tended to maintain their superiority over the low lines in the high income per litter scenarios. However, at high net income per litter the higher longevity lines remained profitable longer than low longevity lines over the range of discount rates considered. This result indicates that herds with a prevalence of sows with high longevity would be exposed to less economic risk than herds with low longevity. These calculations apply to the evaluation of systems on a per-sow basis. Subsequently, dynamic modeling was used to identify the optimal parity at replacement including biological and economical determinants and considering involuntary replacement. The net present value approach used considers the purchase of a gilt and the associated projected value of cash flows to a predetermined stopping point that generally ignores the sow herd dynamics. The stopping point was the optimum parity determined by the dynamic model.

The optimal parity at replacement for the default values in this study was six parities. This indicates that most producers are culling sows more aggressively than would be economically optimal because sows are usually replaced by the third or fourth parity. For the default scenarios, the difference between 4 and 6 parities was $102 per sow in our study. Results from this study confirmed the importance of sow replacement cost and sow salvage value on parity at optimum replacement and profitability. The returns on the weaned pigs had a lower impact on profitability. In this study, higher returns per piglet were able to offset high sow cost minus salvage value costs such that optimal parity decreased with higher returns.

Lay Interpretation: Early removal of sows from the herd due to mortality, health problems and low production is a major bottleneck in the swine industry that amounts to animal welfare and economic concerns due to replacement and veterinary treatment costs. The identification of the optimal average age for sow replacement is challenging due to the many biological and economic factors influencing net revenue. This study identified the factors influencing sow longevity, compared the impact of factors in economic terms, identified the optimal age at replacement for a wide range of production and economic scenarios and quantified the profits from effective removal at the optimal parity. Important differences in genetic lines were observed that could be translated in economic benefits provided that sows remained in the herd for sufficient period to recover the initial investment costs. The benefit of sow longevity was reduced when considering the discount rate used to compute the net present value.

The sow replacement cost and salvage value were the most important considerations in determining the optimal parity to replace sows while simultaneously considering involuntary culling. For most scenarios, producers tend to cull sows before sows become profitable. A reduction of the voluntary culling at early parities will give the producers more options to maximize profitability. The resulting bio-economical characterization of sow longevity can be used to identify bottlenecks and improve the productivity and economic efficiency of sow breeding herds.

References:

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