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**Integrated On-Farm Decision Making:  
Economic Implications of Increased Variation in Litter Size**

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**Abstract**

Increased litter sizes and associated piglet performance consequences, challenge swine producers. Stochastic modeling captured bioeconomic performance of individual piglets. As average litter size increased from 8.8 to 20.8 piglets, costs and revenues per head marketed from the demonstration herd decreased and total profit increased at a decreasing rate.

*Key words:* stochastic modeling, farm business management, swine litter size

## **Introduction**

Increased sow litter sizes have been motivated by economic incentives such as spreading fixed costs over increasing numbers of productive units. Larger average litter sizes have created many challenges associated with managing the resulting, increasingly variable piglet performance, including piglet birth weights, weaning weights, and overall profitability. According to USDA census data, sow litter sizes in Illinois have increased from 6.3 piglets per litter to 9.4 piglets per litter from 1950 to 2008, making this a relevant question to address for swine producers.

Several analyses have been completed surrounding the biological performance of piglets born in larger litters. Foxcroft, et al. (2010) found that as litter size increases, average birth weight of the litter decreases. Increased litter sizes can reduce average pig birth weight and weaning weights (Le Dividich, 1990; Milligan, et al., 2002). Lighter birth weights and weaning weights are shown to reduce the growth rates and survival rates throughout the pig's life (Knol, et al., 2002; Schinckel, et al., 2010). Reduced growth rates and survival rates are expected to impact the profitability of various swine production systems. Larger numbers of potentially increasingly difficult to manage piglets (reduced growth and survival rates) pose a challenge for today's swine management systems.

On one hand, increasing litter size reduces fixed cost per head. On the other, it potentially reduces the biological and economic performance of all the pigs in the litter. The economic consequences of increased litter size are not obvious due to the dynamic biological and economic interactions occurring as a result of changing litter size. The objective of this paper is to evaluate how changes in a hypothetical 10 sow demonstration herd's average litter size affect the group's profitability.

## Methods

To capture the highly dynamic nature of hog production, stochastic modeling has been used to generate a group of individual piglets that, by using draws from specific distributions, are uniquely different. This analysis used a small-scale demonstration sow herd (10 sows) to populate litters and assess the performance of the resulting group of piglets under various average litter size scenarios.

### *Methods: Modeling Farrow to Finish Animal Performance*

The biological implications of changing litter size were modeled beginning with the sow herd. The distribution of sow parity was modeled based on estimates for sow survival rates by Dhuyvetter (2000). For the 10 sows modeled, it was assumed that there was a single sow in parities 1,3,4,5,6,7,8, and 9 and 2 sows in parity 2. Litter sizes (total born), within parity, were assumed to be normally distributed with a mean litter size of 11.5, 12, and 12.5 for parity 1, parity 2, and greater than 2, respectively, with a standard deviation of 2.

Two distinct distributions were used to model piglet birth weight; 10% of piglets' birth weights were drawn from a normal distribution with a mean of 1.0 kg and a standard deviation of 0.10 kg (Schinckel et al, 2010). Ninety percent of piglets' birth weights were modeled with a mean of  $[1.657 \text{ kg} - 0.04725 * (\epsilon - 9.0)]$  with a standard deviation of  $[0.18 \text{ kg} + 0.0152 * (\epsilon - 9.0)]$ , where  $\epsilon$  is the total number born (Schinckel. et al., 2010). Using data from Milligan, et al. (2002), a further adjustment was made to piglet birth weight; piglet birth weight was adjusted by -0.10 kg, +0.05 kg, and +0.08 kg, for pigs born to sows in parity 1, 2, and greater than 2, respectively.

Estimates of body weights at 21-days of age were calculated to facilitate grow/finish growth modeling. Schinckel, et al. (2009a) found that 21-day body weight could be estimated using  $[2.56 \text{ kg} + 3.36 * (\text{BW}) - 0.3473 * (\text{BW})^2 + 0.72 * z_1]$  where BW is the piglet birth weight.<sup>1</sup> Adjustments to 21-day body weight were made for parity affect. Parity 1, parity 2, and those greater than parity 2 were adjusted by -0.10 kg, +0.04 kg, +0.09 kg, respectively (National Swine Improvement Federation, 1996; Milligan, et al., 2002). Based on data from Schinckel, et al. (2010) and The National Swine Improvement Federation (1996), additional adjustments to account for competition while nursing, the number of piglets each sow nursed, the number after transfer (NAT), was used.<sup>2</sup>

Schinckel, et al. (2010) fit growth data to the generalized Michaelis-Menten growth function (GMM function) to estimate individual pig's body weight on any given day. Following Schinckel, et al. (2010) individual birth weights of piglet  $i$ , estimated on day  $t$ , was calculated as,

$$(1) \quad WT_i = BW_i + \{ [WF - wf_i - BW_i] * [t / (K - k_i)]^c \} / \{ 1 + [t / (K - k_i)]^c \}$$

where,  $WT_i$  is the weight of the individual pig at  $t$  days of age;  $WF$  is 379.3 kg, the estimated mature body weight;  $K$  is 252.9, a parameter equal to the number of days until half of mature body weight is achieved;  $C$  is 1.819, a unit less parameter, and  $wf_i$  and  $k_i$ , are estimated following Schinckel, et al. (2010) as,

$$(2) \quad wf_i = b_o + [b_1 * (BW_i)] + [b_2 * (BW_i)^2 + [A + (10.2 * \Omega)] * \{ 1 - \exp[-B * (WT_{Day21})] \}$$

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1 Parameter  $z_1$  is one of several values used in this modeling to introduce a random effect. Throughout Schinckel, et al. (2010) and this analysis,  $(z_n)$  are incorporated as standard normal distributions.

2 See Schinckel, et al. (2010) for in-depth description of NAT. Adjustments to Schinckel, et al. (2010) unique to this model were for NAT greater than 10 and based on data from the National Swine Improvement Federation (1996). For NAT= 11, 0.91; NAT= 12, 0.83; NAT= 13, 0.77; NAT= 14, 0.71; NAT= 15, 0.67; NAT= 16, 0.63; NAT= 17, 0.59; NAT=18, 0.56; NAT=19, 0.53; NAT>19, 0.50.

where,  $b_0$  is 76.6, a unit less parameter;  $b_1$  is 49.2, a unit less parameter;  $b_2$  is -13.7, a unit less parameter;  $A$  is -181.1, a unit less parameter;  $\Omega$  is 1 for barrows and 0 for gilts;  $B$  is 0.1787, a unit less parameter;  $WT_{Day21}$  is the weight of an individual pig on day 21 of life, and

$$(3) \quad k_i = d_o + [d_1 * (BW_i - \varpi)] + [d_2 * (BW_i - \varpi)] + [E + (10.2 * \Omega)] * \{1 - \exp[-D * (WT_{Day21})^F]\}$$

where,  $d_0$  is 39.3, a unit less parameter;  $d_2$  is -10.4, a unit less parameter;  $\varpi$  is zero if BW is less than 1.1 kg and is 1.1 if BW is greater than or equal to 1.1 kg;  $d_3$  is -6.37, a unit less parameter;  $E$  is -51.3, a unit less parameter;  $D$  is 0.00251, a unit less parameter; and  $F$  is 3.276, a unit less parameter.

Adjustments to the pig body weight estimates were made to account for sow parity and crowding affects. Birth weights of pigs born to parity 1 sows were adjusted by factors of 0.965 and 0.970 for gilts and barrows respectively (Schinckel, et al., 2010). Crowding has been shown to reduce the average daily gains for grower/finisher pigs (Gonyou, et al., 2006). An adjustment for a reduced daily gain was made using the estimated body weight for a given day and the previous day's body weight. Following Gonyou, et al. (2006), the daily gain was adjusted for the crowding effect. When space allowance (SA) calculated as  $(\text{area, m}^2)/(\text{WT, kg})^{0.667}$  was less than 0.0336, the percent of expected daily gain achieved is defined as  $817 * SA + 72.55$  (Gonyou, et al., 2006). When SA was greater than or equal to 0.0336, no adjustment to expected daily gain was made (resulting in 100% of expected daily gain achieved).

Schinckel, et al. (2010) used a parameterized Bridges function to estimate individual pig's daily feed intake (kg/d) (DFI) as,

$$DFI_i = (3.03 + c_i)\{1 - \exp[-\exp(-5.9206) WT^{1.5123}]\}$$

for barrows and  $DFI_i = (2.906 + c_i)\{1 - \exp[-\exp(-4.9498) WT^{1.2677}]\}$  for gilts, where,  $c_i = 0.11z_8 + 0.0523z_6 -$

$0.0122[(\text{days to 125 kg}) - (\text{mean days to 125 kg})] * (165 \text{ for barrows, } 175 \text{ for gilts})$ . The parity adjustments for DFI were modeled at 0.965 and 0.0970 for gilts and dams born to parity 1 sows (Schinckel, et al., 2010).

Pig survival was modeled at four points in the model, namely at birth, day-21, day-55, and day-151 based on modeling done by Schinckel, et al. (2010). Therefore, pigs could only die at 4 discrete points. Probability of survival at birth was modeled as 0.95 for piglets of parity 1 and 2 sows and  $0.95 - 0.01125 * (\alpha - 2)$ , where  $\alpha$  is the parity of the piglet's sow, for those born to sows greater than parity 2 (Milligan, et al., 2002). Probability of survival at day-21 was calculated as  $\{-107.79 + [207.555 * (\text{BW}/0.487)^{2.9156} / [1 + (\text{BW}/0.487)^{2.9156}]] / 100\}$  (Knol, et al., 2002). Probability of survival at day-55 was calculated as  $1 - \{\exp[3.635 - 2.5135 * (\text{BW}) + 0.6426 (\text{BW})^2] / 100\}$  (Schinckel, et al., 2010). Probability of survival at day-151 was estimated at 0.95 for pig born to parity 1 sows and 0.966 for all other pigs (Schinckel, et al., 2010). At each of the four points in the model for which survival was simulated, a value was selected from a uniform distribution from 0 to 1. If the individual piglet's probability of survival at that point (birth, day-21, day-55, of day-151) is less than the corresponding value drawn from the uniform distribution, it was modeled that the individual pig had died at that point.

#### *Methods: Economic Implications of Changing Piglet Litter Sizes*

This analysis explicitly considers the dynamic biological and economic implications of the changing litter sizes. Published biological relationships (detailed above) were used to simulate the growth of individual piglets. Biological sow and piglet performance data was then used in calculating the economic implications of variations in litter sizes.



To estimate profitability of the sow herd, the revenue for each market hog generated, costs associated with each market hog generated, and cost of maintaining the sow herd was calculated. The model estimated the individual pig performance for each piglet simulated as born into the production system. Therefore, calculating the revenue for the whole herd was approached by first calculating revenue generated by individual marketed pigs.

Three marketing cuts of the group were modeled. At day-150 of age, the heaviest 17% of hogs were marketed, at day-163, the second cut of heaviest hogs (34% of the total hogs) were marketed, and on day-179 the remainder were marketed (Li, 2003; Boys, et al., 2007). This marketing scheme was employed as an example marketing strategy. It is recognized that marketing systems based on average market weight instead of days of age are likely a better representation of reality, and such systems will be evaluated in future work. These alternative marketing systems are expected to impact the costs, revenues, and therefore profit, of the swine production system.

The revenue for an individual market hog ( $r_i$ ) was calculated as,

$$(4) \quad r_i = (cw_i) * (p_i(f(cw_i, lean_i)))$$

where,  $cw_i$  is the hog carcass weight, which is defined as  $0.6843*(WT_{Market})^{1.02}$  for gilts and  $0.6826*(WT_{Market})^{1.02}$  for barrows (Schinckel, et al., 2009b) where  $WT_{Market}$  is the live weight of the pig when it is marketed. The term  $p_i$  is the hog price received, which is a function of  $cw_i$  and  $lean_i$  (percent lean) and is defined by the pricing grid.<sup>3</sup> Summing individual marketed hogs resulted in the total revenue generated by the herd (R), or,

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<sup>3</sup> To establish the market value of the hogs when marketed through the price grid, back-fat depth (BF) and loin-depth (LD) are estimated. BF, in cm, was estimated as  $0.2344*(WT_{Market})^{0.527} - 2.058*(BW) + 1.1026*(BW)^2 + 0.33*z_6$  for gilts and  $0.04983*(WT_{Market})^{0.3896} - 2.269*(BW) + 1.2048*(BW)^2 - 0.2165*(BW)^3 + 0.40*z_6$  for barrows (Schinckel et al., 2010). LD was calculated as  $0.62*(WT_{Market})^{0.4733} - 0.12 + 0.0757*(BW) - 0.228*z_6 + 0.52*z_7$  for gilts and  $0.596*(WT_{Market})^{0.4733} - 0.228*z_6 + 0.45*z_7$  for barrows (Schinckel et al., 2010).

$$(5) \quad R = \left( \sum_{i=1}^I r_i \right)$$

The total costs of production were broken into four areas; feed ( $FC_i$ ), weaning ( $WC_i$ ), direct market hog ( $DMHC_i$ ), indirect market hog ( $IMHC_i$ ) and were assessed for each individual piglet ( $i$ ). The total cost for each pig simulated as born alive ( $tc_i$ ) is:

$$(6) \quad tc_i = FC_i + WC_i + DMHC_i + IMHC_i$$

The total cost for the whole herd ( $TC$ ) was calculated as,

$$(7) \quad TC = \left( \sum_{i=1}^I tc_i \right)$$

Feed costs ( $FC_i$ ) were minimized subject to the dietary constraints based on data in Van Heughten (2009) and DeRouchey, et al. (2009). Eight feed rations were developed using 15 ingredients and 20 dietary constraints.<sup>4</sup> Rations were switched in the bioeconomic model according to the group's average daily body weight.

Weaning costs ( $WC_i$ ) were all sow and farrowing costs-including sow feed costs, sow veterinary costs, farrowing barn charge and utilities, farrowing labor charges, and were offset by expected cull sow revenue. At \$345 per litter (using the 10 sow herd), the weaning costs were allocated equally across all piglets born in the litter.

Direct market hog costs ( $DMHC_i$ ) were charges for veterinary care, fuel and utilities in the grow/finish barn, marketing, and mortality. The \$10.05 per head charge was applied to all pigs that survived through day-55.

Indirect market hog costs ( $IMHC_i$ ) include interest on the value of pigs on feed, grow/finish barn building and equipment costs, and grow/finish barn labor costs. For the 10 sows

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<sup>4</sup> Contact authors for additional information on ration formulation.

evaluated, the group costs for *IMHC* was \$2,690.81. This cost was spread across all pigs surviving through day-55.

Equations (4) and (6) were used to calculate individual pig's revenue and cost, based on biological performance. Profit for each uniquely simulated pig was calculated as,

$$(9) \quad \pi_i = r_i - tc_i$$

where,  $\pi_i$  is the profit for an individual piglet. Summing profit across all individually marketed pigs results in the total profit for the group ( $\Pi$ ), or

$$(10) \quad \Pi = \sum_{i=1}^I \pi_i$$

The bioeconomic model was constructed in Excel (Microsoft, Seattle, WA) and @RISK Version 5.5 (Palisade Corp., Newfield, NY) was used to capture the stochastic components of biological processes. To evaluate how changing the average litter size affected profitability of demonstration sow herd, 5,000 iterations were run on the group with average litter sizes of 8.8, 10.8, 12.8, 14.8, 16.8, 18.8, and 20.8.

## **Results & Discussion**

Because of the stochastic nature of the model, the iterations each created a unique set of individually modeled pigs. The biological characteristics of the individual pigs were considered in the economic analysis. Costs and revenues per marketed hog were calculated. But, the average cost (revenue) per hog marketed is only one potential metric by which to measure performance. Alternatively, costs (revenues) per piglet born alive could be assessed. Note that the average costs per piglet born alive are different than the average costs per hog marketed due

to death loss. The death loss increases as average litter size increases, therefore decreased costs per hog marketed are impacted by the costs of increased numbers of piglets born, death losses, the weight of piglets at various stages of production (impacted by litter size) and the potential to spread the fixed sow costs over differing numbers of marketed hogs. Table 1 shows the number of hogs marketed from the 10 sow demonstration herd with the corresponding average litter size used to simulate the piglet group. While the average litter size is increasing consistently by 2 piglets per litter, the number of hogs marketed is increasing at a decreasing rate. The number of additional hogs marketed when the average litter size for the demonstration sow herd changed from 8.8 to 10.8 was 15. When the demonstration sow herd changed from 18.8 to 20.8 only 4 additional hogs were marketed. A smaller proportion of the piglets born in the larger litters are surviving to go to market. Therefore, the conclusions drawn based upon average costs per piglet born versus average costs per piglet that survives to be marketed are starkly different.

Costs calculated for individual piglets, using biological data from the simulations, shows that the average total cost per hog marketed decreases as the group's average litter size increases. Figure 1 shows the costs per hog marketed, broken into the 4 cost areas defined for different average litter sizes. As expected, the fixed costs that are spread across the group, *WC* and *IMHC*, decreased as average litter size increased. Total feed costs for the group, as expected, increased as the number of pigs being fed increased. The feed cost per hog marketed, however, decreased as the average litter size increased. The decrease in *FC* per piglet born as average litter size increases is a result of decreased birth weights, decreased 21-day body weights, and a larger number of pigs over which to spread total feed costs. This decrease in *FC* per hog marketed is a result of smaller pigs, born in larger litters, staying lighter throughout the production system and consuming less feed per head than larger, heavier, pigs.

In addition to a reduction in costs, a decrease in average revenue per marketed hog was found. Figure 1 shows the average revenue generated per hog marketed in addition to the costs. The biological implications of crowding are reflected in lower growth rates, lower carcass weights, and carcass composition changes. The economic impacts of crowding are apparent in the average revenue per hog marketed because as the average litter size increased the average revenue that each individual hog generated decreased.

Aggregating the costs and revenues for individual hogs and looking at the profit for the group as a whole, figure 2 shows the group's total profit for the different average litter sizes. Overall increasing average litter size of the group resulted in an increase in total profit. Increasing litter size is resulting in increased profit, but at a decreasing rate. At some point beyond the 20.8 piglet average litter size that was evaluated, total profit is expected to plateau or decrease.

Assessing costs of larger average litter sizes is complex due to the biological and economic impacts which are composed of a number of competing factors. The 'true' cost of larger litters is admittedly not entirely accounted for in this bioeconomic model. The costs used in this simulation and analysis are incomplete as the labor costs associated with larger litters is not explicitly accounted for. Currently the labor costs in the grow/finish barn are fixed, rather than varying with changing litter sizes. Veterinary and medical costs per head would also likely increase as the average litter size increases. The increased labor and veterinary costs are expected to be farm-specific and highly dependent on the management system in place on a specific operation.

## **Conclusion**

This analysis employed a small demonstration sow herd (10 sows) and estimated biological performance and the economic consequences of increasing sow litter sizes. This analysis has provided an insightful glimpse into how swine production system profits change as the average litter size increases. Costs per marketed hog were observed to decrease as fixed costs are being spread over more units of production. Increased numbers of piglets, or units of production, however, created adverse biological implications that resulted in reduced economic value of the average marketed hog. Overall, the assumptions and parameters of the stochastic model used for these evaluations show that the groups' profitability increased, at a decreasing rate, as the average litter size increased (within the litter sizes investigated).

Further research should consider how the production costs, especially those that were considered to be fixed in total, might change as litter sizes become larger. Also, the biological, and consequently economic, implications of sows birthing and nursing larger average litter sizes should continue to be researched in a variety of existing production systems. Farm-specific characteristics are likely to impact the degree to which, for example, death loss increases as litter size increases. Identification of existing swine management systems which are better prepared to handle larger litter sizes would facilitate swine producers adjustment to profitably managing larger litters.

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Growth When Fed Either Corn- and Soybean Meal- Based Diets or Low Nutrient

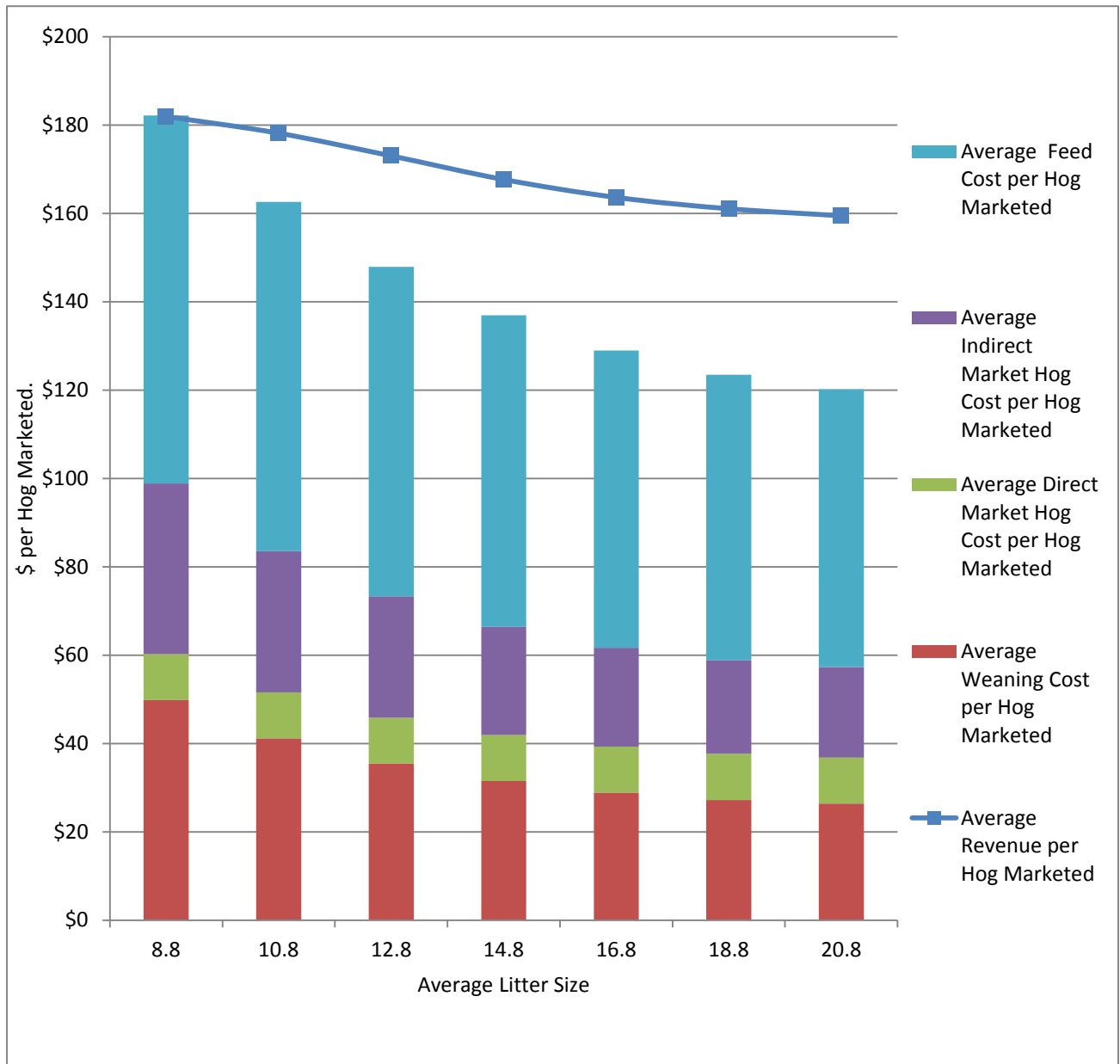
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**Table 1.** Change in Number of Hogs Marketed as Litter Size Increases

<b>Average Litter Size (Number of Piglets)</b>	<b>Number of Hogs Marketed</b>	<b>Gain in Number of Hogs Marketed When Increased Average Litter Size by 2</b>
8.8	69	
10.8	84	15
12.8	98	14
14.8	110	12
16.8	120	10
18.8	127	7
20.8	131	4

**Figure 1.** Average Cost and Revenue per Hog Marketed



**Figure 2** Total Profit Generated by Demonstration Sow Herd

