Feeding Practices and Input Cost Performance in U.S. Hog Operations: The Case of Split-Sex and Phase Feeding

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Abstract: This study determines the factors leading to adoption of split-sex and phase feeding by U.S. hog producers and consequently the impact of adoption on operation's input cost performance. A sample selection model is employed to account for unobservable variables possibly being correlated with the decision to use split-sex and/or phase feeding and input cost performance. Results demonstrate that operations using phase or combination of phase and split sex feeding are most cost effective and productive than hog operations using conventional feeding.

Key words: hog production, input cost performance, productivity

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1. Introduction

Growth in hog production in the U.S. has led to the development and adoption of a wide variety of production technologies, management practices, and production systems. Production costs are a driver of adoption and increasing emphasis is being placed on feed efficiency to continuously maintain or improve an operation's production performance. Maximizing feed efficiency is one method to improve an operation's overall profitability as feed costs represent between 56% and 58% of total production costs for feeder pig to finish operations (McBride and Key 2007).

Some feed efficiency technologies have been shown to increase production performance, but face resistance because of potential concerns about the technology. A prime example includes growth-promoting antimicrobial drugs (commonly referred to as antibiotics) in hog feed (USDA/APHIS/VS/CEAH 1999, Hayes et al. 2001, McEwen and Fedorka-Cray 2002, Goldberg and Wallinga 2007). U.S. hog producers are permitted to use over the counter antibiotics in feed for growth promotion, growth promotion and "various infections", and infections. These products have been found to improve feed conversion and rate of gain, as well as reduce morbidity and mortality in growing pigs (Hayes 1981, Cromwell 1991, Cromwell 2002, and Miller et al. 2003). However, concerns persist that the use of antibiotics in hog feed could promote development of antibiotic resistant bacteria (Goldberg and Wallinga 2007).[1]

In December 2013 the United States Food and Drug Administration took action to promote the judicious use of medically important antimicrobial drugs in food animals with the following statement: *"The goal of the strategy is to work with industry to protect public health by*

[1] Despite widespread concerns about antibiotic use in food animal production, there is no hard scientific evidence to support a clear-cut relationship between antibiotics for growth promotion and adverse consequences on human health (Barber, Miller, and McNamara 2003, Casewell et al. 2003, Phillips et al. 2004, Mathews, 2001).

releasing two documents to help phase out the use of medically important antimicrobials in food animals for production purposes (e.g., to enhance growth or improve feed efficiency), and to bring the therapeutic uses of such drugs (to treat, control, or prevent specific diseases) under the oversight of licensed veterinarians." (U.S. Food and Drug Administration 2013).[2]

In light of this development and the need for hog operations to continuously maintain or improve production performance, production practices in the hog industry that have been shown to improve feed efficiency and have not garnered any known opposition need further assessment. Such examples include split-sex feeding and phase feeding. Phase feeding refers to pigs being fed diets of varying protein and energy content at different stages, or phases, of their life in order to more closely match the diet with their changing nutritional requirements (McBride and Key 2007). Split-sex feeding is a refinement of phase feeding and complements the goals of phase feeding. Split-sex feeding is a production practice where pigs are separated by sex by the time they reach 70 pounds and fed different diets. This is done to improve feed conversion because male (barrow) and female (gilt) pigs develop differently after reaching 50 to 70 pounds (McBride and Key 2007). Even with the potential benefits of these feeding strategies, adoption of phase and split-sex feeding remains relatively low.

We hypothesize that input cost performance of major inputs used in hog production; namely, feed, labor, capital, and other inputs can be improved on some operations by adopting phase and split-sex feeding. For example, feeding barrows and gilts separately and changing the diet more frequently reduces the chances of under and/or over-feeding nutrients. This creates an

[2] Guidance for Industry #213 entitled ''New Animal Drugs and New Animal Drug Combination Products Administered in or on Medicated Feed or Drinking Water of Food-Producing Animals: Recommendations for Drug Sponsors for Voluntarily Aligning Product Use Conditions With Guidance for Industry #209.'' The purpose of this document was to provide information to sponsors of certain antimicrobial new animal drug products who are interested in revising conditions of use for those products consistent with FDA's Guidance for Industry #209, ''The Judicious Use of Medically Important Antimicrobial Drugs in Food-Producing Animals,'' and to set timelines for stakeholders wishing to comply voluntarily with this guidance. (Federal Registrar 2013).

opportunity where the growing pig's nutritional requirement is more accurately being met, which consequently improves overall performance and reduces total feed costs for the hog operation. However, adoption of a phase and split-sex feeding is not always a best management practice for every operation. Higher levels of labor, capital, and other inputs may be needed to properly manage pig flow and the feed delivery system.

The objective of this study is to evaluate the decision to adopt phase and split-sex feeding, and consequently, the impact of adoption on an operation's input cost performance. This assessment is important for several reasons. First, it is necessary to understand how operation-level heterogeneity drives adoption decisions. To our knowledge little focus has yet to develop on assessments of producer preferences or production situations for phase and split-sex feeding. Incorporating and understanding production heterogeneity would provide valuable information on the distributional effects of adoption decisions. Second, hog producers are understandably reluctant to change from well-established production practices unless they increase operation-level performance. Quantifying impacts on an operation's input cost performance will provide needed information to help guide adoption decisions.

2. Background

National surveys have been completed by USDA/APHIS/VS as part of the National Animal Health Monitoring System (NAHMS) to study health and production technologies within the hog industry over time. In 1995, results from the NAHMS survey reported 34.9 percent of grower/finisher sites practiced phase feeding (USDA/APHIS/VS 2002b). When the survey was repeated in 2000, adoption had only increased to 40.1 percent (USDA/APHIS/VS 2002b). A similar pattern exists for split-sex feeding in grower/finisher sites with adoption levels of 18.3 percent in 1995, 22.9 percent in 2000, and 29.6 percent in 2006. Over time adoption has increased for both practices, but this adoption has been relatively slow compared to other feed efficiency technologies (USDA/APHIS/VS 1996, 2002a, 2007).

Production costs and hog industry structure has been studied using the Agriculture Resource Management Survey (ARMS) distributed by USDA's National Agricultural Statistics Service (McBride and Key 2007). Results from the 2004 survey revealed that 34 percent of feeder pig to finish operations used split-sex feeding and 62 percent of operations used phase feeding. Of the feeder pig to finish low cost operations, (e.g., operations that covered operating and ownership costs), 44 percent used split-sex feeding and 77 percent used phase feeding. Feeder pig to finish operations of 5,000 head or more used split-sex feeding (67 percent) and phase feeding (72 percent) to the greatest extent compared to operations of 1-499 head, 500-999 head, and 2,000-4,999 head.

Coffey, Parker, and Laurent (1995) suggest that for split-sex feeding to be a viable practice for producers, improvements in performance must translate into increased economic value above the extra costs associated with the practice. For example, extra costs can include increased feed mixing time, cost of extra bin or storage place for additional diets, and additional time required for feed delivery. The authors also suggest that a higher level of management and attention is required to ensure that diets are properly prepared and delivered to the correct location and entire buildings or sections of buildings that can be all-in/all-out managed work best.

Cline et al. (1995) explored two options for implementing split-sex and phase feeding in smaller operations. They present two models with different levels of investment. The authors indicate that switching from feeding one diet to multiple diets would require modification of the feed delivery system and additional investments — feed bin, bin boot, concrete pad, power unit, sort box, and feed auger. Switching from a low technology system to a split-sex phase feeding system to feed three diets lowered the estimated cost of production by $1.52 per hundredweight (cwt). Switching from a low technology system to a split-sex phase feeding system to feed four diets lowered the estimated cost of production by $1.79 per cwt. Reduction in the estimated cost of production was attributed to the assumed feed efficiency improvements in the split-sex phase feeding system. This is consistent with research from Kansas State University that indicated sorting pigs by weight and feeding a higher energy diet to the lightest 50% of the pigs increases average daily gain (Hastad et al. 2005)

Few, if any, studies have been published solely comparing input cost performance across phase feeding, split-sex feeding, and other technology systems. Part of the explanation for this may be the practical difficulties involved in carrying out research when additional investments are needed. In addition, system comparisons are notoriously difficult to set up and results can show large degrees of variability. Studies involving the use of large numbers of hogs are needed to detect important differences. In addition, operation-level characteristics which allow for direct comparisons between systems; thereby, minimizing confounding ”operation-level” effects with general production practice effects are needed.

This study improves the depth and breadth of evaluating hog production systems. First, we extend the literature to investigate adoption of phase and split-sex feeding and whether these feeding practices have an impact on an operation’s input cost performance. Second, we use a selection model that accounts for the possibility that some determinants are unobservable. Third, we use USDA’s ARMS survey of U.S. hog producers, the most comprehensive and nationally representative hog production data available. This data encompasses industry-wide variation which is a limitation of single-site studies which are more difficult to generalize because of the experimental design.

3. Methods

Past research has indicated that management decisions are endogenous to performance outcomes (Hamilton and Nickerson 2003). The same holds for hog producers. Hog producers want to achieve high levels of input cost performance which influences their decision to adopt new technologies and methods to manage input costs. This implies that hog producers make strategic decisions since it is assumed they choose the option that will result in the best return for their operation based on their individual farm characteristics.

To explain disparity in input cost performance, beyond differences in physical and biographical factors, differences between hog producers who choose to use various types of feeding strategies needs to be considered. For this purpose, a multinomial selection model is employed to measure the impact of phase feeding, a combination of phase and split-sex feeding, and choosing neither (conventional) of these feeding strategies on input cost performance measures (Greene 2003, p. 780). The selection approach is used here, as opposed to, an instrumental variables approach because there are too few variables with which to instrument the three feeding strategy options. Similar models have been applied to contracting and productivity (Key and McBride 2003) and antibiotic use and productivity (McBride, Key, and Mathews 2008) in hog operations.

Empirically, the intuition for using a selection model is as follows. Factors attributed to management ability are unobservable and may be correlated with the decision to use different feeding strategies. In this case, simply regressing input costs on exogenous factors and indicators of feeding strategies could result in biased parameters. For example, if management ability were to be negatively correlated with phase feeding, a combination of phase feeding and split-sex feeding, or conventional feeding, a simple regression would overstate the impact of these feeding strategies on input cost performance. The problem in this example would be one of self-selection because producers who chose to use a specific feeding strategy may have differing input cost performance due to management ability whether or not they chose one of the three feeding strategies.

In order to correct for the hog producers' expectation of performance outcomes with respect to the feeding strategy chosen, we used a two-step process which includes using a selectivity adjusted multinomial regression to determine the likelihood of choosing one of three feeding strategies (Wooldridge 2002, Bourguignon, Fourier, and Gurgand 2007). We then estimate the inverse Mills ratio for each of the three feeding strategies from the multinomial regression results and include it in OLS regressions to estimate input cost performance which results in unbiased coefficient estimates.

Multinomial regressions are used to study the relationship between nominal outcome variables and observed explanatory variables. The hog producer has three options for feeding strategies (phase feeding, a combination of phase feeding and split-sex feeding, and conventional feeding). Considering a discrete choice, the probability of choosing the most preferred feeding alternative *j* such that:

$$(1)\quad P_{y_i=j} = \frac{\exp(x_{ij}^{'}\beta)}{\sum_{k \varepsilon C_i} \exp(x_{ik}^{'}\beta)},$$

where y_i is the feeding choice for farm *i* and x_{ij} are a set of farm and producer level characteristics.

The benefit of using the multinomial logit is that explanatory variables do not change across choices. This results in coefficient estimates for each feeding strategy which facilitates determining the factors that play a significant role across feeding strategies and the decision to choose one of the three strategies. Second, it allows estimation of a separate inverse Mills ratio for each feeding strategy such that:

(2) $\lambda_{ij} = \frac{-\phi(x_{ij})}{1-\Phi(x_{ij})}$.

The inverse Mills ratio allows measurement of the impact of the feeding strategy on input cost performance variables (Equation 3) as well as capture any selectivity-bias in estimates of β which may be in our model if we omit these variables.

The second stage OLS regression is estimated for a series of input cost performance measures such that:

(3) $z_{ij} = \gamma x_{ij} + \mu\lambda_{ij} + \epsilon$,

where z_{ij} are j input cost performance measures for operation i, x_{ij} are a set of operation and producer, and production management characteristics, and λ_{ij} is the inverse Mills ratio for farm i and feeding strategy j. In addition to the estimated inverse Mills ratios, a binary variable is included to capture the three feeding strategy options. All other explanatory variables are identical between the two stages to determine if specific variables have different effects on the decision to adopt a specific feeding strategy versus its effect on input cost performance.

4. Data

Data were derived from the 2009 ARMS survey of U.S. hog producers.[3] This survey collected detailed information from a cross-section of hog operations and was designed to be statistically

[3] Phase III Hogs Production Practices and Costs and Returns Report. The entire survey can be obtained from USDA's Economic Research Service (USDA-ERS) (http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/questionnaires-manuals.aspx#27886).

representative of operations across the hog industry. The data include a wealth of information including measures of operation size, production expenditures, facility use and operation practices, producer demographic information, and financial characteristics that facilitate an in-depth analysis of economic performance among individual operations.

Explanatory variables were collected for the feeder pig to finish stage of production defined as operations where feeder pigs were purchased or placed and then finished and sold or removed at a slaughter weight of approximately 220 to 280 pounds. Explanatory variables were grouped into four categories: operation, principal operator, financial management, and production management characteristics. These categories capture the broad array of management needs on the hog operation which include human resource, financial, and production management (Gloy, Hyde, and LaDue 2002). Since we are using a two stage model to account for management and cost differences, we have two dependent variables. To begin the data section, we will start with the dependent variable discussion and move onto the independent variables followed by a brief discussion of summary statistics.

4.1 Dependent Variables

In the first stage of the analysis, a selectivity adjusted multinomial regression is used to determine the probability of adopting one of three feeding strategies. These feeding strategies were defined as phase, combination, and conventional feeding. Phase feeding was coded as a 0/1 variable with a 1 equal to "yes" as a response to the following question: "Was phase feeding of finishing hogs practiced on this operation in 2009?" All "no" responses were coded as zero and "don't know" was coded as a missing observation. A low number of survey respondents reported using only split-sex feeding, however a larger proportion reported using both phase and split-sex feeding. Combination feeding was a result of survey respondents choosing "yes" for the phase feeding question stated earlier and the following question, “Was split-sex feeding of finishing hogs practiced on this operation in 2009?” Conventional feeding was defined as not using phase-feeding, split-sex feeding, or a combination of phase and split-sex feeding.

In the second stage of the analysis, four input cost measures and two productivity measures were chosen as the dependent variable to determine the effect of operation, principal operator, financial management, and production management characteristics as well as the feeding decision on input cost performance. The four cost categories included feed, labor, capital, and other costs which have been previously used when evaluating performance of hog operations (Key and McBride 2003, Key, McBride, and Mosheim 2008, McBride, Key, and Mathews 2008, Tonsor and Featherstone 2009). Feed cost is comprised of purchased and homegrown feed fed and is computed as the sum of purchased feed and the quantities of homegrown feed valued at 2009 annual average prices in the state where the operation is located. Labor cost included both paid and unpaid labor. Capital cost was the estimated cost of replacing existing capital equipment (barns, feeding equipment, etc.). Other costs were defined as expenditures on veterinary services, bedding, marketing, custom work, energy, and repairs. All input costs measures were standardized by hundredweight (cwt) gain to rule out size effects due to the categorical nature of explanatory variable survey responses.

Two productivity measures were also included in the analysis. Feed productivity was calculated as a summation of all purchased and homegrown feed on a cwt basis standardized by cwt gain. This allowed for determination of how effectively growing pigs were converting feed fed to gain. The second measure included was labor productivity where unpaid and paid labor hours were summed and standardized by cwt gain. By including cost and productivity measures for feed and labor the analysis was able to provide a direct comparison across two measures.

4.2 Independent Variables

4.2.1 Farm Characteristics

The size of the hog operation was measured as the largest number of hogs on the operation at any time. *Operation size* was grouped into four categories following Tonsor and Featherstone (2009): (1) less than 500 pigs, (2) 500 ≤ pigs < 1,999, (3) 2,000 ≤ pigs < 4,999, and (4) greater than 5,000 pigs. Operation size could have mixed impacts on production practice adoption decisions and input cost performance. For example, larger operations may experience efficiencies of size that smaller operations have to compensate for in other ways, such as implementing good management practices. Furthermore, larger operations may have high capital to labor ratios and tend to be less willing to adjust production practices.

The geographic location of a hog operation has been found to have varying impacts on cost of production and the likelihood of operations to adopt production practices (McBride and Key 2007). To capture this impact, hog operations were classified into one of five geographically regional locations: *North* (MI, MN, SD, WI), *East* (NC, PA, VA), *South* (AR, GA, KY, MO), *West* (CO, KS, NE, OK), and *Midwest* (IA, IL, IN, OH) following (Key and McBride 2003, McBride, Key, and Mathews 2008, Tonsor and Featherstone 2009).

4.2.2 Principal Operator Characteristics

Management ability represents an integral component of any successful farm operation and many times principal operator characteristics are used to identify these effects (Gloy, Hyde, and LaDue 2002, Key and McBride 2003, McBride, Key, and Mathews 2008, Tonsor and Featherstone 2009, Hadrich and Olson 2011). Principal operator experience was included in the analysis as a proxy for management ability. It is hypothesized that as years of *experience* increases, producers will be able to better manage production expertise and expenditures and incorporate that in the feeding strategy used on the operation. Furthermore, producers are exposed to new technologies, improved techniques, and high order thinking skills with more experience. As experience continues to increase, one would expect that the hog producer would make plans to exit the industry as they near retirement. A binary variable was included to identify those principal operators that plan on exiting (*exit)* the industry within the next five years. It is expected that those principal operators that plan on exiting will be less likely to adopt new feeding strategies and will take a different approach to managing feed, labor, capital, and other inputs on their operation.

4.2.3 Financial Management

Financial management has been shown to be an important factor in adopting new production technologies (Gloy, Tauer, and LaDue 2002, Purdy, Langemeier, and Featherstone 1997). Liquidity measures the financial flexibility of the operation, and was included in the analysis using total farm assets (*assets)*. Assets can also be a proxy for operation size in some instances, indicating that as assets (hogs, buildings, and technology) increase, additional labor may be needed and/or other costs may increase. A larger number of paid *labor* hours as a percent of total labor (paid and unpaid) hours, would, presumably be, freeing the principal operator to spend more time on management. This may be the best use of the principal operators' time considering the opportunity cost of time. Unpaid labor hours were not included in the dependent variables since they are included in the independent variable in stage two of the analysis.

4.2.4 Production Management

Production management practices can lead to increased operation efficiency, improved performance and feed formulation, as well as decreased input costs. Over the last several years, considerable attention has been focused on analyzing production performance of hog operations

(Sharma, Leung, and Zalenski 1997, Rowland et al. 1998, Key and McBride 2003, Lansik and Reinard 2004, Galanopoulos et al. 2006, Key, McBride, and Mosheim 2008, McBride, Key, and Mathews 2008, and Tonsor and Featherstone 2009). Seven production management technologies were included in this analysis to determine if they affected the decision to adopt one of the three feeding strategies tested as well as to determine how these strategies affected input cost performance and productivity.

Production management is a form of risk management used on hog operations and can vary from production contracts, cooperative agreements, independent contracting of custom work, or a combination of these methods. This analysis used a binary variable to identify those hog producers using a *production contract*. Hog housing is likely to impact the ability of operations to adopt new production practices and could have differing impacts on performance. This is especially important for feeding strategies employed given pig flow and feed delivery system needs. Housing type was included in the analysis as a binary variable, *closed*, which was equal to one if closed confinement without outside access was used, otherwise, equal to zero if open confinement with outside access was used. A similar housing classification was used in Miller et al (2005) and McBride, Key, and Mathews (2008). Using all-in/all-out (*AIAO)* and large-pen *autosort* could affect the feeding strategy adopted as well as the input cost performance.

There has been ongoing research and attention regarding the feeding of antibiotics to growing pigs for *growth promotion*, *disease prevention*, and *disease treatment*. These three variables were included as binary variables in the analysis. If antibiotics are fed, especially for growth promotion, this could have differing effects on the likelihood to adopt other performance enhancing feeding practices.

Summary statistics of the dependent and explanatory variables are presented in Table 1. Regarding the primary variables of interest, conventional feeding was used by 19.03 percent of the operations while phase feeding and combination feeding was used by 60.42 percent and 19.66 percent of the operations respectively. These adoption rates and the differences in operation, principal operator, financial management, and production management statistics and the desire for increased understanding of economic forces driving observed adoption and input cost performance and productivity calls for further in-depth analysis.

5. Results

The first part of this analysis determines the factors that influence the likelihood of adopting one of three feeding strategies (phase, combination, conventional). The base feeding strategy for the multinomial logit analysis is conventional feeding. Multinomial logit coefficients and relative risk ratios with significance levels are presented in Table 2 and 3, respectively. Possible selectivity bias was corrected for by using the two-step process developed by Lee (1983) and pre-packaged in STATA (StataCorp 2011). Different factors can affect the decision to use a specific feeding strategy. To address this, we estimated the inverse Mills ratio (Wooldridge 2002) for each feeding strategy. The inverse Mills ratio captures the probability of choosing feeding strategy *i* and addresses any sample selection bias' that may exist. It is included in the second stage OLS regressions for cost and productivity measures with results presented in Tables 4 and 5.

The survey design used by the USDA's National Agricultural Statistics Service in generating the ARMS data involves multiple phases of sampling and stratification, including post-stratification to adjust for nonresponse. This requires variance estimates to be derived, as conventional methods yield parameter estimates with biased standard errors. All variance estimates are derived using a delete-a-group jackknife procedure, commonly used by users of ARMS data (Dubman 2000).

5.1 Multinomial Logit Results

Empirical results for multinomial regressions are presented in Table 3. Relative risk ratios (RRR) are estimated to provide a numerical result which quantifies the probability of choosing one outcome over the probability of the baseline outcome.[4] For this analysis, two sets of RRRs were calculated for phase and combination feeding with the base-line outcome of conventional feeding (Table 4). Relative risk ratios greater than one imply an increased probability of the outcome occurring compared to the baseline outcome while a RRR less than one indicates a decreased probability compared to the base-line outcome.

Since operation size was coded as a categorical variable, hog operations with more than 500 hogs (*Operation Size 1*) was defined as the base scenario for the analysis, hence, all size results will be compared to this factor. Having a larger operation size increased the likelihood of producers using phase feeding compared to conventional feeding with the largest increase associated with *Operation Size 4* (more than 5,000 hogs). Operation size was not found to play a statistically significant role in making the decision to use a combination feeding strategy compared to conventional feeding.

Operation location, at times, can dictate the type of production technologies used. It can also affect the potential for efficiency gains (McBride and Key 2007). Hog operations located in the *North* region compared to the *Midwest* were more likely to use phase and combination feeding compared to conventional feeding. Hog operations in the *East* were less likely to use combination feeding compared to conventional feeding. The density of hog operations and feed

[4] Relative risk ratios are estimated by taking the estimated coefficient to the exponent (e^{β}), (StataCorp 2011).

supplies in a region to meet pig flow and feed delivery system employed, likely plays a role in adoption decisions, explaining why specific feeding strategies are location specific.

Principal operator characteristics were included as a proxy for human capital considerations and future planning (Rowland et al. 1998, Sharma et al. 1999, Lansink and Reinhard 2004, Tonsor and Featherstone 2009). Increased experience in hog production increased the likelihood of adopting phase and combination feeding compared to conventional feeding. It appears experienced operators are more receptive to and more progressive in adopting these feeding practices.

In terms of financial management, as total *assets* on the hog operation increased, producers were less likely to use phase feeding compared to conventional. This may be due to existing investments in the hog operation not lending themselves to the pig flow and delivery system optimal for phase feeding. Paid *labor* was not found to be a statistically significant determinant in this decision making process.

The use of a *production contract* was found to increase the likelihood of using phase feeding compared to conventional feeding. Since feed is provided by the contactor, growers feed hogs as the feed is delivered in accordance with production contract terms; thus, explaining why the use of a production contact increases the likelihood of using phase feeding. Hog producers that used *AIAO* were more likely to use combination feeding than conventional. This confirms past research that suggests entire buildings or sections of buildings that can be *AIAO* managed work best (Coffey, Parker, and Laurent 1995). The economic benefits of an automatic-sorting, *autosort*, system are thought to be mostly due to labor savings, easier feed withdrawal, reductions in sort variation and sort loss, greater uniformity in pig market weight, and therefore more accurate marketing (Vansickle 2004). The economic benefits of using automatic-sorting systems align with those of phase feeding, thus explaining why some producers using *autosort* were less likely to use phase feeding. However, these systems provide the opportunity to sort pigs into different pens for different diets based on body weight and/or on sex, thus the possible complementary nature of using these two systems might not be fully utilized in the industry.

Feeding antibiotics for *growth promotion* increased the likelihood of using phase feeding and combination feeding compared to conventional feeding. This may result from a producer's goal to maximize growth by adopting a variety of technologies and practices. Feeding antibiotics for *disease treatment* increased the likelihood of using phase feeding. Perhaps, since time and attention is needed to properly prepare and administer antibiotics in diets for disease treatment there is a spill-over affect in regards to managing multiple diets through phase feeding. This explanation could also help explain the finding that feeding antibiotics for *growth promotion* increased the likelihood of using phase feeding and combination feeding compared to conventional feeding. Feeding antibiotics for *disease prevention* was not found to affect the likelihood of using phase feeding and combination feeding. Administering antibiotics in diets for disease prevention is often times a fixed regimen and does vary considerably thus likely explaining this finding.

Housing type was not found impact the likelihood of adopting phase or combination feeding. Data limitations only allowed for the classification of housing type by *closed* and *open*. As such, this does not provide a comprehensive list of possible housing types whereby differences in several factors would exist (e.g., environment, production practices, pig flow, feed delivery, etc.) and notably a reason that housing type, as classified here, was not found to affect the likelihood of adopting phase or combination feeding.

5.2 Second Stage OLS Results

Coefficient estimates for input cost performance (feed, labor, capital, and other) refer to a change in cost in dollars per cwt gain from a one unit change in the independent variable, ceteris paribus. Positive coefficients represent costs increasing while negative coefficients represent costs decreasing (Table 4). Coefficients estimates for productivity refer to a one unit change in an input (cwt of feed or labor hours) from a one unit change in the independent variable, ceteris paribus. Positive coefficients represent decreasing productivity while negative coefficients represent increasing productivity (Table 5).

Estimation of input cost performance and productivity may entail the existence of selection bias. The concern is that hog operations using phase feeding or combination feeding may have better or worse input cost performance (or productivity) without the use of phase feeding or combination feeding. If this is indeed the case, then the impact estimated from the phase and combination variable will be biased, as the error term will be correlated with the phase feeding and combination variable. In the present analysis, the inverse Mills ratios were first estimated in the phase feeding and combination feeding adoption equations and included in the input cost performance and input productivity equations along with the phase and combination feeding variables to test and correct for selection bias.

5.2.1 Feed cost performance and feed productivity

The inverse Mills ratio was not statistically significant for *phase* feeding or *combination* feeding suggesting selection bias was not an issue with respect to phase or combination feeding adoption and feed cost performance. A *production contract* was estimated to reduce feed costs by $8.37 per cwt of gain, or approximately $0.08 per pound of gain. Contractors may be better able to minimize feed costs by purchasing feed components in bulk to avoid transactions costs, thus reducing feed costs. *Phase* feeding was estimated to reduce feed costs by $8.92 per cwt of gain while *combination* feeding was estimated to reduce feed costs by $12.11 per cwt of gain.

The inverse Mills ratio was statistically significant and negative for both *phase* feeding and *combination* feeding suggesting self-selection was an issue with respect to phase feeding and combination feeding adoption and feed productivity (Table 5). This result indicates that we would have underestimated the impact of phase feeding and combination feeding on feed productivity had we not taken into account the selectivity bias. Increases in *operation size* were found to improve feed productivity. Operations located in the *North* appear to have a better feed to gain ratio than operations located in the *Midwest* while the opposite held for operations located in the *West* compared to the *Midwest*. Having more farm *assets* was associated with improved feed productivity. This suggests as larger investments are made in the operation, likely including investments in the feed delivery system, feed productivity is improved.

Four production management technologies were found to improve feed productivity: *production contracts*, *AIAO*, *autosort*, and feeding antibiotics for *growth promotion.* Production contracts provide an incentive structure where the fee paid to the grower is based on animal weight gain, death loss, or feed productivity; therefore, we would expect it to improve feed productivity (Key and McBride 2003). Not surprisingly, feeding antibiotics for *growth promotion* was found to improve feed productivity. *Phase* feeding was estimated to improve feed productivity by 0.5962 per cwt of feed per cwt of gain, while combination feeding was estimated to improve feed productivity by 2.9874 (0.8479 + 2.1395) per cwt of feed fed per cwt of gain.

Jointly, the results for feed cost performance and feed productivity suggest that, in fact, phase feeding and split-sex feeding reduces the chances of under and over-feeding nutrients, and because the hog's nutrient requirement is more accurately being met, improves feed productivity and reduces total feed costs.

5.2.2 Labor cost performance and labor productivity

Of notable importance here is that the dependent variables for labor cost and productivity included both paid and unpaid labor which provides for a more complete assessment regarding the effect of operation, principal operator, financial management, and production management characteristics. Many times unpaid labor is management labor and not included. As *operation size* increased, labor costs decreased on a cwt gain basis. Operation size did not affect labor productivity, except for the largest operation size (*Operation Size 4)*, where labor productivity increased. This demonstrates the potential for economies of size.

Production management was found to play a statistically significant role for labor cost and productivity. Specifically, the use of *production contracts* decreased labor costs and consequently improved labor productivity. The opposite held for feeding antibiotics for *disease treatment*. Using automatic-sorting systems (*autosort*) decreased labor costs and improved labor productivity. This result is consistent with previous research that estimated that an auto-sort barn can save a producer about $250/1000 head in sorting labor cost (Connor and Lowe 2002).

Location of the hog operation and financial management characteristics were not found to have a statistically significant affect on labor costs or productivity. The inverse Mills ratio for phase feeding was positive and significant for the labor cost and labor productivity regressions. This demonstrates that the decision to use phase feeding is directly influenced by labor considerations.

5.2.3 Capital cost performance

Capital costs include costs for replacing existing capital equipment, such as buildings and feeding equipment, as examples. These costs are typically defined as fixed costs, which means the hog operation must pay for these capital assets regardless if they have hogs on their operation or not. Therefore, it is not surprising that *operation* size did not have a statistically significant impact on capital cost per cwt gain. Location was found to have a statistically significant affect with operations located in the *North* having higher capital costs than operations located in the *Midwest*.

Fixed costs must be managed closely, and it was anticipated that additional *experience* would decrease capital costs. Surprisingly, we found the opposite result. Intending to exit the industry within the next five (*exit*) decreased capital costs. It is important to note that the average years of experience was approximately 17 years with a standard deviation of 12 years (Table 1). This indicates we have a relatively young set of hog producers that completed this survey. Past research has shown that young producers are more willing to take on riskier practices (Patrick et al. 2007), and this may be one reason why we observed opposite signs than expected for experience and plans to exit the industry.

Paid labor costs as a percent of total labor were included as a proxy for financial management. It is anticipated that hog operators that have good financial management skills would manage paid labor in an economic and efficient manner resulting in cost decreasing results, which indeed was the finding here regarding capital costs. *Productions contracts* decreased capital costs. The use of contracts likely lowers capital costs as incentives exist for growers to invest effectively in specific productive assets. *AIAO* increased capital costs while *autosort* decreased capital costs. Hog producers typically leave a percentage of pens unfilled to accommodate hogs that have to be sorted during the growing and finishing periods. The reduction in pen space thus restricts square foot per head in the pens that are utilized. The open pen space is thus underutilized, until the manager sorts hogs into those pens. As such, using automatic-sorting systems minimizes underutilized space while all-in/all-out managed systems can increase underutilized space due to the potential for periods of time between pig groups.

The inverse Mills ratio for *combination* feeding was positive and statistically significant. This indicates that making the decision to adopt phase and split-sex feeding directly influences capital costs. This was expected since additional infrastructure is needed for both systems, therefore we assume producers consider the interaction between the cost savings from using both systems and the additional capital costs to obtain said savings.

5.2.4 Other input cost performance

Other costs include expenditures on veterinary services, bedding, marketing, custom work, energy, and repairs. Other costs are defined as variable costs, meaning if hogs are not on the operation, these costs go to zero. Operations located in the *North* had higher other costs than those located in the *Midwest* while hog operations in the *East* and *West* had lower other costs than those in the *Midwest*. This suggests there are unobservable regional factors (e.g., climate, unobserved input quality, or price differences) that are correlated with other costs.

Principal operator and financial management characteristics were found to have a statistically significant effect on other costs. *Experience* increased other costs while plans to *exit* the industry within the next five years decreased other costs. As *assets* increased by $100,000, other costs increased by $0.04/cwt gain. Assets include such items as the hogs on the farm, buildings, and equipment. As the asset value increases, it is assumed that the farm size is increasing, which naturally increases other, or variable costs, in this case. The same holds for labor, as farm size via asset value continues to increase, it is expected that additional labor is needed to manage the assets via hog management (veterinary services, bedding, etc.). *AIAO* managed barns likely were more accommodating to bedding, custom work (i.e., power washing), and repairs, hence, increasing other costs. As expected, *autosort* and feeding antibiotics for *disease prevention* decreased other costs while feeding antibiotics for *growth promotion* increased other costs. Again, the inverse Mills ratio was positive and statistically significant for *combination* feeding demonstrating that the change in other costs was considered when making the decision to adopt a *combination* feeding strategy.

6. Conclusions

New and existing production technologies, management practices, and production systems can face a number of challenges to adoption and continued use. This study determined the factors leading to adoption of phase and split-sex feeding by U.S. hog producers, and consequently, the impact of adoption on an operation's input cost performance and productivity. Operation-level data were used to estimate feed, labor, capital, and other input cost performance (including feed and labor productivity) of each operation. Econometrically controlling for exogenous operation, principal operator, financial management, and production management characteristics, and for sample selection bias we find that operations using phase or a combination of phase and split-sex feeding are more cost effective and productive than non-adopters. This is an important result for the hog industry as a whole. Previous research has shown adoption rates are low for phase and split-sex feeding, but our results demonstrate that the efficiency gains from using these practices not only add production benefits, but result in cost benefits as well. Additionally, these practices are non-controversial which provides the industry with an important marketing tool while jointly improving operation-level efficiency and the economic viability of hog production.

Production costs can severely impact the economic returns to many hog operations. To remain competitive globally, producers must continuously maintain or improve performance. This work should be beneficial to independent producers and growers and contractors considering adoption of phase and split-sex feeding practices. Results should also be valuable to extension educators and industry personnel in future resource allocations aimed at improving operation-level performance in hog operations and other issues hinging on heterogeneous characteristics of producers. The input cost performance and productivity findings provided here should be coupled in future work examining the potential for additional production and value chain benefits of phase and split-sex feeding. Future work would be well served to determine if these practices are economically beneficial for marketing since groups of pigs tend to be more uniform resulting in additional carcass premiums and or less discounts. Moreover, the framework demonstrated here with U.S. feeder pig to finish operations could valuably be extended to other sectors of the livestock industry where adoption decisions and consequent input cost performance and productivity assessments are needed.

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Table 1. Summary Statistics

Variable	Unit/code	Mean	Std. Dev.
1st Stage Dependent Variables			
Phase Feeding	1	0.6042	0.4895
Combination Feeding	2	0.1966	0.3979
Conventional Feeding	3	0.1903	0.3929
2nd Stage Dependent Variables			
Feed cost+	$/cwt gain	29.9826	11.8188
Labor cost+	$/cwt gain	5.9123	14.3842
Capital cost+	$/cwt gain	9.6944	7.0622
Other costs+	$/cwt gain	3.3990	4.2171
Feed conversion+	Cwt feed /cwt gain	1.3292	2.0981
Labor conversion+	Hrs/cwt gain	0.3127	0.8733
Independent Variables			
Operation Characteristics			
Operation Size 1: < 500 pigs	0/1	0.0833	0.2767
Operation Size 2: 500-1,999 pigs	0/1	0.1896	0.3924
Operation Size 3: 2,000-4,999 pigs	0/1	0.4500	0.4980
Operation Size 4: ≥ 5,000 pigs	0/1	0.2771	0.4480
Region			
North (MI, MN, WI, SD)	0/1	0.1667	0.3731
East (NC, VA, PA)	0/1	0.2979	0.4578
South (AR, GA, KY, MO)	0/1	0.0396	0.1952
West (CO, KS, NE, OK)	0/1	0.0792	0.2703
Midwest (IL, IN, IA, OH)	0/1	0.4167	0.4935
Principal Operator Characteristics			
Experience	Years	17.2792	12.2096
Exit	0/1	0.1750	0.3804
Financial Management			
Assets	$100,000	2,661,063	3,049,918
Labor#	hrs	987.4896	1818.0350
Production Management			
Closed	0/1	0.8884	0.3152
Production Contract	0/1	0.7208	0.4491
AIAO	0/1	0.8132	0.3902
Autosort	0/1	0.1068	0.3092
Antibiotics for Growth Promotion	0/1	0.4293	0.4956
Antibiotics for Disease Prevention	0/1	0.6288	0.4837
Antibiotics for Disease Treatment	0/1	0.7059	0.4562

+ Feed includes purchased and homegrown feed. Labor includes paid and unpaid labor. Capital includes the capital replacement value. Other includes veterinary services, bedding, marketing, custom work, energy, and repairs.
# Paid labor as a percentage of total labor.

Table 2. Multinomial regression results

	Phase Feeding			Combination Feeding		
Operation Characteristics	RRR	Std. Error		RRR	Std. Error	
Operation Size 1: < 500 hogs	Base			Base		
Operation Size 2: 500-1,999 hogs	1.4368	0.3706	***	2.2558	15.7256	
Operation Size 3: 2,000-4,999 hogs	1.2647	0.4173	***	2.6311	15.6367	
Operation Size 4: ≥ 5,000 hogs	2.3908	0.5769	***	3.4011	15.4171	
Region						
North (MI, MN, WI, SD)	1.1785	0.4233	**	1.7666	0.5909	***
East (NC, VA, PA)	-0.5431	0.4533		-2.5057	0.6294	***
South (AR, GA, KY, MO)	0.9977	0.5504		1.2588	0.8204	
West (CO, KS, NE, OK)	0.4644	0.5361		0.2400	0.6992	
Midwest (IL, IN, IA, OH)	Base			Base		
Principal Operator Characteristics						
Experience	0.0511	0.0123	***	0.0717	0.0210	***
Exit	-0.0876	0.2355		-0.4979	0.4924	
Financial Management						
Assets	-0.0091	0.0044	*	-0.0036	0.0060	
Labor	0.0106	0.0062		0.0049	0.0053	
Production Management						
Closed	0.2983	0.4838		0.6868	1.0852	
Production Contract	0.7484	0.3259	**	0.8366	0.5339	
AIAO	0.5699	0.5488		2.1115	0.9882	*
Autosort	-1.1464	0.6304	*	-1.0314	0.6620	
Antibiotics for Growth Promotion	1.1839	0.2778	***	1.3821	0.4123	***
Antibiotics for Disease Prevention	0.4126	0.5141		-0.2166	0.7659	
Antibiotics for Disease Treatment	0.7628	0.3425	**	0.4149	0.4807	
Constant	-3.1604	0.9201	***	-6.8406	16.2078	

^ Base Feeding Strategy: Conventional Feeding
Significance at the 1%(***), 5%(**), and 10%(*) level.

Table 3. Multinomial regression results, relative risk ratios

	Phase Feeding			Combination Feeding		
Operation Characteristics	RRR	Std. Error		RRR	Std. Error	
Operation Size 1: < 500 hogs	Base			Base		
Operation Size 2: 500-1,999 hogs	4.2071	1.5592	***	9.5431	150.0703	
Operation Size 3: 2,000-4,999 hogs	3.5421	1.4783	***	13.8887	217.1743	
Operation Size 4: ≥ 5,000 hogs	10.9221	6.3010	***	29.9983	462.4847	
Region						
North (MI, MN, WI, SD)	3.2494	1.3755	**	5.8507	3.4571	***
East (NC, VA, PA)	0.5809	0.2634		0.0816	0.0514	***
South (AR, GA, KY, MO)	2.7119	1.4926	*	3.5211	2.8886	
West (CO, KS, NE, OK)	1.5911	0.8529		1.2713	0.8889	
Midwest (IL, IN, IA, OH)	Base			Base		
Principal Operator Characteristics						
Experience	1.0525	0.0130	***	1.0743	0.0226	***
Exit	0.9162	0.2158		0.6078	0.2993	
Financial Management						
Assets	0.9909	0.0043	*	0.9964	0.0060	
Labor	1.0107	0.0063		1.0049	0.0054	
Production Management						
Closed	1.3475	0.6519		1.9874	2.1566	
Production Contract	2.1137	0.6889	**	2.3085	1.2324	
AIAO	1.7681	0.9703		8.2605	8.1631	**
Autosort	0.3178	0.2003	*	0.3565	0.2360	
Antibiotics for Growth Promotion	3.2669	0.9075	***	3.9832	1.6421	***
Antibiotics for Disease Prevention	1.5108	0.7768		0.8052	0.6168	
Antibiotics for Disease Treatment	2.1443	0.7345	**	1.5142	0.7279	
Constant	0.0424	0.0390	***	0.0011	0.0173	

^ Base Feeding Strategy: Conventional Feeding
Significance at the 1%(***), 5%(**), and 10%(*) level.

Table 4. OLS results for input costs

	Feed Cost/Cwt Gain			Labor Cost/Cwt Gain			Capital Cost/Cwt Gain			Other Cost/Cwt Gain		
Operation Characteristics	Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.	
Operation Size 1: < 500 hogs												
Operation Size 2: 500-1,999 hogs	-4.0496	5.4225		-9.1249	4.5300	*	0.0643	3.0731		1.7978	1.8320	
Operation Size 3: 2,000-4,999 hogs	-3.2392	5.4530		-12.0044	5.6946	*	1.6677	3.8610		3.1884	2.2385	
Operation Size 4: ≥ 5,000 hogs	-4.6561	5.9570		-10.6183	4.5075	**	2.2522	3.6371		1.9476	1.9786	
Region												
North (MI, MN, WI, SD)	-1.5609	3.1612		1.5360	2.7119		3.2207	1.8637	*	3.2112	1.0527	***
East (NC, VA, PA)	9.8756	5.8306		4.6223	7.0382		-8.8188	3.2436		-5.9967	2.4748	**
South (AR, GA, KY, MO)	-0.5806	2.5786		4.2452	1.9949		1.6405	1.5956		-0.4546	0.7057	
West (CO, KS, NE, OK)	3.9036	2.4448		-1.4046	1.0954		-0.5381	0.8710		-1.7742	0.7485	**
Midwest (IL, IN, IA, OH)												
Principal Operator Characteristics												
Experience	-0.0487	0.1004		0.1330	0.0737	*	0.1245	0.0579	**	0.1304	0.0340	***
Exit	1.6446	2.6259		-1.2837	2.7268		-2.9100	1.5342	*	-1.8572	0.4394	***
Financial Management												
Assets	-0.0009	0.0349		-0.0043	0.0314		-0.0090	0.0131		0.0393	0.0098	***
Labor	-0.0343	0.0393		0.0076	0.0215		-0.0415	0.0197	*	-0.0241	0.0118	*
Production Management												
Closed	-1.3760	2.9880		-0.7358	2.7929		0.0906	1.7775		-0.2164	1.3047	
Production Contract	-8.3698	2.2779	***	-2.0596	0.9059	**	-4.7914	0.6396	***	-0.5476	0.6830	
AIAO	-5.4305	4.5763		5.3668	4.7418		6.9600	3.1286	**	6.3001	2.0003	***
Autosort	-0.9416	1.3147		-4.0743	1.5093	**	-4.2174	1.3119	***	-1.3764	0.7576	*
Antibiotics for Growth Promotion	-2.9445	1.7646		1.2384	1.1594		0.3451	1.0399		0.8915	0.3552	**
Antibiotics for Disease Prevention	1.9279	1.9092		1.4813	2.2613		-2.1754	2.1688		-2.3394	1.3096	*
Antibiotics for Treatment	-1.3175	1.7670		3.1096	1.2324	**	-1.3780	0.8743		-0.0004	0.8130	
Mills_Phase	-5.6362	6.6382		15.2877	5.0737	***	2.1544	3.3145		0.3898	2.6846	
Mills_Combination	-7.0313	7.2739		5.9323	6.9348		10.5322	4.1979	**	7.9650	2.4892	***
Phase	-8.9185	2.0642	***	0.8510	0.8373		-1.7518	1.1087		0.3626	0.6296	
Combination	-12.1121	1.9636	***	-0.1460	1.0208		-2.5093	1.5687		-0.4237	0.5780	
Constant	67.4500	27.0786	**	-13.2587	17.4848		-6.8089	12.325		-16.6288	6.3547	

Table 5. OLS results for productivity measures

	Cwt Feed Fed/Cwt Gain			**Labor Hours/Cwt Gain**		
Operation Characteristics	Coef.	Std. Err.		Coef.	Std. Err.	
Operation Size 1: < 500 hogs						
Operation Size 2: 500-1,999 hogs	-2.0942	0.7138	**	-0.4709	0.2841	
Operation Size 3: 2,000-4,999 hogs	-2.3114	0.8749	**	-0.6442	0.3840	
Operation Size 4: ≥ 5,000 hogs	-2.1402	0.8943	**	-0.5430	0.2985	*
Region						
North (MI, MN, WI, SD)	-0.8259	0.4770	*	0.0640	0.1922	
East (NC, VA, PA)	1.1450	0.6749		0.3159	0.4887	
South (AR, GA, KY, MO)	-0.5811	0.5402		0.1338	0.1348	
West (CO, KS, NE, OK)	1.3140	0.3929	***	-0.0486	0.0591	
Midwest (IL, IN, IA, OH)						
Principal Operator Characteristics						
Experience	-0.0087	0.0166		0.0051	0.0048	
Exit	0.4016	0.2494		-0.0040	0.1608	
Financial Management						
Assets	-0.0072	0.0024	***	-0.0010	0.0020	
Labor	-0.0008	0.0035		0.0017	0.0013	
Production Management						
Closed	-0.2011	0.5153		-0.0855	0.1712	
Production Contract	-2.3065	0.3443	***	-0.0898	0.0539	
AIAO	-1.3524	0.7595	*	0.1692	0.3473	
Autosort	-0.4844	0.1504	***	-0.1829	0.0764	**
Antibiotics for Growth Promotion	-0.6137	0.1627	***	0.0535	0.0721	
Antibiotics for Disease Prevention	0.2756	0.2114		0.1457	0.1524	
Antibiotics for Treatment	0.2133	0.3459		0.1488	0.0718	*
Mills_Phase	-0.2455	0.6682		0.8782	0.3002	**
Mills_Combination	-2.1395	0.9415	**	0.1994	0.4930	
Phase	-0.5962	0.3131	*	0.0200	0.0471	
Combination	-0.8479	0.2951	**	-0.0222	0.0538	
Constant	10.4081	3.5576	**	-0.4745	1.2534	