# Sub-therapeutic Antibiotics and Productivity in U.S. Hog Production

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*Abstract*: Antimicrobial drugs are fed to hogs at sub-therapeutic levels to prevent disease and promote growth. However, there is concern that the presence of antimicrobial drugs in hog feed is a factor promoting the development of antimicrobial drug-resistant bacteria. This study uses a sample-selection model to examine the impact that use has on the productivity of U.S. hog operations. The analysis did not find a relationship between productivity and sub-therapeutic antibiotics fed during finishing, but productivity was significantly improved when fed to nursery pigs. Restrictions on feeding antimicrobial drugs during the nursery phase would likely impose significant economic costs on U.S. hog producers.

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Sub-therapeutic levels of antimicrobial drugs have been fed to hogs to prevent disease, promote growth, and improve overall animal health since the 1950's. A 1999 study by a National Academy of Sciences committee (National Research Council) concluded that most drugs and drug residues found in animal-derived foods posed a relatively low public risk so long as the drugs were used responsibly and according to label instructions. However, there has been concern that the presence of antimicrobial drugs in hog feed is a factor promoting development of antimicrobial drug-resistant bacteria. Since many of the drugs used to treat hogs are the same or similar to drugs used in human health care, the worry is that resistant organisms may pass from swine to humans through the handling of swine or their food products (Mathews).

Concerns about antimicrobial drug-resistant bacteria prompted several European countries to ban the use of growth-promoting antimicrobial drugs in hog production as a precautionary measure. Sweden, Norway, Finland, and Denmark were among the first to impose bans (Hayes et al.). A European Union-wide ban on the use of antibiotics as growth promoters went into effect in 2006. Sub-therapeutic use of antimicrobial drugs for hog production in the U.S. has faced increasing scrutiny by public interest groups and the federal Food and Drug Administration. Some major U.S. food companies have announced that they will stop supplying consumers with livestock products that were raised using antibiotics for growth promotion (Hayes and Jensen; USA Today). Legislation has also been introduced to ban selected antibiotics (see Mathews for an overview of the scientific and legislative history).

It is generally accepted that the productivity of major inputs used in swine production, feed, labor, and capital, can be improved on some operations by feeding antibiotics.  Possible modes of action are commonly grouped into three categories: (1) nutritional effects, (2) disease prevention effects, and (3) metabolic effects (Cromwell).  Feed efficiency can be increased by feeding low levels of antibiotics to improve nutrient absorption and depress the growth of organisms competing for nutrients.  By suppressing disease-causing organisms in the animals' environment, antibiotics may reduce the incidence of diseases that hinder performance and thus raise the efficiency of labor and capital use.  However, the greatest productivity response to antibiotics may be on those operations with less than ideal environmental and management conditions--such as those with older buildings, less clean buildings, buildings with mixed-age swine, or those with hogs of inferior genetic potential.

The objectives of this study are to examine the extent of sub-therapeutic antibiotic use in U.S. hog production and to measure the impact that use has on productivity in the sector.  Results of this study provide an indication of the potential impacts that restrictions on feeding antimicrobial drugs to hogs would have on industry productivity in the U.S.--important information for hog producers and policymakers evaluating the implications of legislation that call for such restrictions.

**Previous Research**

Recent research on the impact of feeding antibiotics in U.S. hog production can be distinguished according to its various analytical approaches and data sources.  One line of research has focused mainly on the farm-level impacts.  Data from the European experience with a ban on sub-therapeutic antibiotics have been used to present possible implications of such a ban for U.S. hog producers. In addition, U.S. farm-level data collected in a national survey of hog producers have been examined to suggest impacts of reducing antibiotic use. A second line of research has used aggregate supply and demand models as the analytical framework. Data from hog feeding trials have been used as the basis for modeling assumptions regarding the potential supply and demand impacts of banning sub-therapeutic antibiotics for U.S. producers and consumers.

Hayes and Jensen studied the consequences of Denmark's ban on feed-grade antibiotics in order to present lessons for the U.S. hog sector. A principle finding of their study was that Danish hog producers encountered few costs when antibiotics were withdrawn at the finishing stage, but severe health problems and large costs were incurred with a ban on antibiotics at the weaning stage. The increased mortality and health consequences for weaned pigs were so severe that veterinarians were forced to prescribe additional therapeutic antibiotics which increased total antibiotic use. Other important findings were the wide variation in the effects incurred among producers, with producers using practices that reduce the pressure of infectious diseases, such as all-in/all-out processes, being least affected by the ban. The primary lessons spelled out for U.S. producers were that a ban on antibiotics at the finishing stage might lead to a slight reduction in feed efficiency and an increase in the weight variation of finished hogs, but would create few animal health problems. However, a ban at the weaning stage could create serious animal health problems and lead to a significant increase in mortality. In total, their estimates suggested a first-year impact of $4.50 per head due to the ban of sub-therapeutic antibiotics, which represents approximately a 4.5 percent increase in production costs.

Hayes et al. extrapolated from the European experience with a ban on feeding antibiotics to the U.S. using technical data obtained from Sweden. Their analysis assumed that an antibiotic feeding ban would increase average weaning age by 1 week, and days to reach 50 pounds by 5, while decreasing feed efficiency by 1.5 percent, according to the Swedish experience. Under these assumptions, U.S. production costs per head would increase between $5 and $6, and profits would decline $0.79 per head by banning sub-therapeutic antibiotics. The Swedish experience also suggested that the impact of the ban would be greatest on farms with questionable hygiene practices. For example, farmers who weaned pigs into cold, old, continuous flow buildings encountered the most health problems, and that the more successful farmers were ones that had switched to some form of all-in/all-out nursery practice. Some basic differences between production practices in Sweden and the U.S. were observed that might make the response to antibiotic restrictions different, such as the fact that pigs are never weaned before 5 weeks in Sweden, bedded solid floors are standard, and pen space is considerably larger than in the U.S.

Miller et al. (a.) measured the productivity and economic impact of antibiotics for growth promotion in the grower/finisher phase of U.S. hog production using data collected from U.S. farms in the 1990 and 1995 National Animal Health Monitoring System (NAHMS). The authors conducted linear regressions using NAHMS data that related productivity measures--average daily gain, feed efficiency, and mortality rate--to antibiotic use and other potentially relevant factors of production. Antibiotics fed for growth promotion in the grower/finisher phase were found to improve average daily gain by 1.1 percent, feed conversion by about 0.5 percent, and were associated with reduced hog mortality. In total, these productivity improvements translated to an estimated profitability gain of roughly $0.59 per head. The authors were careful to note the data and analytical limitations of the study, such as the lack of information on antibiotic use in the gestation and farrowing phases, that the role of antibiotics for disease prevention was not considered, and that data on the influence of management (animal husbandry) were limited.

Miller et al. (b.) extended their original study by considering pigs stunted as an additional productivity measure, moving to a system of equations estimation, and employing 2000 NAHMS data which allowed them to more thoroughly characterize management in their model. Results confirmed earlier findings that antibiotics for growth promotion in the grower/finisher stage had a statistically significant impact on average daily gain, but antibiotic use was not statistically significant in estimated relationships with animal feed conversion or pig mortality. Using these findings, a complete ban on sub-therapeutic antibiotics was estimated to cost producers approximately $1.37 per head. The study also suggested that it may be possible for producers to somewhat offset the productivity impacts of a ban by using improved management techniques, such as receiving pigs from on-site sources and tailoring diets more closely to pig needs.

In other work using the 2000 NAHMS data, Liu, Miller, and McNamara examined whether antibiotics reduced production risk among U.S. hog producers. Variability of live weight for growing/finishing pigs was defined as the measure of production risk and regressed against variables describing the use of antibiotics for growth promotion. Results suggested that risk is reduced and profits are increased from feeding antibiotics to growing/finishing pigs. The combined impacts of increased average daily gain and decreased variability in pig weights were estimated to increase producer profits by $2.99 per head.

The economic implications for producers and consumers of a ban on sub-therapeutic antibiotics were estimated by Wade and Barkley. In this study aggregate pork supply and demand functions were specified and estimated to obtain elasticity estimates utilized to calculate consumer and producer surpluses. Key assumptions used in this analysis were that a ban on sub-therapeutic antibiotics would decrease pork supply because of higher producer costs, and increase pork demand because of consumer perceptions of a healthier product. The analysis suggested that both producers and consumers would benefit slightly from a ban on sub-therapeutic antibiotics because of an increase in pork demand, due to elimination of a perceived health risk, which offsets higher production costs associated with the ban.

Brorsen et al. also estimated the economic effects of banning sub-therapeutic antibiotics on producers and consumers using an aggregate supply and demand model. They utilized data from experimental feeding trials to specify the economic benefit of antibiotics from improved feed efficiency, reduced mortality, and reduced sort-loss at marketing. They also were critical of the assumption by Wade and Barkley of an increase in pork demand associated with a ban, arguing that a further decrease in the already extremely low level of antibiotic residue rates would be unlikely, and insufficient to spur consumer demand. Their results showed that a ban on sub-therapeutic antibiotics would be very costly, totaling $243 million annually, with producers incurring the largest portion in the short-run and consumers the largest portion in the long-run.

This past research establishes a context within which to examine the issue and provides insight into the mechanisms by which antibiotics could impact hog farm productivity, both of which inform the empirical approach taken in this study. The empirical approach attempts to contribute to the literature by tackling the issue of self-selection with regard to antibiotic use and measuring its impact on the productivity of U.S. hog operations.

## Empirical Approach

To measure the impact of sub-therapeutic antibiotic (STA) use on input productivity, differences between hog producers who choose to use STA and those that do not should be considered. For example, users of STA may be larger or smaller, have more or less farming experience, use different production practices, or have more or less managerial ability. A problem is that some of these factors are unobservable and may be correlated with STA use and productivity. In this case, simply regressing productivity on exogenous factors and an indicator of STA use will result in biased parameters. For example, the level of management is unobservable and if management ability were to be positively correlated with STA use and productivity, a simple regression would overstate the impact of STA on productivity. The problem in this example would be one of self-selection because producers who chose to use STA would have higher productivity due to better management ability whether or not they chose to use STA.

A treatment-effects sample-selection model is employed to measure the impact of STA use on input productivity (Greene). The model assumes a joint normal distribution between the errors of the selection equation (use or not of STA) and the treatment equation (the measure of productivity). This approach accounts for the possible correlation of unobservable variables with both the decision to use STA and productivity, allowing for an unbiased estimate of the impact of STA on productivity. The unbiased parameter estimates can be derived using a two-stage approach starting with a probit estimation of the selection equation. The probit parameter estimates are then used to compute the selection correction factor, the inverse Mills ratio, which is included as an additional term in a least squares regression of the treatment equation. This two-stage Heckman procedure yields consistent, albeit not efficient parameter estimates (Heckman). Efficient parameter estimates are obtained in this study using the maximum likelihood method.

**Data**

Data used in this study come from the 2004 Agricultural Resource Management Survey (ARMS) of U.S. hog producers. The 2004 ARMS of hog producers includes data from 1,198 hog producers in 19 states. Unlike the data used in previous research, the ARMS data include detailed farm financial information such as farm income, expenses, assets, and debt, and farm and operator characteristics. The 2004 ARMS also included detailed information about the production practices and costs of hog production.

In the hog version of the ARMS, producers were asked whether they fed antibiotics to breeding animals, nursery pigs, and/or finishing hogs. For each of these animal classes, producers were asked whether the antibiotics were fed for growth promotion, disease prevention, and/or disease treatment. A breakdown of antibiotic use for each purpose by different types of hog producers is shown in table 1. Antibiotics were most often fed for disease prevention, especially to nursery pigs. Antibiotic feeding for growth promotion was most common for finishing hogs, reported by more than 40 percent of farrow-to-finish and feeder pig-to-finish operations, but was also common for nursery pigs on farrow-to-finish and on weanling-to-feeder pig operations. Weanling-to-feeder pig operations were most likely to feed antibiotics for disease treatment, done on 80 percent of operations. These operations have weaned pigs placed on the operation at a very young age and feeding antibiotics is a strategy for maintaining the health of these young pigs that are highly susceptible to disease. For the analysis in this study, users of sub-therapeutic antibiotics (STA) were defined as operations that reported antibiotics fed for the purpose of either growth promotion or disease prevention.

The empirical analysis of STA use and impact in this study was confined to feeder pig-to-finish and farrow-to-finish operations because of the large sample size available for these producers. After deleting 42 feeder pig-to-finish and 5 farrow-to-finish observations due to missing data on antibiotic use, 436 feeder pig-to-finish and 326 farrow-to-finish operations were available for the analysis. Less than 100 observations were available for each of the other producer types. The treatment variable in the feeder pig-to-finish model was STA fed to finishing hogs. Two models were estimated for farrow-to-finish producers. In one model the treatment variable was STA use for nursery pigs, while in the other STA use for finishing hogs was specified. STA use in both the nursery and finishing stages of farrow-to-finish production are examined because previous research suggests differential impacts from treating nursery pigs and finishing hogs.

Variables specified in the estimated selection and productivity equations for feeder pig-to-finish and farrow-to-finish operations are shown in table 2. Total factor productivity is measured for each operation as the hundredweight of animal gain per dollar of total costs. Total costs are a measure of the total economic costs of hog production, excluding costs for nursery and feeder pigs purchased or placed on the operation[1]. Exogenous variables specified in the model include

[1] Hundredweight gain is a measure of the value added from the inputs used during the year and equals hundredweight (cwt) of hogs sold or removed under contract, less cwt purchased or placed under contract, plus

farm operator and farm characteristics, and a set of hog production practices that are expected to be associated with the decision to use STA and with productivity of the hog operation.  Operator characteristics, such as operator age, education, primary occupation, and planning horizon are included to account for differences in operator knowledge, goals, and time devoted to hog production.  Farm characteristics account for differences in the structure of hog operations (e.g., size and specialization) and location.  Climatic differences related to farm location may be important to the decision to use STA because of differences in animal disease susceptibility. Other farm characteristics that may affect the STA use decision are the use of production contracts, through which contractors are supplying feed that may or may not include STA, and whether the hog buyer (or contractor) requires that the hogs not be fed antibiotics at any time.

Hog production practices expected to be associated with the selection of STA and productivity include type and age of facilities, the weaning age of nursery pigs, and the purchase/placement weight of pigs to be finished.  Type of facility indicates the degree to which hogs are confined and thus is an indicator of the potential for spreading disease.  Facility age reflects the level of technology and may influence the quality of environment to which hogs are exposed.  Early weaning creates conditions where pigs are more susceptible to disease because natural immunities have yet to form and the selection of antibiotics may be important for maintaining herd health.  Likewise, younger pigs placed in finishing facilities may also be more susceptible to disease.  A number of other variables are specified in the productivity equation, including all in/all out production, crossbreeding program, artificial insemination, the number of rations fed,

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hundredweight of inventory change during the year.  Total costs are the sum of operating and overhead costs, including costs for feed, veterinary and medicine, bedding and litter, marketing, custom operations, fuel and electricity, repairs, paid and unpaid labor, capital, land, general overhead, and taxes and insurance.  Pig costs were excluded because they are not an input contributing to weight gain.

and split-sexed feeding. The purpose of including these variables is to measure effects they are likely to have in order to more accurately isolate the association between productivity and STA use. Therapeutic antibiotic use (for disease treatment) is also added to reflect the impact of chronic disease issues on productivity.

**Results**

Estimates for the STA selection and factor productivity equations for feeder pig-to-finish operations are shown in table 3. None of the operator characteristics were statistically significant in the estimated selection equation and few farm characteristics were significant. Greater farm specialization in hog production increased the likelihood of STA use on the finishing operations, while location in the western states, compared to the Midwest (the control group) decreased the likelihood. Of particular interest is the lack of statistical significance in the coefficients of the farm size and hog contracting variables. STA feeding is a relatively simple technology to employ and does not require a long-term investment in either financial or human capital. Therefore, it is not surprising that a scale-bias was not found with STA selection. Also interesting is that contract operations fed STA neither more nor less often than other operations.

As one would expect, feeder pig-to-finish operations selling hogs to buyers or those that had contractors that specifically required hogs not to be feed antibiotics at any time were less likely to feed STA. Also, hog production practices including type and age of finishing facilities were statistically significant in the selection model. STA selection was more likely in closed confinement facilities that more closely crowd animals increasing the potential for disease transmission. STA use was also associated with older finishing facilities. Animal care in older facilities may not be at the same level as in more modern facilities and STA use may be an inexpensive practice for maintaining animal health in these facilities.

Operator and farm characteristics were much more important for explaining variation in total factor productivity than for the STA selection decision on feeder pig-to-finish operations (table 3). Operator age and a primary occupation off-farm were negatively associated with factor productivity. Some older operators may be semi-retired and may devote less time to the hog operation, or perhaps more often are using aged equipment that they do not plan to replace before retirement. Operators working primarily off-farm may have less time and fewer incentives to devote time to the hog operation. Size of operation was positively and strongly associated with productivity. In addition, the value of the coefficients increased with successive size categories indicating a positive relationship between scale and factor productivity.

Finishing hogs under a contract arrangement was positively associated with factor productivity at a high statistical significance. This finding is consistent with that found in prior work using ARMS survey data from 1998 (Key and McBride). The relationship may reflect the specialized knowledge and resources that contractors and growers each contribute to the production arrangement. Also of interest is that although contracting is most common in eastern states, location in those states was associated with lower productivity than location in the Midwest. It appears that once the impact of contracting is accounted for, the natural advantages of hog finishing in the Midwest (e.g., abundant, low cost feed) improve productivity relative to location in eastern states.

Few hog production practices used by feeder pig-to-finish producers were statistically significant in relation to total factor productivity. The number of rations fed to finishing hogs was highly significant and had a positive impact. This means that productivity was higher on operations that more closely matched feed rations with the varying nutrient requirements of hogs at different weights, a result consistent with previous work (Miller et al. b.). Facility age was negatively associated with productivity, but at a low level of significance. A surprising result was that the use of STA for finishing hogs was statistically significant and negatively associated with productivity, albeit at only the 10 percent level of significance.

Estimates for the STA selection and factor productivity equations for the farrow-to-finish operations are shown in table 4. Estimates are shown for both the selection of STA and the factor productivities in the nursery phase and in the finishing phase. Several farm operator characteristics were statistically significant with respect to STA selection for nursery pigs. Operator age and planning horizon were negatively related to STA selection, indicating that older operators and those approaching retirement were less likely to use STA. This could be the result of devoting less time and attention to the hog operation as retirement nears. Operator education and experience, measured by years in the hog business, were positively associated with STA selection which may reflect a higher level of management provided by more educated and experienced farm operators. All of these farm operator relationships are consistent with expectations about the adoption of farm technologies.

STA selection for nursery pigs was less likely in the eastern and western states compared to the Midwest. Differences in climatic conditions, such as warmer weather in eastern and some western states, may have influenced this relationship. Also, STA selection was more likely in closed confinement facilities. STA are likely used to reduce the potential for disease transmission among young pigs that are more susceptible in these crowded facilities. Size of operation, as in the feeder pig-to-finish model, was not associated with the selection of STA. However, the variable for buyer requirements for antibiotic free hogs was not significant in the STA selection equation for nursery pigs. Hog buyers may not be as concerned about feeding STA to nursery pigs because they are several months from slaughter.

Parameter estimates for STA selection for finishing hogs on farrow-to-finish operations were much different than for the nursery pigs and more similar to those on feeder pig-to-finish operations. No operator characteristics and few farm characteristics were statistically significant. STA selection for finishing hogs was positively associated with farm specialization, while location in the eastern states, compared to the Midwest decreased STA selection. Coefficients on the farm size variables were also not significant for STA use among finishing hogs, like on the specialized hog finishing operations, indicating no scale-bias with STA selection. Also, hog operations with buyers that required hogs not to be fed antibiotics were less likely to fed STA to finishing hogs. None of the production practice variables were statistically significant. A contracting variable was not included because there were too few contract farrow-to-finish operations in the sample.

The factor productivity equations estimated for nursery pigs and finishing hogs on the farrow-to-finish operations showed several similarities (table 4). A primary occupation off-farm had a statistically significant and negative impact on factor productivity in both equations, likely due to the reduced time and resource commitment among operators working off-farm.  Both models revealed a strong and positive association between size of operation and productivity, and coefficients that increased with successive size categories indicating scale-economies in both equations.   Farrow-to-finish operations in northern states were less productive than in the Midwest.  However, only in the finishing equation was a significant relationship found between lower productivity and location in eastern states.  This is the same result as for the specialized finishing operations and may arise from the advantages of hog finishing in the Midwest.  One surprising result was a negative coefficient on the education variable in both models, but this was only significant in the productivity equation for nursery pigs.

Several hog production practices variables were statistically significant in both models.  Most interesting was the relationship between productivity and the hog breeding program.  Variables for terminal and rotational crossbreeding were highly significant and positively related to productivity, indicating that the genetic potential of the hogs has an important role in productivity of the operation.  Also significant were hog finishing facility variables that showed finishing hogs in closed confinement to be positively associated with productivity in both equations.  Producing hogs in these enclosed facilities likely improves feed and labor efficiency.  Oddly, the number of rations fed had a negative relationship with productivity, although at a low level of statistical significance in both models.

With regard to this study, the most important difference between the two factor productivity equations estimated for farrow-to-finish operations is the coefficients on the STA use variable.  Feeding STA to nursery pigs had a statistically significant and positive relationship with total factor productivity. It appears that feeding STA is important for maintaining health and enhancing the performance of young pigs, when they are most susceptible to disease. Also, the magnitude of the coefficient on the STA variable (0.830) was largest among all hog production practices and second only to the influence of size on productivity, but exhibited a high variance[2]. In contrast, the coefficient on the variable for feeding STA to finishing hogs was not statistically significant.

The estimated correlation of errors of the selection and factor productivity equations, rho, is statistically significant and negative in the farrow-to-finish model for nursery pigs. This result implies a negative selection bias and indicates that the impact on productivity of feeding STA to nursery pigs would have been understated had the selection bias not been taken into account[3]. In contrast, the correlation of errors between the two equations was not significant in either model of STA use for finishing hogs indicating that selection bias was not present in these relationships.

To evaluate the robustness of the results, an alternative model specification was examined. The models were re-estimated using antibiotics for growth promotion (AGP) as the dependent variable, as opposed to STA defined as antibiotic use for either growth promotion or disease prevention. Some survey respondents could have confused the difference between disease prevention and disease treatment, or some were using antibiotics for disease prevention and treatment simultaneously because disease issues were associated with the operation that could

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[2] A 95 percent confidence interval around the estimated coefficient of 0.830 ranges from 0.219 to 1.441.

[3] Further evidence of a negative selection bias in the farrow-to-finish equation for nursery pigs was found in an ordinary least squares regression of the factor productivity equation. The estimated coefficient on the variable for STA use for nursery pigs was much smaller than that estimated with the selection model and not statistically significant.

have reduced productivity. It is less likely that the use of AGP would be confused with or confounded by antibiotic use for disease treatment.

Table 5 shows estimation results of the models with the alternative specification, including only the parameter estimate on the AGP variable for each model[4]. The coefficient on the variable for AGP for nursery pigs was 1.018, up from 0.830 in the STA model, and statistically significant, suggesting that this result was robust to the alternative specification. The coefficient on the AGP variable for feeder pig-to-finish operations remained negative, but increased in value from the STA model and was not statistically significant. Likewise, the AGP coefficient for finishing hogs on the farrow-to-finish operations was not statistically significant as in the STA model.

## Conclusions

The analysis of farrow-to-finish operations suggested that feeding STA to nursery pigs significantly improved factor productivity and this result was confirmed with an alternative specification. The magnitude of the estimated coefficient suggests that for the average farm, holding other inputs constants, feeding STA to nursery pigs increased productivity by about a third, but with a confidence interval of about 10 to 60 percent. Such a substantial productivity gain may be explained, in part, by which operations benefit most from using STA. The greatest gains in productivity are thought to be on operations that would otherwise be less productive because of less than ideal environmental and management conditions. The negative selection bias found in the nursery pig equation supports this assertion, suggesting that the impact on productivity of feeding STA to nursery pigs would have been understated by not accounting for

[4] The coefficients and statistical significance of other variables in the alternative models changed little from that in the original models and thus are not shown in table 5.

who chose to use STA.  In other words, the operations that fed STA to nursery pigs were otherwise, on average, less productive than other operations due to unmeasured factors. Therefore, feeding STA to nursery pigs may be compensating for differences in management, the quality of production inputs, or other unobserved aspects of the hog operation.

Results from the analysis of feeding STA to nursery pigs suggests that restrictions on feeding antimicrobial drugs during the nursery phase would reduce the productivity of U.S. hog production as a whole and would impose significant economic costs on hog producers.  These costs would likely result from increased pig mortality and reduced animal performance in the short-term, and in the long-term from necessary adjustments in management and other inputs used on hog operations.

Accounting for exogenous operator and farm characteristics, hog production practices, and sample selection bias, the results of this study showed little relationship between feeding STA and factor productivity for finishing hogs in the U.S.  The analysis of feeder pig-to-finish producers suggested a negative relationship between STA use and productivity for finishing hogs, but this result was not confirmed by an alternative specification or by either of the two specifications for finishing hogs on farrow-to-finish operations.

These results suggest that restrictions on feeding antimicrobial drugs during finishing would have little impact on the productivity of U.S. hog production.  However, it is important to note that these findings do not consider the role that STA may play in the performance of the overall production system.  For example, feeding STA likely facilitates the use of other productivity enhancing practices for finishing hogs such as closed confinement facilities and all in/all out management. STA use may also reduce the variation in productivity and may be used to reduce production risk and to improve the uniformity of finished hogs. Variation in performance is important to hog producers because non-uniformity in hog weights can result in price penalties or reduced payments to contract growers. Further research regarding the impact of STA on the variability of productivity might add to the understanding of why STA are widely fed to finishing hogs.

Results of this study are very similar to those using the European experience with a ban on STA. Analyses of the European experience suggests little impact for U.S. producers at the finishing stage, but major costs incurred from poor animal health and pig mortality at the nursery stage. This is what findings of this study suggest for U.S. hog producers. However, the magnitude of the estimated impact appears to be higher in this study. This could be due to which factor costs were included in the different analyses and to the consideration of selection bias in these results.

The lack of a relationship between STA use and productivity for finishing hogs does not correspond with the previous work using NAHMS survey data that suggested a positive association. An important difference between this study and the NAHMS survey analyses is in the measures of productivity. The previous research implied a relationship between very narrow measures of productivity associated with a single input, such as feed conversion and average daily gain, while here a broader measure is used that includes the impact on total factor productivity. The previous work also could not account for many of the differences in operator and farm characteristics, made possible in this study because of the ARMS data.

## References

Brorsen, B.W., T. Lehenbauer, D. Ji, and J. Conner. "Economic Impacts of Banning Sub-therapeutic Use of Anitbiotics in Swine Production." *Journal of Agricultural and Applied Economics*. 34,3(December 2002):489-500.

Cromwell, G.L. "Why and How Antibiotics and are used in Swine Production." *Animal Biotechnology*. 13(2002):7-27.

Greene, W. *Econometric Analysis*, 4th edn. New Jersey: Prentice Hall. 2000. pp. 993-994.

Hayes, D.J., H.H. Jensen, L. Backstrom, and J.F. Fabiosa. "Economic Impact of a Ban on the Use of Over-the-Counter Antibiotics in U.S. Swine Rations." *International Food and Agribusiness Management Review*. 4(2001):81-97.

Hayes, D.J. and H.H. Jensen. *Lessons from the Danish Ban on Feed-Grade Antibiotics*. Center for Agricultural and Rural Development. Iowa State University. Briefing Paper 03-BP 41. June 2003.

Heckman, J.J. "The Common Structure of Statistical Models of Truncation, Sample Selection, and Limited Dependent Variables and a Simple Estimator for Such Models." *Annals of Economic and Social Measurement*. 5(1976):475-91.

Key, N. and W. McBride. "Production Contracts and Productivity in the U.S. Hog Sector." *American Journal of Agricultural Economics*. 85,1(February 2003):121-133.

Liu, X., G.Y. Miller, and P.E. McNamara. "*Do Antibiotics Reduce Production Risk for U.S. Pork Producers?*" Journal of Agricultural and Applied Economics. 37,3(December 2005):565-575.

Mathews, K. *Antimicrobial Drug Use and Veterinary Costs in U.S. Livestock Production*. U.S. Department of Agriculture. Economic Research Service. Agriculture Information Bulletin Number 766. May, 2001.

McBride, W.D. and N. Key. *Economic and Structural Relationships in U.S. Hog Production*. U.S. Department of Agriculture. Economic Research Service. Agricultural Economics Report Number 818. February, 2003.

Miller, G.Y., K.A. Algozin, P.E. McNamara and E.J. Bush. a. "Productivity and Economic Impacts of Feedgrade Antibiotic Use in Pork Production." *Journal of Agricultural and Applied Economics*. 12(2003):469-82.

Miller, G.Y., X. Liu, P.E. McNamara and E.J. Bush. b. "Farm-Level Impacts of Banning Growth-Promoting Antibiotic Use in U.S. Pig Grower/Finisher Operations." *Journal of Agribusiness*. 23,2(Fall 2005):147-162.

National Research Council. *The Use of Drugs in Food Animals: Benefits and Risks*. Washington, DC. National Academy of Sciences. 1999.

USA Today. '*Natural' Chickens Take Flight: Four Top Producers End Use of Antibiotics*. January 24, 2006.

Wade, M. A. and A. P. Barkley. "The Economic Impacts of a Ban on Sub-therapeutic Antibiotics in Swine Production." *Agribusiness*. 8,2(1992):93-107.

**Table 1. Frequency of Antibiotic Feeding in U.S. Hog Production, by Producer Type, 2004**

| Producer type | Antibiotics fed for: Growth Promotion | Disease Prevention | Disease Treatment | Sub-therapeutic use |
|---|---|---|---|---|
| | percent of farms feeding | | | |
| Farrow-to-Finish: | | | | |
| Breeding animals | 13 | 43 | 20 | 44 |
| Nursery pigs | 38 | 62 | 25 | 64 |
| Finishing hogs | 43 | 38 | 22 | 51 |
| Farrow-to-Feeder Pig | | | | |
| Breeding animals | 17 | 54 | 44 | 68 |
| Nursery pigs | 23 | 15 | 8 | 31 |
| Feeder Pig-to-Finish | | | | |
| Finishing hogs | 44 | 60 | 58 | 67 |
| Farrow-to-Weanling | | | | |
| Breeding animals | 5 | 40 | 37 | 40 |
| Weanling-to-Feeder Pig | | | | |
| Nursery pigs | 42 | 84 | 80 | 85 |

*Notes:* Sub-therapeutic use is the feeding of antibiotics for either growth promotion or disease prevention. Producer types are defined in McBride and Key.

*Source:* 2004 Agricultural Resource Management Survey.

**Table 2. Variables Specified in the Estimated Models, U.S. Feeder Pig-to-Finish and Farrow-to-Finish Operations, 2004**

| Variable Description | Feeder pig-to-Finish | | Farrow-to-Finish | |
|---|---|---|---|---|
| | Mean | Standard Error | Mean | Standard Error |
| Total factor productivity[a] | 4.10 | 0.101 | 2.41 | 0.070 |
| Age (years) | 50.63 | 0.466 | 51.44 | 0.698 |
| Education (years) | 13.82 | 0.090 | 13.02 | 0.100 |
| Primary occupation is off-farm | 0.17 | 0.018 | 0.20 | 0.022 |
| Years in hog business | 13.28 | 0.494 | 19.55 | 0.789 |
| Planning horizon (years) | 12.08 | 0.355 | 10.50 | 0.411 |
| Size class 1: Less than 500 hogs[bc] | 0.26 | 0.021 | 0.61 | 0.027 |
| Size class 2: 500-1,999 hogs[bc] | 0.36 | 0.023 | 0.31 | 0.026 |
| Size class 3: 2,000-4,999 hogs[bc] | 0.26 | 0.021 | 0.06 | 0.013 |
| Size class 4: 5,000 or more hogs[bc] | 0.11 | 0.015 | 0.03 | 0.010 |
| Specialization in hogs (proportion)[d] | 0.61 | 0.016 | 0.47 | 0.017 |
| Location in Midwest (IA, IL, IN, OH)[b] | 0.47 | 0.024 | 0.29 | 0.025 |
| Location in East (NC, VA, PA)[b] | 0.10 | 0.015 | 0.06 | 0.013 |
| Location in South (AR, GA, KY, MO)[b] | 0.03 | 0.008 | 0.16 | 0.021 |
| Location in North (MI, MN, WI, SD)[b] | 0.23 | 0.020 | 0.25 | 0.024 |
| Location in West (CO, KS, NE, OK)[b] | 0.16 | 0.018 | 0.23 | 0.023 |
| Hog production contract[b] | 0.47 | 0.024 | 1.0E-4 | 0.001 |
| Hog buyer requires no antibiotic use[b] | 0.14 | 0.017 | 0.11 | 0.017 |
| Closed confinement nursery facilities[b] | na | - | 0.59 | 0.027 |
| Nursery facility age (years) | na | - | 13.22 | 0.612 |
| All in/all out nursery management[b] | na | - | 0.44 | 0.028 |
| Closed confinement finishing facilities[b] | 0.73 | 0.021 | 0.40 | 0.027 |
| Finishing facility age (years) | 13.78 | 0.395 | 19.00 | 0.601 |
| Weaning age (days) | na | - | 33.56 | 0.643 |
| Pig purchase/placement weight (pounds) | 42.37 | 1.006 | na | - |
| All in/all out finishing management[b] | 0.82 | 0.020 | 0.50 | 0.022 |
| Terminal crossbreeding[b] | na | - | 0.20 | 0.022 |
| Rotational crossbreeding[b] | na | - | 0.60 | 0.027 |
| Artificial insemination[b] | na | - | 0.19 | 0.022 |
| Number of rations fed | 4.16 | 0.106 | 3.74 | 0.119 |
| Split-sexed feeding[b] | 0.34 | 0.023 | 0.17 | 0.021 |
| Nursery disease treatment w/ antibiotics[b] | na | - | 0.25 | 0.024 |
| Finishing disease treatment w/ antibiotics[b] | 0.58 | 0.024 | 0.22 | 0.023 |

[a]Hundredweight of hog production per dollar of total factor cost (X $10^{-2}$).
[b]Binary variable equal to 1 if the characteristic or practice applies, 0 otherwise.
[c]Size is measure by the maximum number of hogs in inventory any time during 2004.
[d]Proportion of the total value of farm production that was generated by hog production.
na means not applicable.

**Table 3. Selection Model Maximum Likelihood Estimates: Total Factor Productivity on U.S. Feeder Pig-to-Finish Operations, 2004**

| Variable Description | Finishing Hogs | |
|---|---|---|
| | Coefficient | Standard Error |
| *Selection Equation* | | |
| Constant | 0.070 | 0.921 |
| Age (years) | -0.005 | 0.009 |
| Education (years) | -0.041 | 0.050 |
| Primary occupation is off-farm | 0.093 | 0.302 |
| Years in hog business | 0.002 | 0.011 |
| Planning horizon (years) | 0.011 | 0.014 |
| Size class 2: 500-1,999 hogs | 0.157 | 0.295 |
| Size class 3: 2,000-4,999 hogs | 0.148 | 0.354 |
| Size class 4: 5,000 or more hogs | 0.422 | 0.479 |
| Specialization in hogs (proportion) | 0.791** | 0.400 |
| Location in East (NC, VA, PA) | -0.136 | 0.251 |
| Location in South (AR, GA, KY, MO) | 0.325 | 0.336 |
| Location in North (MI, MN, WI, SD) | 0.019 | 0.264 |
| Location in West (CO, KS, NE, OK) | -0.591** | 0.282 |
| Hog production contract | -0.249 | 0.263 |
| Hog buyer requires no antibiotic use | -0.907** | 0.335 |
| Closed confinement finishing facilities | 0.702** | 0.249 |
| Finishing facility age (years) | 0.027** | 0.013 |
| Pig purchase/placement weight (pounds) | -0.002 | 0.004 |
| All in/all out finishing management | -0.008 | 0.249 |

*continued*

**Table 3. Selection Model Maximum Likelihood Estimates: Total Factor Productivity on U.S. Feeder Pig-to-Finish Operations, 2004 (continued)**

| Variable Description | Finishing Hogs Coefficient | Finishing Hogs Standard Error |
|---|---|---|
| *Factor Productivity Equation* | | |
| Constant | 4.032** | 0.910 |
| Age (years) | -0.016* | 0.009 |
| Education (years) | -0.073 | 0.044 |
| Primary occupation is off-farm | -0.670** | 0.304 |
| Years in hog business | 0.020 | 0.014 |
| Planning horizon (years) | -0.009 | 0.013 |
| Size class 2: 500-1,999 hogs | 0.475* | 0.254 |
| Size class 3: 2,000-4,999 hogs | 1.255** | 0.322 |
| Size class 4: 5,000 or more hogs | 1.263** | 0.415 |
| Specialization in hogs (proportion) | 0.305 | 0.440 |
| Location in East (NC, VA, PA) | -0.896** | 0.302 |
| Location in South (AR, GA, KY, MO) | 0.285 | 0.250 |
| Location in North (MI, MN, WI, SD) | 0.072 | 0.367 |
| Location in West (CO, KS, NE, OK) | -0.444 | 0.363 |
| Hog production contract | 0.984** | 0.235 |
| Closed confinement finishing facilities | 0.080 | 0.305 |
| Finishing facility age (years) | -0.026* | 0.015 |
| All in/all out finishing management | 0.387 | 0.253 |
| Finishing disease treatment w/ antibiotics | -0.130 | 0.219 |
| Number of rations fed | 0.147** | 0.047 |
| Split-sexed feeding | -0.112 | 0.274 |
| STA fed to finishing hogs | -1.183* | 0.642 |
| | | |
| Sigma | 1.468** | 0.139 |
| Rho | 0.258 | 0.161 |
| | | |
| Log likelihood | -35,247 | |
| Sample size | 436 | |

*Notes:* Dependent variable in the selection equation is the whether sub-therapeutic antibiotics were fed to finishing hogs (0,1). Dependent variable in the factor productivity equation is hundredweight of hog production per dollar of total factor cost (X $10^{-2}$). * and ** denote statistical significance at the 10 percent and 5 percent levels, respectively.

**Table 4. Selection Model Maximum Likelihood Estimates: Total Factor Productivity on U.S. Farrow-to-Finish Operations, 2004**

| Variable Description | Nursery Pigs | | Finishing Hogs | |
|---|---|---|---|---|
| | Coefficient | Standard Error | Coefficient | Standard Error |
| *Selection Equation* | | | | |
| Constant | 0.714 | 0.986 | -1.018 | 1.209 |
| Age (years) | -0.031** | 0.011 | -0.006 | 0.014 |
| Education (years) | 0.110* | 0.066 | 0.080 | 0.059 |
| Primary occupation is off-farm | -0.237 | 0.320 | -0.106 | 0.396 |
| Years in hog business | 0.017** | 0.008 | 0.007 | 0.011 |
| Planning horizon (years) | -0.410** | 0.015 | -0.012 | 0.015 |
| Size class 2: 500-1,999 hogs | 0.360 | 0.274 | 0.001 | 0.305 |
| Size class 3: 2,000-4,999 hogs | 0.891 | 0.744 | 0.378 | 0.383 |
| Size class 4: 5,000 or more hogs | 0.317 | 0.496 | 0.851* | 0.503 |
| Specialization in hogs (proportion) | -0.103 | 0.359 | 0.751 | 0.472 |
| Location in East (NC, VA, PA) | -1.101* | 0.581 | -1.617** | 0.475 |
| Location in South (AR, GA, KY, MO) | -0.462 | 0.306 | -0.439 | 0.274 |
| Location in North (MI, MN, WI, SD) | -0.518 | 0.317 | 0.379 | 0.374 |
| Location in West (CO, KS, NE, OK) | -1.131** | 0.260 | -0.324 | 0.366 |
| Hog buyer requires no antibiotic use | 0.190 | 0.341 | -1.252** | 0.340 |
| Closed confinement nursery facilities | 0.896** | 0.275 | na | - |
| Nursery facility age (years) | 0.004 | 0.012 | na | - |
| All in/all out nursery management | 0.320 | 0.274 | na | - |
| Weaning age (days) | -0.007 | 0.010 | na | - |
| Closed confinement finishing facilities | na | - | 0.263 | 0.306 |
| Finishing facility age (years) | na | - | 0.004 | 0.013 |
| All in/All out finishing management | na | - | -0.053 | 0.278 |

*continued*

**Table 4. Selection Model Maximum Likelihood Estimates: Total Factor Productivity on U.S. Farrow-to-Finish Operations, 2004 (continued)**

| Variable Description | Nursery pigs | | Finishing hogs | |
|---|---|---|---|---|
| | Coefficient | Standard Error | Coefficient | Standard Error |
| *Factor Productivity Equation* | | | | |
| Constant | 1.426** | 0.512 | 1.798** | 0.415 |
| Age (years) | 0.002 | 0.005 | -0.005 | 0.004 |
| Education (years) | -0.062** | 0.030 | -0.028 | 0.021 |
| Primary occupation is off-farm | -0.323** | 0.135 | -0.340** | 0.108 |
| Years in hog business | -0.002 | 0.004 | 0.003 | 0.004 |
| Planning horizon (years) | 0.004 | 0.008 | -0.004 | 0.005 |
| Size class 2: 500-1,999 hogs | 0.530** | 0.152 | 0.587** | 0.141 |
| Size class 3: 2,000-4,999 hogs | 1.016** | 0.215 | 1.126** | 0.243 |
| Size class 4: 5,000 or more hogs | 1.277** | 0.287 | 1.263** | 0.243 |
| Specialization in hogs (proportion) | -0.007 | 0.161 | -0.045 | 0.130 |
| Location in East (NC, VA, PA) | -0.381 | 0.262 | -0.626** | 0.176 |
| Location in South (AR, GA, KY, MO) | -0.029 | 0.142 | -0.157 | 0.119 |
| Location in North (MI, MN, WI, SD) | -0.306** | 0.118 | -0.347** | 0.100 |
| Location in West (CO, KS, NE, OK) | 0.195 | 0.184 | -0.037 | 0.136 |
| Closed confinement nursery facilities | -0.195 | 0.199 | 0.030 | 0.160 |
| Nursery facility age (years) | -0.002 | 0.005 | 0.000 | 0.004 |
| All in/all out nursery management | 0.001 | 0.138 | 0.119 | 0.109 |
| Nursery disease treatment w/ antibiotics | -0.155 | 0.109 | -0.112 | 0.090 |
| Closed confinement finishing facilities | 0.259** | 0.130 | 0.299** | 0.153 |
| Finishing facility age (years) | -0.008* | 0.004 | -0.008 | 0.005 |
| All in/All out finishing management | -0.163 | 0.112 | -0.119 | 0.101 |
| Finishing disease treatment w/ antibiotics | 0.121 | 0.106 | 0.090 | 0.105 |
| Terminal crossbreeding | 0.418** | 0.136 | 0.439** | 0.165 |
| Rotational crossbreeding | 0.257** | 0.109 | 0.209* | 0.111 |
| Artificial insemination | 0.137 | 0.159 | 0.230 | 0.190 |
| Number of rations fed | -0.046* | 0.028 | -0.058* | 0.034 |
| Split-sexed feeding | 0.038 | 0.098 | 0.047 | 0.100 |
| STA fed to nursery pigs | 0.830** | 0.312 | na | - |
| STA fed to finishing hogs | na | - | -0.069 | 0.171 |
| | | | | |
| Sigma | 0.625** | 0.108 | 0.545** | 0.062 |
| Rho | -0.802** | 0.159 | 0.080 | 0.153 |
| | | | | |
| Log likelihood | -14,702 | | -17,079 | |
| Sample size | 326 | | 326 | |

*Notes:* Dependent variable in the selection equation for nursery pigs is the whether sub-therapeutic antibiotics were fed to nursery pigs (0,1). Dependent variable in the selection equation for finishing hogs is the whether sub-therapeutic antibiotics were fed to finishing hogs (0,1). Dependent variable in the factor productivity equation is hundredweight of hog production per dollar to total factor cost (X $10^{-2}$). * and ** denote statistical significance at the 10 percent and 5 percent levels, respectively. na means not applicable.

**Table 5. Selection Model Maximum Likelihood Estimates: Total Factor Productivity on U.S. Hog Operations, Antibiotics Fed for Growth Promotion (AGP) , 2004**

| Variable Description | Coefficient | Standard Error |
|---|---|---|
| *Feeder pig-to-finish operations* | | |
| AGP fed to finishing hogs | -0.794 | 0.653 |
| *Farrow-to-finish operations* | | |
| AGP fed to nursery pigs | 1.018** | 0.236 |
| AGP fed to finishing hogs | -0.108 | 0.153 |

*Notes:* Dependent variable in the selection equation for nursery pigs is the whether antibiotics were fed to nursery pigs for growth promotion (0,1). Dependent variable in the selection equation for finishing hogs is the whether antibiotics were fed to finishing hogs for growth promotion (0,1). Dependent variable in the factor productivity equation is hundredweight of hog production per dollar of total factor cost (X $10^{-2}$). * and ** denote statistical significance at the 10 percent and 5 percent levels, respectively.