Sub-therapeutic Antibiotics and Impacts on U.S. Hog Farms

William D. McBride*
Nigel Key
Kenneth Mathews

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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 describes the extent to which antibiotics are used in hog production and how this changed between 2004 and 2009. This study also uses a sample-selection model to examine the impact that use has on the productivity of U.S. hog operations. Using hog producer data from 2004, 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. These results are being evaluated using similar data from 2009.

*The authors are with the U.S. Department of Agriculture, Economic Research Service. The views expressed herein are those of the authors and do not necessarily reflect the views or polices of the U.S. Department of Agriculture. Direct any correspondence to: wmcbride@ers.usda.gov , (202) 694-5577.

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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 how it changed between 2004 and 2009. This study uses data from a large-scale representative survey for each year. Also, the impact of sub-therapeutic antibiotic use on U.S. hog farms is measured. Results of this study provide an indication of the potential impacts that restrictions on feeding antimicrobial drugs to hogs would have on U.S. hog farms.

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.

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[1].

Data

Data used in this study come from the 2004 and 2009 Agricultural Resource Management Surveys (ARMS) of U.S. hog producers. The 2004 ARMS of hog producers includes data from 1,198 hog producers in 19 states. The 2009 ARMS of hog producers includes data from 1,286 hog producers in the same 19 states. Unlike data used in much of the previous research, the ARMS data include detailed farm financial information such as farm income, expenses, assets, and debt, and farm and operator characteristics. The ARMS data also include detailed information about the production practices and costs of hog production.

The analysis of STA use is confined to feeder pig-to-finish and farrow-to-finish operations because of the large sample size available for these producers[2]. The 2004 data include 321 farrow-to-finish operations and 478 feeder pig-to-finish operations. The 2009 data include 268 farrow-to-finish operations and 570 feeder pig-to-finish operations. In the ARMS hog versions, producers were asked whether they fed antibiotics to breeding animals, nursery pigs, and/or finishing hogs. For each of these classes, producers were asked whether antibiotics were fed for growth promotion, disease prevention, and/or disease treatment. A breakdown of antibiotic use for each purpose on farrow-to-finish and feeder pig-to-finish farms in 2004 and 2009 is shown in table 1.

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[1] A more detailed description of the empirical approach is in McBride, Key, and Mathews.
[2] The producer types are defined in McBride and Key.

In both 2004 and 2009, antibiotics were most often fed for disease prevention, especially to nursery pigs on farrow-to-finish farms. 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 in 2004, but use declined in 2009 to 22 and 35 percent of farms, respectively. The use of antibiotics for both growth promotion and disease prevention for nursery pigs on farrow-to-finish operations declined by 8-9 percent of farms from 2004 to 2009.

For analysis, we define users of sub-therapeutic antibiotics (STA) as operations that reported antibiotics fed for the purpose of either growth promotion or disease prevention. More farms fed STAs to nursery pigs on farrow-to-finish farms in 2004 (64 percent) than in 2009 (55 percent). Likewise, the percent of farrow-to-finish farms feeding STAs to finishing hogs declined 11 percent from 2004 to 2009, and feeder pig-to-finish farms feeding STAs declined 9 percent. Also, more feeder pig-to-finish farm operators did not know about antibiotic use in the hogs feed in 2009 (20 percent) than in 2004 (4 percent)[3].

Farm characteristics for STA users and non-users in both 2004 and 2009 are shown in table 2. Among farrow-to-finish operations, STA users for both nursery and finishing hogs are much larger than other producers, and their average size increased from 2004 to 2009 much more than non-users. Hog and pig inventory for STA users was more than double that for non-users in 2004, but increased to 3.5 times the size for operations feeding STAs to nursery pigs and nearly

[3] Some of this difference in antibiotic use may be due to the questionnaire design of each survey. A "don't know" option was offered as a choice to producers in 2009, but not in 2004. Also, the proportion of feeder pig-to-finish farms producing hogs under contract increased from 50 to 75 percent between 2004 and 2009. Contract growers were less likely to know if antibiotics were in the hog feed delivered by contractors than were other producers. More than 90 percent of those that did not know if antibiotics were fed were contract growers.

5 times the size for operations feeding STAs to finishing hogs. STA users were also more specialized in hog production than non-users with about two-thirds of farm product value from hogs, compared with about a third for non-users in 2009. Most farrow-to-finish operations using STAs were located in the Midwest, and the concentration of users increased in the Midwest during 20004-2009 to where about half of STA users in 2009 were in the Midwest. Most non-users of STAs were located in the West.

Among feeder pig-to-finish operations, differences between STA users and non-users were less pronounced. Hog and pig inventory for STA users in 2004 were about twice those of non-users, but this difference narrowed in 2009 (table 2). Contract hog production increased among both STA users and non-users during 2004-2009, to where about 70 percent of hog finishing farms produced hogs under contract in 2009. STA users were more likely to be located in the Midwest than non-users. This difference was much the same in both 2004 and 2009.

The 2009 ARMS collected data from hog producers about use of the Pork Quality Assurance (PQA) Plus program and other practices that could indicate farm cleanliness. The PQA Plus program provides producers with information about on-farm Good Production Practices (GPPs) for the promotion of pork safety and pig well-being[4]. We are particularly interested in whether producers not using STAs were offsetting STAs by using other practices, like the PQA Plus program. MacDonald and Wang report that some broiler producers are using ways other than STAs address animal health and food safety.

[4] The PQA Plus program is comprised of two main elements—food safety and animal well-being. Food safety refers to practices that minimize physical, chemical, or biological hazards that might be injurious to consumers. Animal well-being encompasses producer responsibilities for all aspects of animal well-being, including proper housing, management, nutrition, disease prevention and treatment, responsible care, humane handling, and when necessary, humane and timely euthanasia (National Pork Board).

Use of the PQA Plus program by users and non-users of STAs is shown in table 3. Among farrow-to-finish operations, STA users more often used the PQA Plus program and other farm cleanliness practices that did other producers. About 80 percent of farrow-to-finish producers using STAs used the PQA Plus program, compared with around 40 percent of non-users producers. STA users among the feeder pig-to-finish producers more often used the PQA Plus program, but this difference was less pronounced (81 versus 67 percent). For neither farrow-to-finish nor feeder pig-finish farms was there evidence that producers were using the PQA Plus program or other practices to compensate for not using STAs.

Model Specification

Variables specified in the estimated selection and productivity equations for feeder pig-to-finish and farrow-to-finish operations using the 2004 ARMS data are shown in table 4[5]. 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[6]. Exogenous variables specified in the model include 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

[5] The ARMS data for 2009 are being processed. Results of the models estimated using the 2009 data will be included later.

[6] 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 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.

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 STAs, and whether the hog buyer (or contractor) requires that the hogs not be fed antibiotics.

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, 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.

Model Results: Feeder Pig-to-Finish Operations

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.

Model Results: Farrow-to-Finish Operations

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[7].

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

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[8]. 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.

Sensitivity Analysis

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

[8] 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.

Table 5 shows estimation results of the models with the alternative specification, including only the parameter estimate on the AGP variable for each model[9]. 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 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.

[9] 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.

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 use of STAs among U.S. farrow-to-finish and feeder pig-to-finish operations declined about 10 percent from 2004 to 2009. This could be due to increased concerns about antibiotic use in U.S. livestock production and more buyers looking for antibiotic free alternatives. Further analysis of the 2009 ARMS data will examine how the impacts of sub-therapeutic antibiotic use on U.S. hog farms may have changed from 2004 to 2009.

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Table 1. Frequency of Antibiotic Feeding in U.S. Hog Production by Farrow-to-Finish and Feeder pig-to-Finish Producers, 2004 and 2009

Producer type	Growth Promotion	Disease Prevention	Disease Treatment	Sub-therapeutic use	Don't know
2004	Percent of farms feeding				
Farrow-to-Finish					
Breeding animals	13	43	20	44	*
Nursery pigs	38	62	25	64	*
Finishing hogs	43	38	21	52	*
Feeder Pig-to-Finish					
Finishing hogs	42	58	56	65	4
2009					
Farrow-to-Finish:					
Breeding animals	12	37	30	39	2
Nursery pigs	29	52	29	55	*
Finishing hogs	22	34	23	40	*
Feeder Pig-to-Finish					
Finishing hogs	35	49	55	56	20

Notes: Sub-therapeutic use is the feeding of antibiotics for either growth promotion or disease prevention. Producer types are defined in McBride and Key. *=less than 1 percent.
Source: 2004 Agricultural Resource Management Survey.

Table 2. Characteristics of U.S. Farrow-to-Finish and Feeder pig-to-Finish Operations, by use of Sub-therapeutic Antibiotics, 2004 and 2009

Item	2004 users	2004 non-users	2009 users	2009 non-users
Farrow-to-finish		STAs for nursery pigs		
Percent of farms	64	35	55	45
Percent of production	73	27	79	19
Average hog & pig inventory	1,048	485	2,392	676
Percent of farms w/ production contracts	0	*	2	*
Percent of farm product value from hogs	59	56	61	34
Percent of farms located in:				
Midwest (IA, IL, IN, OH)	37	15	50	18
East (NC, VA, PA)	4	8	3	9
South (AR, GA, KY, MO)	14	21	11	18
North (MI, MN, WI, SD)	32	14	18	23
West (CO, KS, NE, OK)	13	42	18	33
Farrow-to-finish		STAs for finishing hogs		
Percent of farms	52	48	41	58
Percent of production	70	30	71	24
Average hog & pig inventory	1,197	474	2,998	613
Percent of farms w/ production contracts	0	*	2	*
Percent of farm product value from hogs	63	50	66	31
Percent of farms located in:				
Midwest (IA, IL, IN, OH)	34	25	56	22
East (NC, VA, PA)	1	10	2	8
South (AR, GA, KY, MO)	11	22	7	20
North (MI, MN, WI, SD)	32	18	24	17
West (CO, KS, NE, OK)	21	25	12	33
Feeder pig-to-finish		STAs for finishing hogs		
Percent of farms	65	31	56	24
Percent of production	80	14	57	23
Average hog & pig inventory	2,185	1,055	3,104	2,793
Percent of farms w/ production contracts	51	39	72	66
Percent of farm product value from hogs	73	64	70	72
Percent of farms located in:				
Midwest (IA, IL, IN, OH)	52	38	56	43
East (NC, VA, PA)	12	7	10	21
South (AR, GA, KY, MO)	4	2	2	7
North (MI, MN, WI, SD)	23	22	24	21
West (CO, KS, NE, OK)	9	30	9	8

*=less than 1 percent.

Table 3. Production Practices used on U.S. Farrow-to-Finish and Feeder pig-to-Finish Operations, by use of Sub-therapeutic Antibiotics, 2009

	Nursery		Finishing	
	STA users	STA non-users	STA users	STA non-users
Farrow-to-finish		percent of farms		
PQA Plus certification[1]	79	35	82	43
Employees w/ PQA Plus certification	45	24	41	31
Premises PQA Plus site accessed	24	17	29	14
Buyer requires PQA Plus certification	48	18	57	19
Written bio-security plan	16	16	20	13
Cleaned hog hauling vehicles	40	29	36	35
Cats or wildlife w/ access to operation	66	66	66	67
Rodent control program	90	53	90	62
Bird-proofed facilities	33	18	37	18
Dewormed hogs	80	76	83	75
Feeder pig-to-finish		percent of farms		
PQA Plus certification[1]	na	na	81	67
Employees w/ PQA Plus certification	na	na	60	49
Premises PQA Plus site accessed	na	na	47	42
Buyer requires PQA Plus certification	na	na	66	55
Written bio-security plan	na	na	49	47
Cleaned hog hauling vehicles	na	na	76	69
Cats or wildlife w/ access to operation	na	na	18	22
Rodent control program	na	na	93	75
Bird-proofed facilities	na	na	81	77
Dewormed hogs	na	na	33	30

[1]Pork Quality Assurance Plus program.

*=less than 1 percent. na=not applicable.

Table 4. Variables Specified in the Estimated Models, U.S. Feeder Pig-to-Finish and Farrow-to-Finish Operations, 2004

Variable Description	Feeder pig-to-Finish Mean	Feeder pig-to-Finish Standard Error	Farrow-to-Finish Mean	Farrow-to-Finish 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 5. 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 5. Selection Model Maximum Likelihood Estimates: Total Factor Productivity on U.S. Feeder Pig-to-Finish Operations, 2004 (continued)

Variable Description	Finishing Hogs	
	Coefficient	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 6. Selection Model Maximum Likelihood Estimates: Total Factor Productivity on U.S. Farrow-to-Finish Operations, 2004

Variable Description	Nursery Pigs Coefficient	Nursery Pigs Standard Error	Finishing Hogs Coefficient	Finishing Hogs 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 6. 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 whether sub-therapeutic antibiotics were fed to nursery pigs (0,1). Dependent variable in the selection equation for finishing hogs is 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 7. 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.