An Econometric Analysis of the Economic Contribution of Subtherapeutic Antibiotic Use in Pork Production

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Introduction

Since the early 1950's, antibiotics have been widely used at subtherapeutic[1] levels to promote the growth and overall health of livestock. However, there is growing concern among health officials, physicians, veterinarians, and the public at large regarding the diminishing efficacy of antimicrobial therapy in human and veterinary medicine. Many fear that the practice of administering antibiotics at subtherapeutic levels over the course of an animal's production cycle contributes to the accelerated development of antibiotic resistance in bacteria. Resistant bacteria can cause antibiotic resistant disease directly or they can pass the genetic material associated with resistance to other bacteria, thus increasing the problems in disease treatment for both humans and animals. A recent report issued by the Union for Concerned Scientists (Mellon, Benbrook and Benbrook) emphasizes the significant information gaps that still exist regarding the use of antimicrobials on farm and their impact on human health through the development of antimicrobial-resistant bacteria. Their findings suggest that the animal health industry has greatly underestimated the level of antibiotic use in animal agriculture, and recommend that the federal government step up data collection of antibiotic usage within the meat producing industries. As regulatory agencies, consumer advocacy groups, and the livestock industry continue to debate the pros and cons of antibiotic use in animal agriculture, there is an increasing need for a thorough economic

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[1] While a precise definition is still the subject of debate, antibiotic use is generally classified as subtherapeutic if it is used to improve animal performance, and therapeutic if used to treat specific health problems (National Research Council). Subtherapeutic use typically involves lower dosages (less than 200 g per ton of feed) and longer treatment times while therapeutic use typically involves high dosages for a relatively short period of time.

analysis of the benefits and costs of animal antibiotics to society. Understanding the economic value of antibiotics to the livestock industry is a critical first step when considering policies to reduce or eliminate the availability of this input to producers. This paper attempts to estimate the implicit value of subtherapeutic antibiotics to swine producers, and to identify gaps in the knowledge base. The results obtained from this effort will assist policy makers in the design of a balanced, science-based response to this critical issue.

The Benefits of Antibiotics in Pork Production

Feed-grade antibiotics are widely used in U.S. pork production. A 1995 survey conducted by the National Animal Health Monitoring System (NAHMS) determined that over 91 percent of the operations surveyed reported using antibiotics as a disease preventive or growth promotant in feed (USDA 1995). The benefits associated with the use of subtherapeutic antibiotics in swine production are thought to include improvements in average daily gain, feed use efficiency, farrowing rate, baby pig survival, and mortality rate. Cromwell (2000) estimates the net economic benefit of subtherapeutic antibiotic use from post-weaning through the grower-finisher phase of production to be $2.99 per market hog. Of this total, savings from improvements in feed use efficiency and daily gain represent 47 and 42 percent of the benefits from antibiotics, respectively. Reported improvements in daily gain and feed use efficiency vary widely among studies due in part to differences between studies in the age of pigs, in animal genetics, the cleanliness of study operations, and variation in facility management practices. After analyzing data from 1,194 studies on the efficacy of antibiotics in

U.S. pig production, Cromwell (1991) observed that the effect of antibiotics on growth rate and feed use efficiency is greatest for young pigs, and declines as pigs approach market weight (Table 1). He noted that overall antibiotic effectiveness did not appear to diminish over the 36-year period (1950 to 1986) in which these studies were conducted. His findings confirmed that antibiotic response is significantly greater for pigs raised in actual farm conditions as compared to pigs raised on experimental research facilities and university farms, where the conditions tend to be cleaner and pigs are less subject to disease. Beran estimated that the cost of adding antibiotics to feed rations is approximately 3.75 percent of the total ration costs, and that producers realize a $2.00 return through improved feed efficiency for each dollar spent on feed-grade antibiotics.

Pork production is complex and multidimensional, complicating farm-level economic analyses considerably. Microeconomic studies that determine the economic value of subtherapeutic antibiotics in pork production all have strengths and weaknesses in study design. The traditional approach to evaluating the economic importance of inputs to a production process is to estimate the production function using econometric methods (Heady and Dillon, Dillon and Anderson). Since feed costs represent a large share of the total cost of producing hogs, most of the productivity-related econometric research has focused on identifying least-cost feed combinations (Heady et al., Sonka, Heady and Dahm). In the study by Heady et al., production functions were derived to estimate productivity and substitution rates between corn and soybean meal in hog rations. These functions were estimated using results from experimental hog feeding trials in Iowa. Productivity comparisons were also made between rations with and without the antibiotic chlortetracycline added, though estimating the productivity of antibiotics was not the main objective of the study. Their results indicate that the marginal value product of chlortetracycline, when used at the dosage of 10 g per ton of feed, is more than three times greater than the marginal input cost; i.e., for every dollar invested in antibiotics, marginal value product increased by more than $3.

In a more recent study, Losinger analyzed data from the 1995 NAHMS Swine Study to identify the effect of different management practices on the feed conversion ratio (kg of feed fed per kg of gain) for finisher pigs. Using a forward-stepwise variable selection approach, Losinger found that improvements in feed conversion were associated with <u>not</u> administering chlortetracycline (the most commonly used growth promotant antibiotic) through feed or water as a disease preventive or growth promotant. One possible explanation for this negative relationship may be due to the ineffectiveness of low doses of chlortetracycline in the presence of certain pathogens having limited susceptibility to this class of antibiotic. The other management practices identified by the model as being associated with improvements in the feed conversion ratio were the use of more than three different feed rations in the grower/finisher (G/F) phase, and that no rations are mixed on the farm. In a related study, Losinger et al. (1998a) used the 1995 NAHMS survey to examine the factors associated with mortality among G/F pigs. Using a stepwise logistic procedure, their results suggest that the use of antibiotics as a disease preventive or growth promotant significantly increased the odds of experiencing mortality rates that exceed the median 2.3%.

A number of studies have estimated the economic impact of eliminating the use of subtherapeutic antibiotics in the production of swine (Gilliam and Martin, Mann and Paulsen, Hayes et al.). Gilliam and Martin assumed that without antibiotics, growth rates for pigs between 15 and 40 pounds would decline by approximately 23 percent, while feed use efficiency would decrease by roughly 6.5 percent. For grower-finisher hogs weighing more than 40 pounds, growth rates were predicted to decline by 5.5 percent and feed use efficiency reduced by almost 2 percent. Using the assumption that producers maintain output at pre-ban levels by feeding additional animals, their analysis suggests that production costs for hog producers will increase by $533 million ($6.94 per head), which is based on output, price and cost conditions in 1973. In Mann and Paulsen's study, growth rates following a ban on antibiotics were expected to fall by 10.7 percent, and feed efficiency by 3.8 percent. Their findings suggest that due to decreased production following a ban, the increase in hog prices will more than offset the rise in production costs, resulting in a 4.5% ($4.42 per head) increase in profits to pork producers in the short-run. In the long run, they predict little change in pork producer profitability. In a recent study by Hayes et al., their assumptions regarding the biological impacts of antibiotics on hog production were based on the experiences of Swedish producers following a ban on over-the-counter antibiotics ban in 1986. In their *most-likely* scenario, average daily gain was predicted to decline by 1.3 percent for pigs weighing 50 to 100 pounds, and 1.8 percent for pigs above 100 pounds following a ban on antimicrobial feed additives. For these same weight categories, feed efficiency was expected to decline by 1.7 percent and 1.5 percent, respectively. Expected increases in mortality following the ban were 1.5 percent for baby piglets and 0.04 percent for grower-finishers. Based on the results from their "most-likely" scenario, a ban on subtherapeutic antibiotics would increase production costs by $6.05 per head initially and

$5.24 per head after 10 years. Profit would decline initially by $4.17 per head, and by $0.79 per head after 10 years.

The reliance on feed-grade antibiotics by U.S. pork producers is summarized in Dewey et al. Using the NAHMS 1990 survey results, they describe the extent of in-feed antimicrobial use across the different stages of production. Of the 712 producers surveyed, 88% reported using antimicrobials in feeds. The production phases most reliant on in-feed antimicrobials were nursing piglets fed creep feed and nursery piglets fed starter rations. Of the feeds used for G/F pigs, 62% to 73% contained antimicrobials, with the majority being fed on a continuous basis. The antibiotics most commonly fed to G/F pigs were tetracyclines, bacitracin, tylosin, and carbadox. The feedgrade antibiotics most commonly used (as a percent of operations reporting) by producers surveyed for the 1995 NAHMS survey are bacitracin (52.1%), chlortetracycline (41.1%) and tylosin (30.4%). Approximately 78 percent of the operations surveyed reported using at least one of these antibiotics during the G/F phase of production (USDA 1996). In a recent study issued by the Union of Concerned Scientists (Mellon, Benbrook and Benbrook) it is estimated that in 1998, G/F pigs were fed more than 9 million pounds of nontherapeutic antibiotics.

The pork industry has changed dramatically in the last few decades (Rhodes). Thus, it is likely that the productivity and economic impact of feed grade antibiotics has changed since the mid-1970’s when much of the U.S. work (Gilliam and Martin, Mann and Paulsen) on the economics and productivity impacts of antibiotics was done. Additionally, Hayes et al. acknowledge that the main weakness of their study is that their biological assumptions are derived from European pork producers and these assumptions may be quite inappropriate for the U.S. pork production system. Combined with the growing concerns of the development of resistance, the amount of antimicrobial usage, and the potential for resistance development, further study on this important topic is warranted. Thus, the primary objectives of our research are: (1) to use U.S. industry-level data to identify the relationships between subtherapeutic antibiotic use and other animal health and management practices on production performance in the G/F phase of hog production; (2) to estimate the economic impact of feedgrade antibiotics for pork producers at the farm level; (3) to identify where knowledge gaps exist in this overall topic and to suggest future research needs.

Material and Methods

The data used in this study comes from the 1990 and 1995 NAHMS National Swine Surveys. These surveys were designed to provide statistically valid estimates of key parameters relating to the health, management, and productivity of the U.S. swine herd. Each survey was targeted to address a specific aspect of the swine industry. The primary objective of the 1990 NAHMS study was to examine the scope and severity of preweaning morbidity and mortality, and to identify management factors that may affect piglet health in the farrowing unit (Tubbs et al.). The 1995 Survey's focus was on the G/F phase of production. Data were gathered on the management practices, productivity, and health status of operations with at least 300 finisher pigs (Losinger et al, 1998b). Data collection for each survey was conducted in two phases. In the first phase, operations were identified and contacted by a National Agricultural Statistics Service (NASS) enumerator who asked producers to fill out the General Swine Farm

Management (GSFM) survey. The GSFM survey asked general questions about herd management and production. In the second phase, a subset of operations from the first phase were selected and visited by a NAHMS-trained Veterinary Medical Officer (VMO). These visits involved a more detailed inquiry into the specific practices and experiences of the operation. In 1990, sampling occurred in 18 states, representing 84% of the U.S. swine operations and 95% of the nation's hog population (USDA 1992). In 1995, sampling occurred in 16 states, accounting for approximately 75% of the pork producers and 91% of the U.S. hog inventory (USDA 1995, USDA 1996).

With the emphasis of the 1995 Survey on the G/F phase of production and the availability of average daily gain (ADG) and feed conversion ratio (FCR) as productivity measures, the initial analysis was intended to include operations solely from the 1995 dataset. For the 418 operations included in the 1995 dataset, only 47% (196) reported values for both ADG and FCR. Of these 196 operations, only 55% (107) indicated that both productivity measures were accurately calculated (as opposed to being estimated or guessed). An additional concern was the small number of operations (20) that reported using no antibiotics as feed additives in the G/F phase. Thus, to improve sample size, observations from the 1990 survey were incorporated.

The 1990 and 1995 NAHMS datasets had several inconsistencies in data across the two surveys, making merging problematic. The most serious of these inconsistencies was that the productivity measures ADG and FCR were not reported in the 1990 survey. It was possible to calculate ADG for the 1990 data using reported values for the average days spent and the average weight gained in the G/F unit. Estimating FCR was more difficult, and required first calculating average daily feed consumption rates for three different weight groups within the G/F unit: 40-99 lbs., 100-179 lbs., and 180 lbs. and over. These values were generated from feed diaries kept by producers over a 7-day period. In many cases, feed consumption values were missing for one or more weight groups. When two of the three feed consumption values were missing, the observation was deleted. When only one value was missing, the missing value was estimated based on the magnitude of the other two values and the average difference between the three feed consumption rates across all operations. The length of time that pigs spent in each weight group was estimated using an expected feed intake schedule as reported in de Lange and Baidoo. Total feed consumption during the G/F phase was estimated as the sum across weight groups of length of feeding (days) times average daily feed consumption. The ratio of feed consumed to total gain in the G/F unit provided an estimate of FCR.

Another inconsistency between the two surveys is the level of detail regarding antibiotic use. For the 1990 survey, producers reported the dosage of each antibiotic used as a feed additive, but were not asked the length of time that the antibiotic was fed to pigs. In the 1995 survey, producers reported the number of days each antibiotic was administered in feed, but not the dosage. There was some limited information on antibiotic dosage provided in the feed collection section of the 1995 survey, but these samples were typically collected from a single feed bin on the operation. In order to have a consistent measure of the intensity of antibiotic use across both datasets, missing values for the number of days of feed-administered antibiotics in the 1990 dataset were estimated using the IMPUTE command in Stata.[2]

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[2] Stata's IMPUTE command fills in missing data values by performing regressions based on patterns identified between the specified variable list and the variable containing the missing values (StataCorp.).

Minor inconsistencies across datasets were also recognized with variables related to the number of different rations fed to pigs during the G/F phase and the number of pigs that entered the G/F unit over the period. In 1995, producers were specifically asked to report the number of different rations fed to pigs throughout the G/F phase. In 1990, the number of rations was determined by the number of different feeds fed to pigs in the three weight classes, as reported in the producer's 7-day feed diary. Based on this short 7-day window, the average number of rations fed by operators in 1990 was 2.4, significantly less than the 4.3 rations from the 1995 survey. The 1990 mean number of rations is likely biased downward from the true mean. The number of pigs entering the G/F unit was not reported in 1990. Pigs entering the G/F unit were estimated for 1990 by subtracting the number of deaths in the nursery from the total number of pigs weaned. Since this calculation applies only for farrow-to-finish operations, only those operations identified as farrow-to-finish were used from the 1990 dataset.

Linear regression was used to identify relationships between productivity in the G/F unit, antibiotic use, and other potentially relevant factors of production. A separate model was estimated for ADG and FCR using Stata's backward-stepwise maximum likelihood estimation procedure (StataCorp.), where candidate explanatory variables with *p*-values less than 0.30 were retained. A description of all explanatory variables considered for inclusion or forced into the models is provided in Table 2. Following an approach employed by Losinger (1998a), several explanatory variables were forced into the models to control for geographic region, size and type of operation, the year the operation was surveyed by NAHMS, and the average number of days spent in the G/F unit.

A linear regression model was also estimated with G/F phase mortality rate as the dependent variable using the same backward-stepwise maximum likelihood estimation procedure. The data used to estimate the mortality model were taken exclusively from the 1995 NAHMS dataset, since several key variables were missing from the 1990 dataset. Mortality rate is defined as the percentage of pigs that died in the grower finisher unit during the six-month period prior to the second phase of the 1995 survey. The variables considered for inclusion in the mortality model are listed in Table 3. In addition to the forced variables used in the productivity models, variables that describe the type of facility were also included. Of the variables considered for model inclusion, several relate to biosecurity (*d_offsite*, *d_restrct*, *d_quar*) and disease prevention (*vacc*, *d_clean*) measures adopted by producers.

To evaluate the effect of antibiotics-related variables as a group on the estimated productivity and mortality models, a joint hypothesis test was performed with exclusion restrictions imposed on the relevant variables. Using the sum of squared residuals generated by the unrestricted and restricted models, the joint significance of these variables was evaluated by computing the *F*-statistic, determining its sampling distribution, and calculating the *p*-value to determine the significance level.

Results

Productivity Models

A total of 519 observations were used to estimate the regression models for ADG and FCR, with 337 operations originating from the 1990 NAHMS survey and 182 from the 1995 survey. Table 4 lists the summary statistics for ADG and FCR by NAHMS survey year. While FCR appears to be lower (better) in 1990, the difference in FCR values across the two survey years is not significant at $P<0.10$. (Note that a reduction in the FCR means it takes less feed to achieve a pound of gain, resulting in an improvement in feed use efficiency.) It should be reiterated that the FCR was estimated in 1990 based on assumptions about feed intake at different stages of growth, while producers reported FCR values in 1995.

The estimated models for ADG and FCR are presented in Table 5. In terms of the relationship between antibiotic use and productivity, these results suggest that both ADG and FCR are improved as the number of days that antibiotics are used in feed is increased. In the case of FCR, however, using more than one antibiotic implies higher (poorer) feed use efficiency. Improvements in productivity are also associated with the feeding of multiple rations during the G/F phase. There does appear to be a substitution effect between multiple rations and antibiotic use, where increasing the number of rations lowers productivity when subtherapeutic antibiotics are used. The interaction between antibiotic use and the number of diseases diagnosed in the G/F unit also has a negative impact on ADG, though this effect may be capturing the response of producers to use antibiotics as a preventive when there is an increase in the prevalence of disease. Medium- and large-size operations experience better FCRs. Independent producers who market through a cooperative have poorer FCR. Higher mortality rates are significantly ($p = 0.054$) associated with lower productivity.

Mortality Model

There were 288 observations included in the dataset used to explain G/F mortality. All observations were from the 1995 NAHMS study. Summary statistics for the dependent variable *rmort* and explanatory variable *rmort2* are shown in Table 6. The correlation coefficient between these two variables is 0.93 ($p = .0001$).

Variables explaining mortality rate (Table 7) suggest that reductions in mortality rate are associated with antibiotics being fed over a longer period of time (*abxdays*). The suggested effect of using two antibiotics in the presence of disease in the G/F unit (*dabx2dia)* is an increase in the mortality rate, while vaccination against disease (*vacc*) lowers mortality. The lowering of mortality rates is also significantly associated with weaning piglets at an older age (*weanage*). The average age at weaning is 26.4 days, with a standard deviation of 9.2 days. The results also indicate that there is a positive relationship between mortality rate and cull rate (*pcull*). In terms of the forced variables, the only apparent relationship is the positive coefficient associated with *d_fac4*, which implies that mortality rates are significantly higher for pasture-raised pigs, and the magnitude of the estimated coefficient is also large. Among the biosecurity measures evaluated, it appears that the practice of restricting entry only to employees (*d_restrct*) does have a beneficial impact on mortality, while purchasing pigs from off-site sources (*d_offsite*) tends to increase mortality in the G/F unit.

The results of the *F*-tests for the three models are shown in Table 9. Based on these results, the only model where the antibiotic variables are jointly statistically significant with a reasonable level of significance ($p < 0.10$) is the ADG model. The *F*-

test results for the FCR ($p = 0.229$) and mortality rate ($p = 0.223$) models suggest that the antibiotic variables are jointly significant at a 0.25 level of statistical significance.

Predicting the impact of antibiotic use on productivity, mortality, and profit

Using the results from the regression models, we can estimate the effect of subtherapeutic antibiotics on the performance of G/F pigs in percentage terms. Predictions were generated for an independent, medium-sized, midwestern farrow-to-finish producer in 1995. The values and assumptions used for the key parameters used in the models are presented in Table 9. It was also assumed that no pigs were purchased from off-site sources, and access to facilities was restricted to employees only. Given these assumptions, it is estimated that subtherapeutic antibiotics improve ADG and FCR by 0.9% and 2.3%, respectively. Mortality in the G/F unit is reduced 0.29 percentage points.

To express these performance figures in economic terms, the model results were evaluated using a swine enterprise budgeting model developed by Miller, Song and Bahnson. The model estimates the profitability of batch finishing of pigs for a barn designed to place any number of feeder pigs, and is well suited to evaluating the effects of antibiotics on productivity and mortality. Important basic economic summary values are calculated including total revenue per year, total costs per year, return above total costs, return above operating costs, and net present value.

With the values used to generate the aforementioned improvements to ADG, FCR and mortality, the estimated increase in annual returns above total costs from antibiotics for a 1,020-head finishing barn is $3,424, or $1.26 per pig. The economic significance of this number is revealed when compared to the estimated net returns to pig finishing operations as reported by the Illinois Farm Business Farm Management Association, which in 2000 is estimated to be $3.09 per hundredweight, or $6.52 per pig. These values suggest that the economic benefit generated from using feed-grade antibiotics in the G/F unit represents almost 20% of the net return realized by Illinois pig finishing operations in 2000.

Input Substitution

An interesting result from the ADG and FCR models is the relationship between the productivity influence of feed-grade antibiotics and the number of rations used during the G/F phase. The number of rations improves ADG and FCR when considered alone (*rations*), but the interaction term *dabx1rat* carries the opposite sign on the estimated coefficient. Figure 1 shows the estimated impact of increasing the number of different rations fed during the G/F phase on ADG and FCR when feed-grade antibiotics are and are not used. In both cases, improvements in productivity from the use of multiple rations are more pronounced when feed-grade antibiotics are not used. The economic implications of using multiple rations indicate that when five rations are used, the net economic benefit of feed-grade antibiotics is negative (Figure 2).

These results do not take into account the added variability in ADG and FCR that is likely to be observed when subtherapeutic antibiotics are not used. This might be critically important. These results show that tailoring rations specifically to meet the dietary needs of pigs throughout the G/F phase can serve as a substitute for subtherapeutic antibiotics. Our results suggest that subtherapeutic antibiotics are of value mainly when a smaller number of rations are used in finishing. Producers managing finishing operations where diets are tailored to meet pig growth needs over time will not see the same benefits from using antibiotics as those who feed a small number of different diets.

Summary

Our results suggest that the economic impact of the use of feedgrade antibiotics in G/F units in the U.S. is sufficiently high that pork producers might be reluctant to produce pigs without this input. However, we also found that there is the potential for substantial substitutability with this input and other production inputs. The potential trade off in applying some alternative inputs may be the added complexity associated with the use of these inputs.

There were difficulties and data manipulations needed to obtain these results. The extent to which these difficulties obscure the real relationships that exist between feedgrade antibiotic use and productivity measures in pork production is unknown. Given the widespread use of feedgrade antibiotics within the U.S. pork industry, it is clear that most producers believe their profits are higher with use than they would be otherwise. There is a need for controlled feeding trials that will carefully quantify the relationships between growth promoting antibiotic use and productivity measures carried out in field situations reflective of current U.S. production systems, including current genetics, size of operations, typical disease and other environmental pressures, among other factors. Additionally, there is a need for assessing the risk to human health of the use of feedgrade antibiotics in swine production.

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Table 1. Efficacy of Antibiotics as Growth Promoters for Pigs

Stage of growth	Daily gain	Feed/gain
	Improvement from antibiotics (%)	
Starter phase (7-25 kg)	16.4	6.9
Growing phase (17-49 kg)	10.6	4.5
Growing-finishing phase (24-89 kg)	4.2	2.2

Adapted from Cromwell 1991.

Table 2. Productivity model variables

Variable	Description of explanatory variables
	Dependent variables
adg	Average daily gain during G/F phase
fcr	Average pounds of feed fed during the G/F phase for each pound gained
	Variables forced into model
d_reg1	Regional identifier (1 = southeast)
d_reg2	Regional identifier (1 = north)
d_reg3	Regional identifier (1 = west)
d_med	1 = medium operation size (between 800 and 3,000 pigs entered unit in last 6 months)
d_large	1 = large operation size (more than 3,000 pigs entered unit in last 6 months)
d_year90	NAHMS survey year data (1 = 1990)
d_optype	Type of operation (1 = other than farrow-to-finish)
*daysingf***	Average number of days spent in G/F phase
d_coop	1 = independent producer – markets through cooperative
d_contract	1 = contract producer
	Variables considered for model inclusion
abxdays	Number of days antibiotics administered in feed throughout G/F phase
diag_gf	Number of diseases diagnosed in the G/F unit in last 12 months
*feed**	Pounds of feed fed per day per pig entering G/F unit
d_aiao	1 = facility managed as "all-in-all-out"
d_abx1	1 = Only 1 antibiotic fed in G/F unit
d_abx2	1 = 2 antibiotics fed in G/F unit
d_abx3	1 = 3 or more antibiotics fed in G/F unit
rations	Number of different rations fed in G/F unit
rmort	Mortality rate in G/F unit during last 6 months
dabx1rat	*d_abx1* × *rations*
dabx2rat	*d_abx2* × *rations*
dabx3rat	*d_abx3* × *rations*
dabx1dia	*d_abx1* × *diag_gf*
dabx2dia	*d_abx2* × *diag_gf*
dabx3dia	*d_abx3* × *diag_gf*

* *feed* was considered for entry only in the ADG model.
** *daysingf* was forced only in the FCR model.

Table 3. Mortality model variables

Variable	Description of explanatory variables
	Dependent variable
rmort	Mortality rate in G/F unit during last 6 months
	Variables forced into model
d_reg1	Regional identifier (1 = southeast)
d_reg2	Regional identifier (1 = north)
d_med	1 = medium operation size (between 800 and 3,000 pigs entered unit in last 6 months)
d_large	1 = large operation size (more than 3,000 pigs entered unit in last 6 months)
d_optype	Type of operation (1 = other than farrow-to-finish)
daysingf	Average number of days spent in G/F phase
d_fac1	1 = open building with no outside access
d_fac2	1 = open building with outside access
d_fac3	1 = lot with hut or no building
d_fac4	1 = pasture with hut or no building
	Variables considered for model inclusion
abxdays	Number of days antibiotics administered in feed throughout G/F phase
diag_gf	Number of diseases diagnosed in the G/F unit in last 12 months
d_offsite	1 = Pigs entered G/F unit from an off-site source not owned by the operation
d_separ	1 = Pigs are removed from nursery to a "separate-site" G/F facility
d_clean	1 = Feeders in the G/F unit are rarely or never cleaned
d_restrct	1 = Entry to premises restricted to employees only
d_aiao	Facility management (1 = all-in-all-out)
d_quar	1 = New feeder pigs arrivals are separated or quarantined before being introduced to the farm
vacc	Number of vaccines administered to pigs in G/F phase
weanage	Average age at weaning
pcull	Percentage of G/F pigs culled and marketed below market weight in last 6 months
rmort2	Mortality rate during 6 month period prior to initial NASS visit
dabx1dia	*dabx1 × diag_gf*
dabx2dia	*dabx2 × diag_gf*

Table 4. Productivity model summary statistics

Variable	NAHMS survey year	Mean	Standard deviation	Minimum	Maximum
adg	1990	1.626	.2607	.942	2.37
	1995	1.633	.2608	.740	2.9
fcr	1990	3.17	.6708	1.67	5.93
	1995	3.262	.5164	2.18	5.91

Table 5. Productivity model results

Variable	Average Daily Gain (ADG)		Feed Conversion Ratio (FCR)	
	Coefficient	*P*-value	Coefficient	*P*-value
constant	1.431	<0.001	3.647	<0.001
		Variables forced into models		
d_reg1	- 0.015	0.628	- 0.062	0.461
d_reg2	- 0.024	0.371	- 0.045	0.539
d_reg3	0.050	0.225	- 0.14	0.218
d_year90	0.035	0.203	- 0.22	0.002
d_med	- 0.013	0.575	- 0.091	0.146
d_large	- 0.017	0.598	- 0.25	0.004
d_coop	- 0.057	0.144	0.21	0.046
d_contract	0.078	0.179	- 0.22	0.160
d_optype	- 0.050	0.276	0.17	0.166
daysingf	N/A	N/A	- 0.00056	0.685
		Variables included in models		
d_abx1	0.057	0.229	--	--
d_abx2	--	--	0.14	0.250
d_abx3	--	--	0.29	0.072
abxdays	0.00058	0.045	- 0.0018	0.032
feed	0.033	<0.001	--	--
rations	0.030	0.102	- 0.035	0.067
rmort	- 0.011	0.003	0.019	0.054
dabx1dia	- 0.011	0.133	- 0.018	0.290
dabx2dia	--	--	--	--
dabx3dia	- 0.025	0.017	--	--
dabx1rat	- 0.027	0.174	0.033	0.167
dabx2rat	- 0.036	0.030	--	--
dabx3rat	- 0.023	0.209	--	--
R^2	0.125		0.0682	

Table 6. Mortality model summary statistics

Variable	Mean	Standard deviation	Minimum	Maximum
rmort	2.280	2.274	0	27.5
rmort2	2.231	2.636	0	29.9

Table 7. Mortality model results

Variable	Coefficient	*P*-value
constant	3.783	0.002
	Variables forced into model	
d_reg2	0.24	0.594
d_reg3	0.24	0.628
d_med	- 0.38	0.256
d_large	- 0.25	0.579
d_coop	0.078	0.887
d_cntrct	- 0.65	0.427
d_optype	0.55	0.542
daysingf	0.0039	0.577
d_fac2	- 0.022	0.959
d_fac3	0.28	0.830
d_fac4	1.036	<0.001
d_fac5	- 0.21	0.877
	Variables included in model	
abxdays	- 0.0033	0.225
weanage	- 0.048	0.006
pcull	0.13	0.016
rmort2	0.089	0.163
diag_gf	0.24	0.116
vacc	- 0.21	0.094
d_aiao	- 0.30	0.296
d_offsite	1.035	0.109
d_quar	- 0.45	0.182
d_restrct	- 0.41	0.138
dabx2dia	0.22	0.209
R^2	0.226	

Table 8. Exclusion restrictions for *F*-tests

Model	Exclusion restrictions (H_0)	Prob > F
ADG	*abxdays*=0, *dabxuse1*=0, *dabx1rat*=0, *dabx2rat*=0, *dabx3rat*=0, *dabx1dia*=0, *dabx3dia*=0	0.0739
FCR	*abxdays*=0, *dabxuse2*=0, *dabxuse3*=0, *dabx1rat*=0, *dabx1dia*=0	0.2289
MORT	*abxdays*=0, *dabx2dia*=0	0.2234

Table 9. Parameter assumptions

Model parameters	Values
Number of antibiotics fed (*d_abx1* = 1)	1
Number of days antibiotics are fed during G/F phase (*abxdays*)	86
Pounds of feed fed per day during G/F phase (*feed*)	4.8
Number of different rations fed during G/F phase (*rations*)	3
Mortality rate (*rmort*)	2.3 %
Mortality rate during previous 6 month period (*rmort2*)	2.2 %
Cull rate (*pcull*)	1.6%
Age at weaning in days (*weanage*)	26.4
Number of diseases diagnosed in G/F unit in last 12 months (*diag_gf*)	1
Number of vaccines administered to pigs in G/F phase (*vacc*)	3

Figure 1. Estimated effect of increasing the number of rations on productivity with and without the use of feed-grade antibiotics.

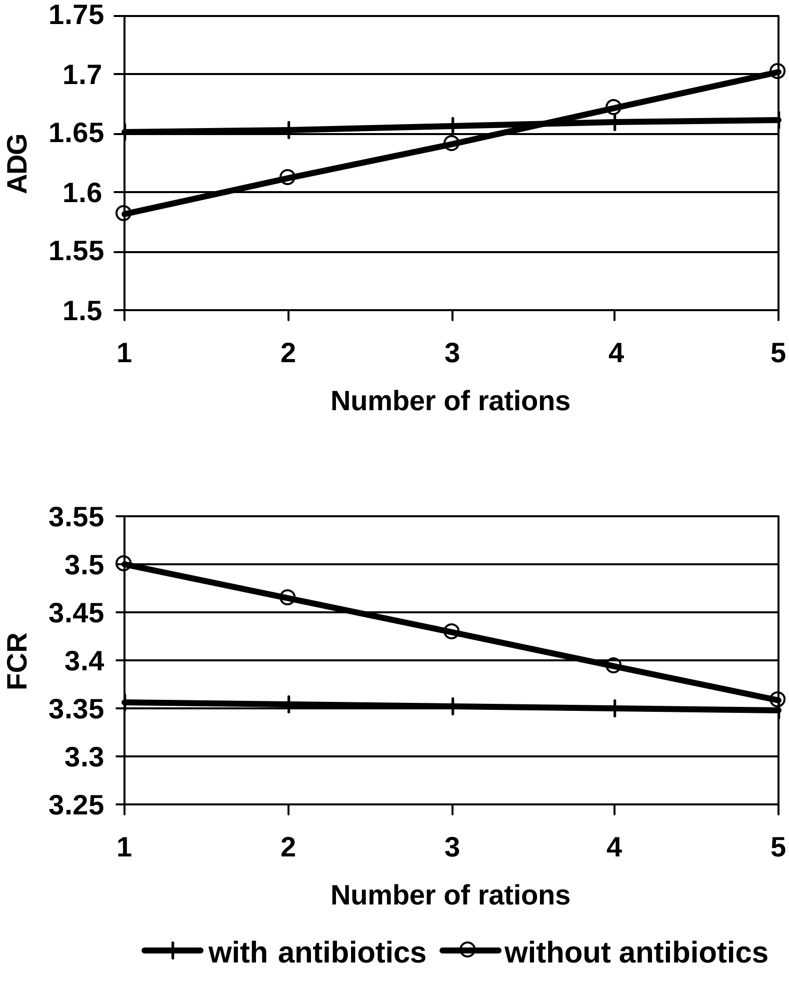

Figure 2. Estimated impact of increasing the number of rations fed during the G/F phase on the annual net return from using feed-grade antibiotics.