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Productivity and Economic Effects of Antibiotics Used for Growth Promotion in U.S. Pork Production

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Public health experts are concerned about the diminishing efficacy of antibiotics. Some have called for a ban on growth-promoting antibiotics in animal agriculture. This study identifies the contribution of growth-promoting antibiotics in the grower/finisher phase of U.S. pork production. With National Animal Health Monitoring System swine data, relationships are estimated between growth-promoting antibiotic use and productivity. Results indicate improvements in average daily gain (0.5%), feed conversion ratio (1.1%), and mortality rate (reduced 0.22 percentage points); these productivity improvements translate into a profitability gain of $0.59 per pig marketed, or an improvement of 9% in net profits associated with growth promotion antibiotics.

Key Words: antibiotics, economics, growth promotants, productivity, resistance, swine

JEL Classifications: Q12, Q18

Since the early 1950s, antibiotics have been used at subtherapeutic[1] levels to promote the growth and overall health of livestock (Zimmerman). There has been concern for many years, and there is now a growing concern among health officials, physicians, veterinarians, and the public at large, regarding the diminishing efficacy of antibiotics in human and veterinary medicine (Levy; Mazel and Davies; McEwen and Fedorka-Cray; World Health Organization Director-General). 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 (Levy; Teuber). Resistant bacteria

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[1] Although a precise definition is still the subject of debate, antibiotic use is generally classified as subtherapeutic if it is used to improve animal performance (e.g., for growth promotion) and therapeutic if used to treat specific health problems (National Research Council). Subtherapeutic use typically involves lower dosages and longer periods of use, whereas therapeutic use typically involves higher dosages for a relatively short period of time.

can cause an antibiotic-resistant disease directly or they can pass the genetic material associated with resistance to other bacteria (Mazel and Davies), thus increasing the problems in disease treatment for both humans and animals. Resistant *Salmonella* that could cause food-associated illness in people have been documented in pork (Farrington et al.), and salmonellosis is a costly condition in humans (Buzby et al.).

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 farms in the United States and their effect on human health through the development of antimicrobial-resistant bacteria. A thorough economic analysis of the benefits and costs of subtherapeutic animal antibiotics to society is needed, accounting for today's food animal genetics and production practices, so that the science base for the debate includes an economics contribution. Understanding the economic value of growth-promoting antibiotic use to the individual pork producer is a critical first step when considering policies to reduce or eliminate the availability of this input to the pork industry. In this study, we attempted to estimate the implicit value of antibiotics used for growth promotion to swine producers using national data 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.

Previously Reported Benefits of Antibiotics in Pork Production

Growth-promoting 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% of the operations surveyed reported using antibiotics as a disease preventive or growth promotant in feed (USDA/APHIS 1995). The extensive use of growth-promoting antibiotics by U.S. pork producers is summarized in Dewey et al. Using the NAHMS 1990 survey results, they described the use of in-feed antimicrobials across different stages of production. Of the 712 producers surveyed, 88% reported using antimicrobials in feeds. The production phases with the highest use were nursing piglets fed creep feed and nursery piglets fed starter rations. Of the feeds used for grower/finisher (G/F) pigs, 62–73% 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 antibiotics most commonly used for growth promotion (as a percentage of operations reporting) by producers surveyed for the 1995 NAHMS survey were bacitracin (52.1%), chlortetracycline (41.1%), and tylosin (30.4%). Approximately 78% of the operations surveyed reported using at least one of these antibiotics during the G/F phase of production (USDA/APHIS 1996).

Pork production is complex and multidimensional, complicating farm-level economic analyses considerably. The traditional approach to evaluating the economic importance of inputs to a production process is to estimate the production function using econometric methods (Dillon and Anderson; Heady and Dillon). In a recent study, Losinger analyzed data from the 1995 NAHMS Swine Study to identify the effect of different management practices on the feed conversion ratio (FCR) for finisher pigs. Using a forward-stepwise variable selection approach, Losinger found that improvements in FCR were associated with *not* administering chlortetracycline (the most commonly used growth-promoting antibiotic) through feed or water as a disease preventive or growth promotant. Losinger suggested one possible explanation for this finding was the ineffectiveness of low doses of chlortetracycline in the presence of certain pathogens that have limited susceptibility to this class of antibiotic. The other management practices identified by Losinger as being associated with improvements in FCR were the use of more than three different feed rations in the G/F phase and the practice of mixing rations off-farm. In a related study, Losinger et al. (1998a) used the 1995 NAHMS survey to examine the factors associated with mortality rate (MR) 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 MR above the median (2.3%).

The benefits associated with the use of growth-promoting antibiotics in swine production are thought to include improvements in average daily gain (ADG), FCR, farrowing rate, baby pig survival, and MR. A number of studies have estimated the economic effect for pork producers of eliminating antibiotic use (Beran; Cromwell 2000; Gilliam and Martin; Hayes et al.; Mann and Paulsen). Cromwell (2000) estimates the net economic benefit of growth-promoting antibiotic use from post-weaning through the G/F phase of production to be $2.99 per market hog. Of this total, he estimates that savings from improvements in FCR and ADG represented 47 and 42% of the benefits from antibiotics, respectively. Reported improvements in ADG and FCR vary widely among studies, in part because of differences between studies in the age of pigs, 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 ADG and FCR was greatest for young pigs and declined as pigs approach market weight. He noted that overall antibiotic effectiveness did not appear to diminish over the 36-year period (1950–1986) in which these studies were conducted. His findings confirmed that antibiotic response was significantly greater for pigs raised in actual farm conditions as compared to pigs raised on experimental research facilities and on 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 was approximately 3.75% of the total ration costs and that producers realize a $2.00 return through improved FCR for each dollar spent on growth-promoting antibiotics. Gilliam and Martin assumed that without antibiotics, ADG for pigs between 15 and 40 pounds would decline by approximately 23% while FCR would decrease by roughly 6.5%. For G/F hogs weighing more than 40 pounds, ADG and FCR were predicted to decline by 5.5 and 2%, respectively. Assuming that producers maintained output at preban levels by feeding additional animals, their analysis suggested that production costs for hog producers would 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, ADG and FCR following a ban on antibiotics were expected to fall by 10.7 and 3.8%, respectively. Their findings suggest that because of decreased production following a ban, the increase in hog prices will more than offset the rise in production costs, resulting in a 4.5% increase in profits to pork producers resulting from increased farm prices in the short run. In the long run, they predict little change in pork producer profitability. A recent study by Hayes et al. suggested that the most likely scenario following a ban would be a decline in ADG of 1.3% for pigs weighing 50–100 pounds and 1.8% for pigs above 100 pounds. For these same weight categories, FCR was expected to decline by 1.7 and 1.5%, respectively. Expected increases in MR following the ban were 1.5 percentage points for baby piglets and 0.04 percentage points (there is some uncertainty if this is percentage points or percentages) for G/F hogs (Hayes et al.). On the basis of the results from their "most likely" scenario, a ban on antibiotics used for growth promotion 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.

Other authors have approached the problem from a societal welfare perspective (Manchanda, Kliebenstein, and McKean; Wade and Barkley). In their study, Wade and Barkley first estimate the supply and demand for pork. Then using these estimated curves, they conduct a welfare analysis of the possible implications in welfare from a ban of antibiotics if pork supply decreases by as much as 8%, and pork demand increases by as much as a 10%. Their analysis shows that the welfare effects can be either positive or negative for both consumers and producers depending on how much demand expands and how much production declines. At one extreme, producer and consumer surplus each expands in excess of $200 million (when the pork supply declines very little, but demand increases by 10%); at the other extreme, consumer surplus declines by $199 million and producer surplus declines by $224 million (when pork supply declines by 8% with no corresponding increase in demand). Manchanda, Kliebenstein, and McKean use the Food & Agricultural Policy Research Institute (FAPRI) model in conjunction with a report from Rachelle Laboratories that documents productivity differences between different antibiotics used for growth promotion. Combining these materials with varying assumptions about the possible expansion in the demand for pork that might be associated with a perceived safer product (e.g., less chance of antibiotic residues), they estimated retail pork price shifts as small as $0.05/lb higher (with no change in demand) up to an increase of $0.09/lb (with a 5% expansion in demand). They also estimated farm prices would rise by $2.14/cwt (with no change in demand) and as much as $3.96/cwt (with an increase in pork demand of 1%) from a complete ban in antibiotics.

The pork industry has changed dramatically in the last few decades (Rhodes). The industry is more concentrated, with fewer and larger producers. Pig genetics and production practices have changed. Thus, it is likely that the productivity and economic effect of feed-grade antibiotics has changed since the mid-1970s, when much of the work was done (Gilliam and Martin; Mann and Paulsen) with productivity estimates for U.S. production systems on the economics and productivity effects of antibiotics. One criticism of the Hayes et al. study is that their biological assumptions are derived from European pork producers, and these assumptions could be quite inappropriate for the U.S. pork production system. Considering the dated nature of many studies, the wide variability in published results, 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 study were (1) to use U.S. industry-level data to identify the relationships between antibiotics used for growth promotion and other animal health and management practices on production performance (specifically, ADG, FCR, and MR) in the G/F phase of hog production, (2) to estimate the associated economic effect for pork producers at the farm level, and (3) to identify where knowledge gaps exist in this overall topic and to suggest future research needs.

Material and Methods

The 1990 and 1995 NAHMS Swine Survey data were used. These surveys were designed to provide statistically valid estimates of key parameters related to the health, management, and productivity of the U.S. swine herd. 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 Report (GSFMR) survey. The GSFMR 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. 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/APHIS 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/APHIS 1995, 1996).

To improve sample size and, hence, power of our analysis, observations from the 1990 and 1995 surveys were combined. Data definitions and details on additional methods are outlined in the Appendix.

Linear regression was used to identify relationships between productivity in the G/F unit, antibiotic use, and other potentially relevant factors of production. Salient predictors for ADG, FCR, and MR were retained if $p \leq 0.30$ (on the basis of type III sums of squares). Stata (StataCorp), a commercially available statistical software package, was used to conduct statistical analyses. Stata's backward-stepwise maximum likelihood estimation (MLE) procedure was used. Several explanatory variables were added to the models to control for geographic region, size and type of operation, and survey year because of the stratified sampling strategy used by NAHMS (Losinger et al. 1998b). The average number of days spent in the G/F unit was considered a required variable in the FCR model because we know feed use efficiency declines as pigs get older and bigger. A description of all explanatory variables either added or considered for inclusion in the models is provided (FCR and ADG models in Table 1; MR model in Table 2). The FCR and ADG models were treated as a system of seemingly unrelated regression equations, with the two equations estimated jointly with the assumption of a correlated error structure. Treating the error terms as correlated accounts for the likelihood that there were unobserved factors of the production process that affect both ADG and FCR. By estimating the models jointly rather than separately, this approach produces parameter estimates that are more efficient. The seemingly unrelated regression was performed with the SUREG command in Stata. A linear regression model was estimated with G/F phase MR as the dependent variable in the backward-stepwise MLE procedure.

The backward-stepwise MLE was chosen because it provides reasonably consistent and efficient estimators. We chose the set of possible explanatory variables (Tables 1 and 2) from among those available in the NAHMS dataset on the basis of our review of the literature on the productivity effects of antibiotic use, the basic animal production literature, and what we believed is generally common knowledge about pig growth among production-focused veterinarians and producers. Thus, we proceeded without a specific theory as to the exact specification of the regression model. Under such circumstances, using the back-

Table 1. ADG and FCR 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 Added into Model	
Dreg1	Regional identifier (=1 if Southeast)
Dreg2	Regional identifier (=1 if North)
Dreg3	Regional identifier (=1 if West)
Dmed	=1 if medium-size operation (between 800 and 3,000 pigs entered unit in last 6 months)
Dlarge	=1 if large operation (more than 3,000 pigs entered unit in last 6 months)
Dyear90	=1 if from 1990 NAHMS survey
Doptype	=1 if other than farrow-to-finish operation
daysingf[a]	Average number of days spent in G/F phase
Dcoop	=1 if independent producer and markets through cooperative
Dcontract	=1 if contract producer
Variables Considered for Model Inclusion	
abxdays	Number of days antibiotics administered for growth promotion in feed throughout G/F phase
diag_gf	Number of diseases diagnosed in the G/F unit in last 12 months
feed[b]	Pounds of feed fed per day per pig entering G/F unit
Daiao	=1 if facility managed as all in–all out
Dabx1	=1 if only one antibiotic fed in G/F unit
Dabx2	=1 if two antibiotics fed in G/F unit
Dabx3	=1 if three or more antibiotics fed in G/F unit
rations	Number of different rations fed in G/F unit
MR	Mortality rate in G/F unit during last 6 months
Dabx1rat	*Dabx1* × *rations*
Dabx2rat	*Dabx2* × rations
Dabx3rat	*Dabx3* × rations
Dabx1dia	*Dabx1* × *diag_gf*
Dabx2dia	*Dabx2* × *diag_gf*
Dabx3dia	*Dabx3* × *diag_gf*

[a] *daysingf* was added only in the FCR model.
[b] *feed* was considered for entry only in the ADG model.

Table 2. Mortality Model Variables

Variable	Description of Explanatory Variables
Dependent Variable	
MR	Mortality rate in G/F unit during last 6 months
Variables Added into Model	
Dreg1	Regional identifier (=1 if Southeast)
Dreg2	Regional identifier (=1 if North)
Dmed	=1 if medium-size operation (between 800 and 3,000 pigs entered unit in last 6 months)
Dlarge	=1 if large operation (more than 3,000 pigs entered unit in last 6 months)
Doptype	=1 if other than farrow-to-finish operation
daysingf	Average number of days spent in G/F phase
Dfac1	=1 if open building with no outside access
Dfac2	=1 if open building with outside access
Dfac3	=1 if lot with hut or no building
Dfac4	=1 if pasture with hut or no building
Variables Considered for Model Inclusion	
abxdays	Number of days antibiotics administered for growth promotion in feed throughout G/F phase
diag_gf	Number of diseases diagnosed in the G/F unit in last 12 months
Doffsite	=1 if pigs entered G/F unit from an off-site source not owned by the operation
Dsepar	=1 if pigs are removed from nursery to a separate-site G/F facility
Dclean	=1 if feeders in the G/F unit are rarely or never cleaned
Drestrct	=1 if entry to premises restricted to employees only
Daiao	=1 if facility managed as all in-all out
Dquar	=1 if new feeder pig 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*
Diabx2dia	*Dabx2* × *diag_gf*

ward-stepwise MLE seemed an appropriate choice.

To evaluate the effect of antibiotic-related variables as a group on the estimated models, a joint hypothesis test was performed with exclusion restrictions imposed on the relevant variables. The test compares the significance of two models: one with the antibiotic variables included and one without. With the use of 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.

With the results from the regression models, we then estimated the effect of growth-promoting antibiotics on the performance of G/F pigs in terms of percentage. Predictions were generated for an independent, medium-sized (between 800 and 3,000 head entering the G/F unit in the last 6 months), Midwestern farrow-to-finish producer in 1995. We then express these performance figures in economic terms with a swine enterprise budgeting model developed by Miller, Song, and Bahnson. This budgeting model estimated the profitability of batch finishing of pigs for a barn designed to place any number of feeder pigs and was well suited to evaluating the effects of antibiotics on productivity and mortality. Default values for market hog weight and price, fixed and variable costs of production, and other variables used by this model reflected 1995–1998 U.S. averages. We upgraded these default values to reflect 1996–1999 U.S. averages for important costs. Upgraded cost assumptions included: feeder pig price, $40.85/head; corn, $2.76/bushel; soybean meal, $199.40/ton; and base market hog price, $41.88/live cwt. We express profitability differences between using and not using antibiotics for growth promotion on a per-pig marketed basis.

Results and Discussion

ADG and FCR Models

Summary statistics for ADG, FCR, and MR by NAHMS survey year demonstrate no dif-

Table 3. Productivity Models—Summary Statistics

Variable	NHMS Survey Year	Mean	Standard Deviation	Minimum	Maximum
ADG	1990	1.626	0.2263	0.942	2.37
	1995	1.631	0.2595	0.740	2.90
FCR	1990	3.179	0.6749	1.67	5.93
	1995	3.268	0.5104	2.18	5.91
MR	1995	2.280	2.274	0.00	27.50

ferences in ADG or FCR between 1990 and 1995 (Table 3). Although FCR appears to be better (lower) in 1990, the difference in FCR values across the two survey years is not significant ($p > .10$). Mean ADG (1.626 and 1.631) of finishers was comparable to that reported by PigCHAMP® (1.61) (Regents of the University of Minnesota) for 1999. Mean FCR (3.179 and 3.268) also was comparable to PigCHAMP reports (3.12). MR (2.28) was lower than that reported by PigCHAMP (2.80).

The estimated models for ADG and FCR are presented in Table 4. An increase in the number of days that antibiotics were fed during the G/F phase was associated with improvements in both ADG and FCR. In the case of FCR, however, using more than one antibiotic was associated with poorer (higher) feed conversion. Improvements in ADG and FCR

Table 4. ADG and FCR Model Results

	Average Daily Gain (ADG)[a]		Feed Conversion Ratio (FCR)[b]	
Variable	Coefficient	*p*-value	Coefficient	*p*-value
Constant	1.341	<.001	3.700	<.001
Variables Added into Models				
Dreg1	−0.007	.819	−0.071	.402
Dreg2	−0.017	.526	−0.047	.520
Dreg3	0.061	.142	−0.12	.302
Dyear90	0.043	.121	−0.24	.001
Dmed	−0.0062	.796	−0.056	.380
Dlarge	0.012	.724	−0.28	.002
Dcoop	−0.049	.203	0.19	.074
Dcontract	0.081	.182	−0.19	.253
Doptype	0.034	.447	−0.16	.202
daysingf	N/A	N/A	−0.00086	.495
Variables Included in Models				
Dabx1	0.068	.135	—	—
Dabx2	—	—	0.13	.264
Dabx3	—	—	0.30	.056
abxdays	0.00062	.026	−0.0020	.019
feed	0.047	<.001	N/A	N/A
rations	0.030	.081	−0.036	.052
MR	−0.011	.004	0.017	.092
Dabx1dia	−0.010	.175	−0.021	.224
Dabx2dia	—	—	—	—
Dabx3dia	−0.025	.007	—	—
Dabx1rat	−0.030	.112	0.036	.118
Dabx2rat	−0.034	.026	—	—
Dabx3rat	−0.024	.166	—	—
R^2	.126		.0661	

[a] For ADG model, number of observations = 505, chi-square = 113.96, and $p = .0000$.
[b] For FCR model, number of observations = 505, chi-square = 36.98, and $p = .0034$.

were also associated with the feeding of multiple rations during the G/F phase. There did appear to be a substitution effect between multiple rations and antibiotic use; increasing the number of rations was associated with poorer ADG and FCR when antibiotics were used for growth promotion (negative estimated coefficients for *Dabx1rat, Dabxrat2,* and *Dabx3rat* in the ADG model and a positive coefficient for *Dabx1rat* in the FCR model). The interaction between antibiotic use and the number of diseases diagnosed in the G/F unit also was associated with poorer ADG; this effect might be capturing the response of producers who use antibiotics for growth promotion when there is an increase in the prevalence of disease, or the positive effects of antibiotics used for growth promotion are simply overwhelmed by the negative influence of diseases. When interpreting these results, it is important to emphasize that this study focuses on antibiotic use for growth promotion and not antibiotic use for disease treatment. Being a medium- or large-sized operation was associated with better (lower) FCR. Independent producers who marketed through a cooperative were associated with poorer (higher) FCR. Higher MR was associated with poorer ADG and FCR.

Testing the joint significance of the antibiotic variables for the ADG and FCR models, the *F*-tests suggest that when the ADG and FCR models are evaluated together, the antibiotic variables were jointly significant ($p = .026$). When ADG and FCR were evaluated separately, the only model in which the antibiotic variables were jointly significant was the ADG model ($p = .058$). The *F*-test for joint significance for the FCR model alone was not significant ($p = .123$).

MR Model

Variables explaining MR (Table 5) suggest that antibiotics fed over a longer period of time (*abxdays*) were associated with reduced MR. Using two antibiotics for growth promotion in the presence of disease in the G/F unit (*Dabx2dia*) was associated with an increase in MR, whereas vaccination against disease (*vacc*) was associated with lower MR. The interpretation of the use of two antibiotics in the presence of disease is uncertain. It is likely simply that more disease is associated with higher mortality; it is also possible that producer response to more disease is to try to decrease the effect by using a second antibiotic for growth promotion. Weaning piglets at an older age (*weanage*) was also associated with a lower MR. The average age at weaning was 26.4 days, with a standard deviation of 9.2 days. As cull rate (*pcull*) increased, MR increased.

In terms of the added explanatory variables, the only apparent relationship is the positive coefficient associated with *Dfac4,* which implies that higher MR was associated with pasture-raised pigs. The magnitude of this estimated coefficient was also large.

Table 5. Mortality Model Results[a]

Variable	Coefficient	*p*-value
Constant	3.783	.002
Variables Added into Model		
Dreg2	0.24	.594
Dreg3	0.24	.628
Dmed	−0.38	.256
Dlarge	−0.25	.579
Dcoop	0.078	.887
Dcontract	−0.65	.427
Doptype	0.55	.542
daysingf	0.0039	.577
Dfac2	−0.022	.959
Dfac3	0.28	.830
Dfac4	1.036	<.001
Dfac5	−0.21	.877
Variables Included in Model		
abxdays	−0.0033	.225
weanage	−0.048	.006
pcull	0.13	.016
rmort2	0.089	.163
diag_gf	0.24	.116
vacc	−0.21	.094
Daiao	−0.30	.296
Doffsite	1.035	.109
Dquar	−0.45	.182
Drestrct	−0.41	.138
Dabx2dia	0.22	.209

[a] Number of observations = 288; $F(23, 264) = 3.35$; Prob $> F = 0.0000$; $R^2 = .2261$.

Table 6. Parameter Assumptions—Base Used for Economic Calculations

Model Parameter	Value
Number of antibiotics fed (*Dabx1* = 1)	1
Number of days antibiotics fed for growth promotion in G/F phase (*abx-days*)	65
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 (*MR*)	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

Among the biosecurity measures evaluated, it appeared that the practice of restricting entry only to employees (*Drestrct*) was associated with a lower MR, whereas purchasing pigs from off-site sources (*Doffsite*) was associated with increased MR.

Testing the joint significance of the antibiotic variables for the MR model revealed that these variables were not jointly significant ($p = .223$).

Predicting the Effect of Antibiotic Use on Productivity, Mortality, and Profit

The values and assumptions used for the key parameters in the models are presented in Table 6. These data reflect the typical (mean or mode) values for commercial swine farms in the NAHMS data. 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, and combining with the estimated coefficients from the associated models (Tables 4 and 5), it was estimated that antibiotics were associated with improved ADG and FCR of 0.5 and 1.1%, respectively, and with better MR (Table 7).

Important basic economic summary values were calculated, including total revenue per year, total costs per year, return above total costs, return above operating costs, and net present value. Combined with the improvements to ADG, FCR, and MR (Table 7), the estimated increase in annual returns above total costs from antibiotics for a 1,020-head finishing barn was $1,612, or $0.59 per pig marketed. 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/cwt or $6.52/pig. These values suggest that the economic benefit generated by using antibiotics in the G/F unit represents approximately 9% of the net return realized by Illinois pig finishing operations in 2000.

Table 7. Predicted Improvements in ADG, FCR, and MR with Antibiotics Used for Growth Promotion

Productivity Measure	Without Antibiotics	With Antibiotics	Percent Change
ADG	1.626178	1.633541	0.453%
FCR	3.472747	3.433428	−1.132%
MR	1.910795	1.693221	−0.2176[a]

[a] Value expressed in percentage points.

Input Substitution

An interesting result from the ADG and FCR models is the relationship implied by the productivity influence of growth-promoting antibiotics and the number of rations used during the G/F phase. Increasing the number of rations was associated with improved ADG and FCR when considered alone (*rations*), but the interaction term *Dabx1rat* carried the opposite sign on the estimated coefficient. Figure 1 shows the implied association of increasing the number of different rations fed during the G/F phase on ADG and FCR when antibiotics are and when they are not used. In both cases, improvements in productivity from the use of multiple rations were associated with no use of antibiotics. The economic implications of

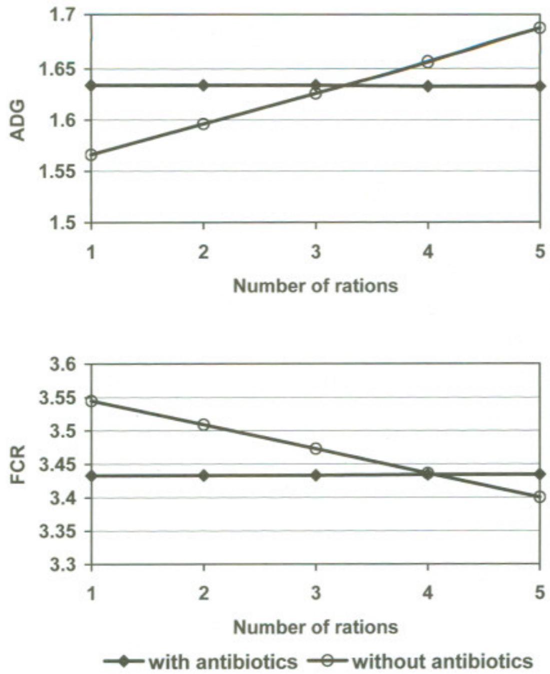

Figure 1. The Effect of Multiple Rations and the Use of Growth-promoting Antibiotics on Grower/Finisher Productivity (These results reflect the parameter assumptions reported in Table 6, where we assume one antibiotic used.)

Figure 2. The Effect of Feeding Multiple Rations on the Predicted Annual Net Return from Using Antibiotics for Growth Promotion during the Grower/Finisher Phase

using multiple rations indicate that when five rations are used, the associated net economic benefit for the use of growth-promoting antibiotics is negative (Figure 2).

Tailoring rations more specifically to meet the dietary needs of pigs throughout the G/F phase (the number of different rations is a good proxy for this) might serve as a substitute for antibiotics used for growth promotion. Our results imply that antibiotics used for growth promotion are of value mainly when four or fewer different rations are used in finishing. Producers managing finishing operations where diets are tailored to meet pig growth needs over time might not see the same benefits from using antibiotics as those who feed a small number of different diets.

It is also possible that a positive association exists between the number of rations used and the level of management, with better managed operations tending to use more rations. In this study, we see improved productivity as the number of rations increase when no antibiotics are used. We also see improved ADG as more rations are used when one antibiotic is used, but a decrease in ADG with increasing number of rations when more than one antibiotic is used, and we see no change in FCR by increasing the number of rations with one antibiotic used for growth promotion. Therefore, if number of rations used is in some way a proxy for management, then it appears mainly to have a positive effect on productivity in the absence of antibiotics; antibiotic use substitutes (up to some point) for increased number of rations (perhaps a proxy for better management).

Knowledge Gaps and Further Research

These econometric results face several limitations, and care is needed to interpret the results. First, although this study uses the best available national survey data on U.S. hog production, improved data sources would allow additional hypotheses to be explored. For example, it is possible that there would be increased variability in ADG and FCR when antibiotics are not used for growth promotion. With increased variability in ADG and FCR, pigs would likely be marketed at a wider range of sizes, and this would contribute to increased revenue variability given the pricing structure for pigs. Additional survey information concerning size variation at marketing could then be combined with information on market premiums by size to determine whether this effect is economically significant.

Second, productivity effects of antibiotic use in gestation and farrowing phases of production are poorly understood, but it is believed that antibiotics increase litter size. Additionally, implications in preweaning and nursery phases of production, where antibiotic use can influence growth, growth efficiency, and mortality are not well documented (Tubbs et al.). A better understanding in these other production phases is needed to begin to assess the true economic implications for the swine industry.

Third, the economic value of growth-promoting antibiotics in their role in disease prevention could be significant. Our econometric framework applied in this study might not capture the entire value that pig finishing producers could realize from antibiotic use for growth promotion in their role of reducing the risk of a significant decline in herd health status. Mean values fail to capture downside risks associated with variance around the mean. Additional studies, such as surveys of producer willingness-to-pay to reduce herd health risks might be conducted to help in providing derived estimates of growth-promoting antibiotic input valuation.

Fourth, the estimated economic value assumes that, on average, we expect to see the productivity gains predicted by the models. However, the joint significance testing on the antibiotic use variables suggests that perhaps this will not be the case. If only this hypothesis testing were considered, with no effects on MR, the economic gain from growth-promoting antibiotic use would be even smaller than estimated here.

Other effects that could markedly influence the economic implications of antibiotic use, but where virtually no evidence exists, are the influence on leanness, the interaction between antibiotic use and pig genetic makeup, or the interaction with a host of environmental pressures that can influence pig diseases and productivity. Additionally, the influence of management (or animal husbandry) affects efficiency of production and the economics of pig production. It is hoped that future NAHMS datasets will include additional environmental factors on farms, as well as information on pig genetics, in order to facilitate estimation of some of these interactions.

Further statistical analyses focusing on the risk-reducing effects of antibiotics used for growth promotion are needed but are beyond the scope of the current investigation. Examination of the influence of antibiotics on variability of productivity parameters is a possible approach to capturing these risk-reducing aspects if they exist. The price differential associated with under- and overweight pigs is an important influence of revenues and profits; if antibiotic use decreases variability of growth, it will decrease even further the variability of revenue and profit. This occurs because many producers have production contracts that are time sensitive for either delivery of finished pigs to packers or arrival of young pigs for placement in the barns, thus requiring empty barns on specific dates rather than removal on the basis of pig size (Miller, Song, and Bahnson).

We do have some measurements that might capture "good management"; at least some of the variables would be included in a set of good production practices (e.g., number of rations, hygiene and biosecurity measures such as all in–all out management, and quarantining pigs on arrival). The latter two of these variables were not significant and, therefore, not retained in the final model. But an open question that remains is whether better managed herds might be more likely to survive in the face of reduced availability of antibiotics for growth promotion. Although the answer to this question is not simple, it is our opinion that better managed farms carry a number of attributes that could increase the likelihood of surviving all types of changes, including the elimination of the use of antibiotics for growth promotion.

Summary

Our results suggest that the economic effect of the use of antibiotics for growth promotion in G/F units in the United States is sufficiently high ($0.59/pig marketed, or an improved profitability of 9%) that pork producers might be reluctant to produce pigs without this input. However, we also found a potential for substantial substitutability with this input and other production inputs that could help overcome the negative influence of removing antibiotics. The potential trade-off in applying some alternative inputs might be the added complexity associated with the use of these inputs. This is particularly important if the added complexity is such that the alternatives are excluded or limited to smaller production units.

The widespread use of antibiotics for growth promotion within the U.S. pork industry suggests that most producers believe their profits are higher with use than they would be otherwise or that antibiotics are a low-cost risk-reducing measure. Further research is needed to determine the degree of the latter possibility. There is a need for additional economic research as well as 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; such studies should reflect current pig genetics, size of operations, typical diseases, and other environmental pressures, among other factors. Additionally, the risk to human health from the use of antibiotics in growth promotion in swine production needs to be assessed. Combining a risk analysis framework with an integrated bioeconomic model for consumers would provide important and substantial input to the current debate on growth-promoting antibiotic use in food animal production.

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Appendix

ADG (average daily gain) was defined as the average weight gained (lbs./head/day) during the G/F phase. FCR (feed conversion ratio) was defined as the average pounds of feed fed during the G/F phase for each pound gained.

The 1990 and 1995 NAHMS datasets had inconsistencies in some of the variables collected for the two surveys. For example, the productivity measures ADG and FCR were not reported directly in the 1990 survey but were reported directly in 1995. It was possible to calculate ADG for the 1990 data with the use of reported values for the average days spent and the average weight gained in the G/F unit. Estimating FCR for 1990 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 estimated using feed diaries kept by producers in 1990 over a 7-day period. The length of time that pigs spent in each weight group was estimated with 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 gained in the G/F unit then provided the estimate of FCR.

The two surveys also had different details 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. In order to have a consistent measure of the intensity of antibiotic use across both datasets, we define *abxdays* as the number of days antibiotics were administered for growth promotion and used in the feed. Missing values for the number of days of feed-administered growth-promoting antibiotics in the 1990 dataset were estimated with the IMPUTE command in Stata. Stata's IMPUTE command fills in missing data values by performing regressions on the basis of patterns identified between the specified variable list and the variable containing the missing values (StataCorp).

Additionally, the number of pigs entering the G/F unit was not reported directly in 1990. This was calculated using reported numbers of pigs placed/moved/dead in previous phases (farrowing and nursery) within the production system.

The data used to estimate the mortality model were taken exclusively from the 1995 NAHMS dataset because several variables were missing from the 1990 dataset. MR (mortality rate) was defined as the percentage of pigs entering the G/F phase that died during the 6-month period prior to the second phase of the 1995 survey. In addition to the added explanatory variables used in the productivity models, variables that describe the type of facility also were included in the MR model. Of the variables considered for model inclusion, several related to biosecurity (*Doffsite, Drestrct, Dquar*) and disease prevention (*vacc, Dclean*) measures were adopted by producers.

A total of 505 observations were used to estimate the regression models for ADG and FCR, with 325 operations originating from the 1990 NAHMS survey and 182 from the 1995 survey. There were 288 observations included in the dataset used to explain G/F MR.