Producer Incentives for Antibiotic Use in U.S. Pork Production[1]

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Abstract: Antibiotics have been used in animal production for several decades. Antibiotics are used routinely now in pork production (NAHMS 2002). There is increasing concern about the use of antibiotics in animal production. There is no hard evidence supporting the link of antibiotic use in animals to observations of antibiotic resistance infections in people. Nonetheless a careful examination of the value of continued antibiotic use in agricultural, and in pork production in particular is warranted. Therefore, the objective of our study is to validate the productivity and economic impacts of antibiotic use for pig producers at the farm level. We use data from the NAHMS 2000 swine survey. We estimate the combined affects from antibiotics used for growth promotion (AGP) and antibiotics used for disease prevention (ADP) on 4 productivity measures. We also estimate the economic impact of AGP and ADP for individual pig producers. We estimate these 4 productivity measures using seemingly unrelated regression analysis. We evaluate 4 scenarios which ban antibiotic use, and use a simple synthetic firm partial budget to estimate the economic consequences of these scenarios.

We find that pig productivity is improved with AGP, but decreased with ADP. A total ban on AGP would cost pig producers $1,271 in lost profits per 1,020 head pig barn. A total ban on ADP however, would result in pig producers improving profits slightly. This occurs because productivity is negatively influenced by ADP. A ban of both AGP and ADP results in a small loss of producer profits ($376/1,020 head barn) because of the offsetting effects of ADP compared to AGP. Producers have higher profits when AGP and ADP are applied at levels where pig productivity is maximized. In this case, producers gain $4,146 for each 1,020 head barn compared to no antibiotic use.

Keywords: antibiotics, antimicrobial resistance, growth promotion, pigs, production

JEL codes:Q10, Q12, Q28

Introduction

Antibiotics have been used in animal production for several decades. The amount of antibiotics used in animal feeds increased in the 1950's and 60's, and had reached about 2.2 million lbs. by 1963 (Cromwell 1991). Antibiotic use continued to increase into the 90s (Miller, et al. 2003). Antibiotics are recognized as an important tool for efficient animal production (Cromwell 2002). It has been estimated that antibiotics used for growth promotion may now constitute half of all antibiotic use worldwide (Wegener et al. 1999).

Antibiotics are used routinely now in pork production (NAHMS 2002). According to the most recent survey conducted by National Animal Health Monitoring System, 88% of farms used antibiotics , and the most common reason was for growth promotion. Antibiotics are used for multiple purposes and administered in a variety of ways. Antibiotics used for growth promotion (AGP) or antibiotics used for disease prevention (ADP) are often administered at subtherapeutic levels, or in other words, at levels below those which would be used to treat clinical disease.

There is increasing concern about the use of antibiotics in animal production in recent years, with particular concern about what some view as unnecessary antibiotic use. Some people deem AGP and ADP as unnecessary. Depending on the degree of risk (either real or perceived), some might argue that all antibiotic use in animals causes concern. The use of antibiotics is associated with selecting organisms which have higher antimicrobial resistance. This is true with any antibiotic usage in any population of animals or humans generally. To the extent that antibiotic use in swine relates to the resistance observed in organisms that affect humans, there is the potential for adverse affects on human health. Other concerns surrounding antibiotic use relate to the potential for antibiotic residues. Together, these concerns have led to serious considerations about the value of AGP and ADP in swine production.

In spite of these concerns, however, there is no hard scientific evidence to support a clear-cut relationship between AGP and ADP with adverse consequences on human health (Barber, et al., Mathews; Brorsen et al.). Significant gaps in knowledge about antibiotic resistance make evaluation or adoption of any policy banning either AGP or ADP on the grounds of the contribution to resistance quite challenging.

Because of the lack of knowledge and the uncertainty surrounding the science of antimicrobial resistance, it behooves us to make decisions as carefully as possible based on the grounds of productivity impacts of antibiotics. The productivity impacts and associated economic value of subtherapeutic use of antibiotics in swine production has been documented (Miller et al.2003; Cromwell, 1991 and 2000; Hayes. 2001 and 2002; Losinger, et al, 1998; Hays, 1977; Zimmerman, 1986; Butz, 1971). Additionally, a high proportion of producers use AGP and ADP suggesting a strong belief by producers of their value. AGP have been shown to improve productivity by decreasing disease prevalence, increasing average daily gain (ADG), and decreasing (improving) feed conversion (FCR). As a result, more pork is supplied to the markets at lower cost, providing benefits for consumers and producers alike. However, current antibiotic usage may not accurately reflect optimal antibiotic use given the improvements in animal production, especially those seen in the last 5-10 years.

The objective of this study is to validate the productivity and economic impact of antibiotic use for pig producers at the farm level using data from the NAHMS 2000 survey. The combined affects from AGP and ADP are estimated. Four different scenarios related to varying degrees of bans of AGP and ADP are also evaluated.

Literature Review

The economic impacts of restricting or eliminating antibiotics has been extensively studied (Butz, 1971; USDA, 1972; Hays, 1977; Cromwell, 1991 and 2000; Miller, et al, 2003; Losinger, et al., 1998; Hayes, et al. 2001, and 2002). The conclusion of most studies is that subtherapeutic use of antibiotics significantly improves pork productivity. Butz (1971) cited sixty-one comparisons conducted in 1970 by experiment stations with growing/finishing pigs and demonstrated an average improvement of 10.7% for rate of gain and 5.1% for feed conversion rate if antibiotics are used in feeds. Cromwell's review (2000) found similar, but somewhat lower productivity when drawing on the addition of the last 3 decades of research. He noted that improvement in productivity gains was even more significant when the level of sanitation on the farm was lower. Hays (1977) examined the efficacy of AGP. He found that the stage of pig growth, farm sanitation, herd diseases, plus the dosage and type of antibiotics influence pig growth. Using data from 279 experiments with 5,666 grower/finisher pigs, he estimated ADG increased by 4% from AGP and FCR improved 2%. Cromwell (2002) summarized the data of a large number of experiments conducted from 1950 to 1985. He found ADG improved by an average of 4.2% and FCR improved by 2.2% when pigs were fed AGP. Losinger (1998) and Miller et al. (2003) used public survey data (NAHMS 1990-95 swine data) rather than experimental data to evaluate the impact of AGP on productivity. Miller et al. (2003) conclude that subtherapeutic use of antibiotics was associated with improved ADG (0.5%), and improved FCR (1.1%); these 2 productivity gains considered together improved net farm profits by 9%. In a model by Hayes et al. (2002) which includes meat supply and demand and is based on productivity impacts of antibiotics from European data conclude that a ban on over-the-counter antibiotics would increase production costs per head by $6.05 initially, and by $5.24 10-years post-ban.

Some of the existing literature suggests that the productivity gains from AGP and ADP are minimal. Dritz et al. (2002) evaluated the effects of various regimens for antibiotics on ADG and FCR. They studied 24,099 growing pigs in three production systems, and found that treated (those receiving antibiotics) nursery pigs had significantly higher ADG than did control pigs. However, they did not find significant differences in ADG or FCR in finishing pigs. Likewise, Keldsen (2002) studying 62 Danish finishing herds, found the majority (63%) of herds experienced no long-term change in productivity (no change in ADG or diarrhea treatment) when AGP use was discontinued. Keldsen did find that 26% of the herds experienced a temporary decrease in the ADG. It is noted that return to baseline levels of a productivity measure such as ADG is, however, not the same as there being no long-term change. However, it is fair to say that both Dritz et al. and Keldsen suggest that a ban on AGP and/or ADP has been fairly unproblematic at the finisher stage in some herds.

In summary, most of the literature suggests that AGP and ADP in pork production have a positive impact on pig productivity. Most studies have been based on experimental data, which have advantages of obtaining more reliable results for testing specific hypotheses. However, results from experimental studies may not be robust for discussing implications from a policy perspective, especially if confounding factors exist or if the experimental herds are not representative of the industry.

The literature review does suggest that there may be a possibly diminishing return (somewhat lower productivity gains in more recent studies compared with earlier studies) from AGP and ADP. Thus, further study and validation of previous studies using the most recent available data to address the issue and evaluate further potential policy regulations is warranted. Hence, our current study extends earlier research in three distinct dimensions. First, we measure pork productivity with four different indices of productivity, rather than just ADG and FCR as in the majority of earlier studies. Second, our model specification was examined from the perspective of possible structural relationships among the four productivity measurements for the first time. Third, our study uses NAHMS 2000 data, which is the most recent data available to investigate current productivity impacts of AGP and ADP.

Data Sources

Data is from the NAHMS 2000 swine survey. These data are from 2,499 farms in the top 17 swine producing states in the U.S., and then subset surveys of these farms. The dataset includes data on general management (from the complete set of 2,499 farms), antibiotic use, swine diseases and preventative practices (a subset of 895 farms surveyed), and pig productivity, bio-security, and environmental practices (a further subset of 799 farms surveyed). Farms with incomplete data (with regard to the variables of interest) were screened out of the dataset. Thus, the final dataset used was from 315 farms which completed all three of the NAHMS swine surveys and had complete data.

We evaluate the degree to which our 315 final farms are different from the farms screened out. The farm size where data are used are compared with those farms screened out using a t-test.

Modeling and estimating antibiotic productivity impacts

Productivity changes from subtherapeutic use of antibiotics were measured with a multiple variables econometric model. Generally, outputs in a pork production system are more than just live weight of pigs. Groundwater contamination, odor, antibiotic resistance, and other intermediate products are potential endogenous variables that might have application to the problem of deciding antibiotic use. In a general form, the multiple output production system could be depicted as:

$$(y_{1,s}, y_{2,s}, y_{3,s} \ldots\ldots y_{m,s}; x_{1,s}, x_{2,s}, x_{3,s} \ldots\ldots x_{n,s}; \theta_{1,s}, \theta_{2,s}, \theta_{3,s}, \ldots\ldots \theta_{r,s}) = \varepsilon_{1,s} \quad (1.1)$$

$$(y_{1,s}, y_{2,s}, y_{3,s} \ldots\ldots y_{m,s}; x_{1,s}, x_{2,s}, x_{3,s} \ldots\ldots x_{n,s}; \theta_{1,s}, \theta_{2,s}, \theta_{3,s}, \ldots\ldots \theta_{r,s}) = \varepsilon_{2,s} \quad (1.2)$$

$$(y_{1,s}, y_{2,s}, y_{3,s} \ldots\ldots y_{m,s}; x_{1,s}, x_{2,s}, x_{3,s} \ldots\ldots x_{n,s}; \theta_{1,s}, \theta_{2,s}, \theta_{3,s} \ldots\ldots \theta_{r,s}) = \varepsilon_{3,s} \quad (1.3)$$

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$$(y_{1,s}, y_{2,s}, y_{3,s} \ldots\ldots y_{m,s}; x_{1,s}, x_{2,s}, x_{3,s} \ldots\ldots x_{n,s}; \theta_{1,s}, \theta_{2,s}, \theta_{3,s} \ldots\ldots \theta_{r,s}) = \varepsilon_{k,s} \quad (1.k)$$

where s denotes that we are estimating a production system of equations, m = the number of endogenous variables, n = the number of exogenous variables, r = the number of parameter estimates, $y_{i,s}$ represent endogenous variables that are determined within the system, $x_{i,s}$ are exogenous variables used in the system, $\theta_{i,s}$ are the corresponding parameter estimates, $\varepsilon_{i,s}$ are the uncontrolled factors in the system of equations. The general system can contain many equations. With a subset of endogenous variables, we may establish a system with less than k equations. In this study, we estimate a subset of four productivity measurements which have been previously demonstrated or are believed to be related to the use of antibiotics. Further model specification is briefly described below.

(1) Productivity Variables Estimated

We have chosen to estimate four productivity variables, ADG, FCR, mortality rate (MR) and lightweight rate (LR). ADG measures the farm average of increased live weight gained per pig daily; FCR measures the efficiency of feed intake and is given as the pounds of feed used per pound of live weight gain; MR measures death losses and is calculated as the number of deaths divided by the average pig inventory; LR is the percentage of market pigs sold with a substantial price penalty, which usually occurs at a live weight of less than approximately 220 lb. Each variable measures a specific productivity dimension, and together they measure more accurately the overall productivity performance of a herd.

(2) Exogenous Variable Selection.

The NAHMS 2000 survey data provide over 1200 pieces of data corresponding to various queries in the survey. The selection and exclusion of variables as potential exogenous variables were based primarily on production practices in the swine industry, previous experimental or observational studies on swine productivity, and relevance to addressing questions related to antibiotic use. Relevant variables include basic factors such as management, facility, ration, operation size, bio-security and environmental factors, plus antibiotic use variables. Some variables were combined to form indices and avoid information loss in aspects of interesting. The exogenous variables used/retained are outlined in table 1.

(3) Functional Forms and System Specification

Three estimation methods were considered during the evolutionary development of the production system; 1) separate equations and ordinary least squares (OLS) or maximum likelihood methods in SAS; 2) estimation by seemingly unrelated regression (SUR) combining equations for ADG, FCR, lnMR, and lnLR into a related production system; and 3) estimation by a simultaneous production system using three stage least squares (3-SLS) or full information maximum likelihood (FIML) combining equations (1.1)-(1.4).

We considered both the error structure and possible relationships between productivity variables. Our data is cross sectional with 4 different productivity measures per farm. Because there may be factors common to a farm which affects simultaneously all productivity (outcome) measures, there would be error dependence between equations. Estimation then by OLS of 1.1 to 1.4 for each productivity measure as an independent equation, might not be unbiased; also the estimated parameters might not be either efficient or consistent. Depending on the relationships assumed among the productivity measures, 1.1 - 1.4 could be estimated as a production system by either SUR or 3-SLS. SUR takes into account the dependence among errors between the equations, while the simultaneous equation estimation takes into account the causal relationships among the outcome measures.

Theoretic considerations do not always clarify the optimal estimation method. Data considerations are also important. Missing data, even when distributed randomly among observations, cause loss of some of the analytical advantages of system estimations. OLS uses varying subsets of the data for each equation; while this minimizes the loss of information, the relationships when several outcome measures (in this case productivity measures) must be considered in aggregate are obscured. Given these considerations, the use of SUR seemed the best for system estimation.

To estimate the SUR system, we used a combination approach in that OLS results informed variables presented to the SUR estimation. Variables presented to the SUR estimation were those from the OLS estimations when $P < 0.15$. Then within SUR, if a variable had a $P > 0.50$, it was deleted unless deletion caused major shifts in the parameter estimates of other variables.

We use a linear form production system because of its simplicity and because of the limitations of categorical data (16 of 29 of our variables are categorical) as exogenous variables. ADG and FCR equations use linear functional forms. The MR and LR endogenous variables are transformed (lnMR and lnLR), and then are fitted to linear functional forms. Using logit transformation for these two variables was used to decrease inaccuracy of linear models for bounded variables and predictions outside the probability range, Zhao (2001).

Thus, a more specific form of our estimated swine production system is as follows:

$$ADG = F_1(x_{1,s}, x_{2,s}, x_{3,s} ......x_{n,s}; \theta_{1,s}, \theta_{2,s}, \theta_{3,s}, ...\theta_{r,s}) + \varepsilon_{1,s} \quad (2.1)$$

$$FCR = F_2(x_{1,s}, x_{2,s}, x_{3,s} ......x_{n,s}; \theta_{1,s}, \theta_{2,s}, \theta_{3,s}, ...\theta_{r,s}) + \varepsilon_{2,s} \quad (2.2)$$

$$\ln MR = F_3(x_{1,s}, x_{2,s}, x_{3,s} ......x_{n,s}; \theta_{1,s}, \theta_{2,s}, \theta_{3,s} ......\theta_{r,s}) + \varepsilon_{3,s} \quad (2.3)$$

$$\ln LR = F(x_{1,s}, x_{2,s}, x_{3,s} ......x_{n,s}; \theta_{1,s}, \theta_{2,s}, \theta_{3,s} ......\theta_{r,s}) + \varepsilon_{k,s} \quad (2.4)$$

Now $x_{i,s}$ are exogenous variables that are particularly important for explaining these 4 productivity measures (ADG, FCR, lnMR = ln(MR/(1+MR)), and lnLR = ln(LR/(1+LR))) and include in particular variables which reflect antibiotic use.

Estimated Results of Antibiotics Impacts on Pig Productivity

Four equations of pig productivity are estimated. The variable descriptions, along with their associated means, and standard standard deviations (or proportions for the case of categorical variables) for those variables used and retained in the SUR estimation are listed in table 1. Estimated coefficients, with associated statistics are outlined for each estimated equation in tables 2-5. The SUR system related R-squared is 0.0904.

There are fifteen exogenous variables used to explain ADG (table 2). Antibiotics used for growth promotion (AGP) were important determinants of ADG. The effect of AGP depends on the amount of time AGP was fed. ADG was highest when AGP were fed between 61 to 90 days with an increased ADG of 0.09 pounds (5.6% improvement) compared with no AGP. ADP decreased ADG. The number of different antibiotics used, either for growth promotion or disease prevention, was not significantly related to ADG. Besides antibiotic use variables (AGP and ADP), other explanatory factors contributed to variation in ADG. These variables include enhanced biosecurity by the use of all-in-all-out pig flow (ADG increases by 0.031), and number of restrictive procedures required for entry (ADG increases by 0.012 with each restrictive procedure added). Also, ADG is improved by feeding more rations (ADG increases by 0.055 if 5 or more different rations are used). Contracting with a packer, obtaining a higher percentage of pigs from offsite sources, and increasing the number of vaccinations injected were associated with a lower ADG.

Eleven exogenous variables contribute to explaining variation in FCR (table 3). Here we find that ADP was associated with poorer (increased) FCR. The estimated coefficients from ADP suggest FCR improves (decreased FCR) only when ADP are fed for more than 31 days. No effects of AGP on FCR are identified, either in terms of the number of different antibiotics or time AGP was fed. Other factors affecting FCR are total confinement (improves FCR, estimated coefficient = -0.158), all-in all-out pig flow (improves FCR, estimated coefficient = -0.165), use of feed supplements (improves FCR, estimated coefficient = -0.087), and being from the East-central U.S. (improves FCR, estimated coefficient = -0.10). Some exogenous variables contribute to poorer FCR, although both associations are in the direction anticipated; these include increased number of vaccinations (estimated coefficient = 0.012), and re-sorting pigs after they are placed in the finishing barn (estimated coefficient = 0.027).

Neither AGP or ADP are important in explaining variation in lnMR (table 4). The antibiotic related variables that are associated with MR are the number of antibiotics used to treat disease is 3 or more (this was associated with increased MR) and the number of days used for antibiotic treatment (this was associated with decreased MR). The number of diseases on the farm, and the number of reasons listed that cause death on the farm were positively linked to MR as expected; the geographic regions were all linked to decreased MR compared with the baseline region (Midwest).

AGP generally decreases LR (table 5). Use of AGP from 61 to 90 days had the most improvement in LR. AGP of less than one month is not significantly associated with lnLR. Most exogenous variables are associated with increased (poorer) LR. We see increased number of rations, increased ingredient numbers, environmental testing, the number of veterinary visits, the use of confinement facilities, all-in all-out pig flow, and re-sorting of pigs during the production process are all associated with increased LR. Only region appears to decrease (improve) LR.

The data used were examined for bias because of having used only a subset of the original data. Data screening decreased the number of small farms. Our screened dataset had a mean total herdsize of 11,005 head compared to the larger (but incomplete) dataset which had a mean herdsize of 5,549 (P=0.08). Thus, results have some biases towards larger swine farms. However, swine farms responsible for producing at least 1,000 head or more per year produce most (87%) of the U.S. pork production (USDA, NASS, 2002). Additionally, we could not use farms which did not provide the needed data. We think our results are representative of production swine agriculture.

Loss from Banning Antibiotics

The parameters estimated in each individual equation have shown that the use of antibiotics generally improves pig productivity. However, antibiotics used for different purposes have different impacts on productivity. Antibiotic use could improve productivity in one dimension, but reduce productivity in another dimension. In this section, we formulate several scenarios of what might happen to pig productivity and profitability under different antibiotic ban scenarios; we combine the effects of antibiotic use from each separate dimension in the overall profitability estimation.

Losses to pork producers from an assumed ban of different types of antibiotics are simulated. A simple partial budget calculation is used to estimate the economic impact for a producer for each 1,020 head pig barn. We assume in our simplistic spreadsheet budgeting model that the economic impact of ADG, FCR, MR, and LR are not causally linked with each other. We use average pig revenues and costs of production data for 1999-2001 (Miller, et al, 2001, University of Illinois, and USDA, NASS). These scenarios include a total ban on AGP, a total ban on ADP, a total ban on AGP and ADP, and a partial ban on AGP and ADP. The converse of the scenario interpretation is the gain which producers realize from antibiotic use compared to the situation if no AGP or ADP were available to them. We estimate the influence of a ban on producer profitability by projecting changes in each of the four productivity measurements from the baseline model. The liveweight price received by producers was assumed to be $40.17/cwt. All other variables involved in the estimated model are assumed to take values of the NAHMS 2000 data averages.

Ban Scenario 1: A Ban on AGP.

Banning AGP is the first scenario to be tested. AGP are considered by some people to be an elective use because the purpose is purely growth promotion, in contrast to either disease prevention or disease treatment. Many individuals who oppose AGP will accept ADP because its purpose is to prevent disease in animals. We also know that a higher proportion of farms use AGP compared to ADP and also use AGP for a longer period of time compared to ADP.

Nonetheless, AGP are still an important contributor to improved productivity in swine production. A ban on AGP will decrease ADG from 1.67 to 1.63 and increase LR from 0.021 to 0.036 (table 6). The producer also realizes an estimated loss of $1,271 in profits from a ban on AGP for each 1,020 head barn of pigs.

Ban Scenario 2: A Ban on ADP.

The use of ADP is looked on by many people as a more appropriate use of antibiotics than AGP. When antibiotics were first being banned in Europe, ADP was allowed while AGP was prohibited. Our results reveal that neither ADG and FCR are improved with ADP. In fact, our simulation results suggest a ban on ADP will improve ADG from 1.67 to 1.69 and FCR from 2.98 to 2.97. A producer would realize a gain of $901 for each 1,020 head barn under a ban on ADP.

Ban Scenario 3: A Ban on both AGP and ADP.

This scenario is seldom discussed as a feasible policy in the US. However, purely from a theoretical and conceptual framework, considering this has merit. First, the definition of AGP and ADP is ambiguous. Some AGP use has the same affect as ADP and vice versa. Often the same antibiotics are used for both purposes, sometimes in the same dosage, and sometimes for similar lengths of time. Additionally, while the initial ban in the EU was only for AGP, this has now been extended to also include ADP. The experience in the EU after the initial ban on AGP was an increase of ADP; this again suggests that there is definitional overlap between these 2 categories of antibiotic use. Our simulation suggests that a ban on AGP and ADP will decrease ADG from 1.67 to 1.64, will improve FCR (from 2.98 to 2.97), and will increase LR from 0.021to 0.036. The influence on producer profits was estimated to be a loss of $376 for each 1,020 head barn from banning both AGP and ADP.

Ban Scenario 4: A limitation on AGP and ADP to levels which maximize production.

This simulation starts under the assumption that antibiotics will be limited in use and antibiotics will not be used beyond that amount which maximizes productivity gain. From this perspective, antimicrobial selection pressure is reduced but both AGP and ADP are still allowed. Under this scenario, ADG increases from 1.67 to 1.74; similarly FCR improves from 2.98 to 2.93, and LR also improves from 0.021 to 0.009 (table 6). Our synthetic firm producer also realizes an estimated gain in profits of $4,146 for each 1,020 head barn under an antibiotic use regime which is closer to an optimal use of antibiotics from better use choices.

Summary and Conclusions

This study with NAHMS 2000 data validates and extends our previous work (Miller et al., 2003) which was based on NAHMS 1990-1995 data. We extend previous work by measuring antibiotic influence on lightweight rate. Our results confirm the value of sub-therapeutic use of antibiotics in feed. We illustrate that a ban would be costly for pork producers.

First, we found the number of different ADP or AGP do not have significant productivity impacts. Therefore, it may be possible to reduce or eliminate certain classes of antibiotics while still maintaining the productivity gains received from antibiotic use.

Our second notable result is that the productivity gains differ substantially by varying the amount of time they are fed to pigs. Maximum production from antibiotics occurs when they are fed between 61 to 90 days. In 2000, 23% of swine farmers use AGP for more than 90 days. Decreasing the amount of time AGP are used so that use does not exceed 90 days is recommended.

ADP are not as important as AGP in improving productivity. We found ADP actually decreases ADG and FCR. Our study suggests that ADP should not be used routinely. Possibly different regimes than may be currently practiced with ADP, such as antibiotics given using a pulse strategy (slightly higher doses used intermittently), would be associated with improved productivity.

Some policy implications are revealed by our work. A total ban on subtherapeutic use of antibiotics would likely cause substantial short term loss for swine producers. However, decreasing antibiotic use toward their more optimal level is worth further consideration. It is possible that restrictions on classes of AGP, the amount of time antibiotics are fed and on ADP may be implemented without major losses. However, it may also be possible that producers who had lower productivity responded to this observation by feeding AGP longer, thus attempting to increase productivity. Thus some of the time dimensions ignored in our analyses could be important. Because we cannot determine causality, but only associations, using non-experimental data of the type used for this study, requires careful interpretation and also makes it necessary to express subsequent policy recommendations with great care.

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Table 1. Variables related to pig productivity: variable names, descriptions, and descriptive statistics*

Variable	Description	Standard deviation	Means/ Proportion
Endogenous variables			
ADG	Average daily gain	0.184	1.672
FCR	Feed conversion ratio	0.384	2.980
LnMR	ln mortality rate	0.658	-3.654
LnLR	ln light weight rate	2.652	-5.817
Antibiotic use variables			
AGP1-30	Growth promotion antibiotic used in feed between 1-30 days (dummy variable)	0.280	0.086
AGP31-60	Growth promotion antibiotic used in feed Between 31-60 days (dummy variable)	0.347	0.140
AGP61-90	Growth promotion antibiotic used in feed between 61-90 days (dummy variable)	0.298	0.098
AGP91-up	Growth promotion antibiotic used in feed more than 91 days (dummy variable)	0.451	0.283
ADP1-30	Disease prevention antibiotic used in feed between 1-30 days (dummy variable)	0.429	0.241
ADP31-up	Disease prevention antibiotic used in feed more than 31 days (dummy variable)	0.425	0.235
dabxnumtreat2-3	2-3 different antibiotics used for treatment (dummy variable)	0.429	0.241
Abxdaytreat	Num. of days antibiotic used for treatment	26.343	15.330
AbxnumGP	Num. of antibiotics used for growth promotion	0.849	0.876
Animal health/disease			
ingredientNum	Num. of ingredient added	1.265	1.517
vetvisitNum	Num. of veterinary visit	0.833	1.254
deathreasonNum	Num. of reasons given for pig death	1.594	3.844
vaccNum	Num. of vaccinations	2.742	3.063
disnumG	Num. of diseases observed in the G/F stage	2.290	3.286
Management			
dcontract	Contract producer (dummy variable)	0.452	0.286
holdingdays	Days in the G/F stage	19.724	114.867
offsite source	Percent of other site	0.193	0.040
Re-sort	Re-sorting (dummy variable)	0.938	0.876
Facility Description			
confinement	Total confinement (dummy variable)	0.414	0.781
Bio-security			
biosecurityNum	Num. of procedures required for entry	2.009	5.187

daiao	All-in-all-out (dummy variable)	0.500	0.533
PreventN2	Num. of prevention practice	1.068	2.530
Rations			
dRation3-4	Using 3-4 different rations (dummy variable)	0.497	0.435
dRation5-up	Using 5 or more different rations (dummy variable)	0.499	0.457
supplNum	Num. of supplements (fish, meat, bone, soybean meal, other protein bakery/food by products and animal or vegetable fat supplements)	1.238	2.327
Environment			
EnvtestNum	Num. of air, water tests	6.698	4.051
Eastcentral	East Central region (Illinois, Indiana Iowa and Ohio) (dummy variable)	0.488	0.387
Northern	Northern region (Michigan, Minnesota, Pennsylvania and Wisconsin) (dummy variable)	0.405	0.206
Westcentral	West central region (Colorado, Kansas, Nebraska, Missouri and South Dakota) (dummy variable)	0.452	0.286

* There are 16 dummy variables among 29 variables

Table 2. Exogenous variables associated with average daily gain (ADG) in finishing pigs

Variable	Coefficient	SE	t-Ratio	P-value
Intercept	1.614	0.051	31.430	<.0001
AGP1-30	0.052	0.039	1.350	0.177
AGP3 1-60	0.062	0.032	1.950	0.052
AGP61-90	0.093	0.037	2.530	0.012
AGP91-up	0.069	0.026	2.680	0.008
ADP1-30	-0.054	0.025	-2.120	0.035
dcontract	-0.047	0.026	-1.810	0.072
daiao	0.031	0.022	1.410	0.159
offsite source	-0.083	0.055	-1.530	0.128
biosecurity Num	0.012	0.005	2.240	0.026
deathreasonNum	-0.015	0.006	-2.310	0.022
ration3-4	0.016	0.035	0.450	0.653
ration5-up	0.055	0.035	1.590	0.113
VaccNum	-0.006	0.004	-1.590	0.112
SupplNum	0.005	0.009	0.610	0.545

Table 3. Exogenous variables associated with feed conversion ratio (FCR) in finishing pigs

Variable	Coefficient	SE	t-Ratio	P-value
Intercept	3.616	0.092	39.260	<.0001
ADP1-30	0.088	0.048	1.850	0.065
ADP31-up	-0.037	0.047	-0.780	0.435
confinement	-0.158	0.047	-3.380	0.001
daiao	-0.165	0.040	-4.080	<.0001
vaccNum	0.012	0.007	1.650	0.100
biosecuritytNum	-0.037	0.010	-3.690	0.000
supplNum	-0.087	0.016	-5.380	<.0001
dration3-4	-0.063	0.066	-0.950	0.341
dration5-up	-0.078	0.067	-1.170	0.241
re-sort	0.027	0.021	1.280	0.201
Eastcentral	-0.100	0.040	-2.470	0.014

Table 4. Exogenous variables associated with mortality rate (lnMR) in finishing pigs

Variable	Coefficient	SE	t-Ratio	P-value
Intercept	-4.382	0.274	-15.990	<.0001
dabxnumtreat3_up	0.180	0.160	1.120	0.262
disnumG	0.053	0.016	3.300	0.001
abxdaytreat	-0.003	0.002	-1.640	0.102
vaccNum	0.002	0.013	0.190	0.853
deathreasonNum	0.046	0.023	2.030	0.043
preventN2	0.094	0.033	2.820	0.005
holdingDay	0.003	0.002	1.480	0.140
Re-sort	0.046	0.038	1.230	0.221
Northern	-0.168	0.130	-1.300	0.195
Westcentral	-0.245	0.127	-1.930	0.055
Eastcentral	-0.225	0.119	-1.900	0.059

Table 5. Exogenous variables associated with ln Lightweight rate (lnLR) in finishing pigs

Variable	Coefficient	SE	t-Ratio	P-value
Intercept	-4.826	0.973	-7.010	<.0001
Abxnum1	0.412	0.290	1.420	0.156
AGP1-30	0.437	0.636	0.690	0.493
AGP31-60	-1.023	0.596	-1.720	0.087
AGP61-90	-1.400	0.644	-2.170	0.031
AGP91-up	-0.889	0.573	-1.550	0.122
dration5-up	0.480	0.289	1.660	0.098
ingredientNum	0.311	0.113	2.740	0.007
envtestNum	0.104	0.021	4.960	<.0001
vetvisitNum	0.428	0.172	2.480	0.014
confinement	0.535	0.344	1.560	0.120
daiao	0.860	0.291	2.950	0.003
dcontract	-0.218	0.338	-0.640	0.520
holdingDay	-0.009	0.007	-1.210	0.226
Re-sort	0.237	0.152	1.550	0.122
Northern	-0.686	0.368	-1.860	0.064
Westcentral	-1.350	0.342	-3.940	0.000

Table 6. Productivity under different scenarios

Productivity[1]	Scenarios [2]				
	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
ADG (lbs)	1.672	1.630	1.685	1.643	1.736
FCR (lbs)	2.980	2.980	2.967	2.967	2.930
MR	0.025	0.025	0.025	0.025	0.025
LR	0.022	0.036	0.022	0.036	0.009
Net Impact		-$1,271	$901	-$376	$4,146

1. ADG average daily gain; FCR Feed conversion ratio; MR mortality rate; LR lightweight rate.

2. Scenario 1: Ban AGP; Scenario 2: Ban ADP; Scenario 3: Ban AGP & ADP; Scenario 4. limit antibiotic use.