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Submitted Article

Foregoing Sub-therapeutic Antibiotics: the Impact on Broiler Grow-out Operations

James M. MacDonald* and Sun-Ling Wang

Economic Research Service, U.S. Department of Agriculture, Washington, DC.
*Correspondence to be sent to E-mail: macdonal@ers.usda.gov.

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Abstract *We use data from a recent national survey to analyze the use of sub-therapeutic antibiotics (STAs) among broiler growers. We estimate that 42% of growers do not use STAs in their feed or water, and instead rely on a set of other practices, including pathogen testing, expanded sanitary protocols, altered feeding regimens, and Hazard Analysis and Critical Control Point HACCP plans to maintain production. Suspending STAs has no statistically significant impact on production given other inputs, but producers who forego STAs receive higher contract fees, suggesting that they bear higher costs to realize a given level of output.*

Key words: Animal antibiotics, broiler industry, costs of production.

JEL codes: Q12, L11, L23.

Introduction

Livestock producers use an array of strategies to prevent the emergence and spread of animal disease, including vaccinations, the segregation of herds or flocks by age, sanitary protocols and ventilation systems in housing, age-specific and sex-specific feed rations, and physical biosecurity measures. The provision of antibiotics, which are used for disease treatment, disease prevention and growth promotion, are also an important measure.

Because animals are closely commingled in modern livestock production, bacterial respiratory or enteric diseases can quickly spread among animals to infect entire herds or flocks. Producers or veterinarians may treat affected animals individually, but they may also intervene to prevent the spread of disease by treating an entire group of animals with sub-therapeutic antibiotics (STAs), usually through their feed or water.

STAs are also used to promote growth. Researchers in the 1940s discovered that animals that were fed low levels of antibiotics realized faster rates of growth and improved feed efficiency (Hays 1991); this appears to operate through the antibiotic inhibition of normal microflora within the animal's gastrointestinal system, thereby enabling more energy to be expended for nutrient use and conversion to weight gain.

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These scientific discoveries, combined with shifts toward more intensive production practices, spurred increased antibiotic use in agriculture just as human use was also increasing. However, there are substantial scientific concerns over increased use. Isaacson and Torrence (2002) summarize the basis for concerns as such: "In addition to being used in humans and companion animals, antibiotics have been used extensively in agriculture for many years for multiple purposes. Antibiotics are used as growth promoters for food animal production and for therapeutic and prophylactic uses in humans, animals, and plants. The intensive and extensive use of antibiotic agents, however, has resulted in the emergence of highly drug-resistant bacterial pathogens. Some of these pathogens are resistant to most commercially available antibiotics."[1]

Regarding antibiotic use in agriculture, Isaacson and Torrence (ibid) identify three specific concerns: "1) that antibiotic resistance genes are amplified in the environment because of antibiotic use in agriculture; 2) that these antibiotic resistance genes negatively impact public health; and 3) that antibiotic resistance genes negatively impact animal health and production."

At the same time, the authors identified considerable uncertainty surrounding the precise extent of each of these specific concerns and their causal mechanisms.

In particular, there is considerable disagreement over the magnitude of risks to human health from STA use. Mathew, Cissell, and Liamthong (2007) write that, "While it is clear that use of antibiotics can over time results in significant pools of resistance genes among bacteria, the risks posed to humans by resistant organisms from farms and livestock has not been clearly defined." Phillips et al. (2004) assert that, "The use of antibiotics in food animals selects for bacteria resistant to antibiotics used in humans and these might spread via the food to humans and cause human infection, hence the banning of growth-promoters. The actual danger seems small, and there might be disadvantages to human and to animal health. The low dosages used for growth promotion are an unquantified hazard. Although some antibiotics are used both in animals and in humans, most of the resistance problem in humans has arisen from human use." The Philips article became a focal point of contention, with five published comments and a reply by Philips contesting these points.

Antibiotic use in animal agriculture has become an important and controversial issue of public policy. There is considerable disagreement over the precise effects of the use of animal antibiotics on human health, and limited information on the economic effects of on livestock operations. This paper analyzes STA use on U.S. broiler grow-out operations, using data from a large-scale representative survey. We summarize trends in STA use through 2006, and identify the alternative inputs and production practices used in the absence of STAs. We next estimate an enterprise-level production function for broiler grow-out operations to identify production outcomes at farms that do and do not use STAs. Finally, we estimate the impact of STA restrictions on the fees received by contract growers.

Because we rely on data from grow-out operations, we cannot evaluate the impact of STA suspension on all costs and revenues borne by the

[1]*Isaacson, Richard E., and Mary E. Torrence. 2002.* The Role of Antibiotics in Agriculture. *A Report from the American Academy of Microbiology. Washington, D.C. Available at: www.asmusa.org*

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industry (including integrators), and we do not evaluate the scientific issues of resistance and health.[2] However, policy-making suffers from limited information on the extent of antibiotic use, the specific effects of STA usage on bacterial resistance and on human health, and the economics of antibiotics in livestock. An understanding of the role played by STAs on grow-out operations is an essential component of the larger issues.

Public Policy: Restrictions on Antibiotic Use in Agriculture

STA use has become an important issue in public policy. Sweden banned the use of certain antibiotics in livestock production in 1986, and Denmark and Norway followed in 1995-98, initially with bans on the agricultural use of specific antibiotics, then with industry-led bans on any antibiotic used for growth promotion (Grave et al. 2006). The European Union (EU) followed a similar path, with bans on the agricultural use of five antimicrobials used for human medicine from 1995-2000, and then with a 2006 ban on the use of any animal antibiotics for growth promotion (Miller et al. 2006).

Public policy in the United States focuses on regulation, and on the provision of information to producers, drug manufacturers, and veterinarians. The Food and Drug Administration (FDA) approves for sale and regulates the manufacture of drugs used in veterinary medicine. Prior to approving a new animal drug application, the FDA must determine that the drug is safe and effective for its intended animal use, and that the drug is safe with regard to human health. The FDA can withdraw approval when a drug is no longer shown to be safe, as it did in 2005 with a ban of Baytril for poultry production. However, the agency relies primarily on the development and dissemination of prudent use principles for the provision of antibiotics by livestock producers and veterinarians.

FDA policy has come under increased scrutiny, and bills introduced in the U.S. Congress would follow the EU approach by directing the FDA to phase out non-therapeutic uses in animals of antimicrobial drugs deemed important for human health. A recent Congressional hearing, which featured a panel of industry, government, and academic scientists, highlighted the controversial scientific issues involved in broad-based STA bans (U.S. Congress 2010). Proponents argued that the evidence of links between antibiotic use in agriculture and antibiotic-resistant infections in humans was strong enough to support the phase-out of STAs. Opponents argued that the avenues of impact from specific antibiotic uses to human impacts were too complex and uncertain to support broad-based bans, and that the net human health impacts of bans were uncertain because STAs also suppressed animal pathogens that could endanger humans.

Food retailers also have an important influence on U.S. practices. For example, the McDonald's Corporation announced in 2003 that it would require all direct suppliers of meat products to end the use of antibiotics for growth promotion.[3] Several major retail chains and food service providers followed, and by early 2006 several leading chicken

[2]*Other studies assess the impact of STA suspension on total antibiotic use (Wierup 2001; Emborg and Hannerum, 2008).*

[3]*That action had an immediate impact on the highly integrated poultry industry, where direct suppliers raise poultry, while beef and pork suppliers usually purchase animals raised by others.*

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processors were reported to have ended the use of antibiotics for growth promotion, and severely limited antibiotic uses for disease prevention (Weise, 2006).

Such private actions can raise further challenges for regulatory policy. Because of the issue's salience with the public, firms can realize competitive advantages by differentiating their products as having been raised without antibiotics if U.S. regulatory authorities approve labeling claims. The U.S. Department of Agriculture (USDA) approved a "Raised without Antibiotics" label for Tyson Foods in May, 2007, but later withdrew the label approval and approved a more explanatory labeling claim–"Raised without Antibiotics that Impact Antibiotic Resistance in Humans". In June, 2008, USDA withdrew label approval for that claim, following the disclosure that antibiotics for disease prevention within the baby chicks were being provided in hatcheries. Tyson Foods argued that "raised" referred to grow-out operations of the birds prior to harvest, but USDA concluded that such labeling would be misleading to consumers when antibiotics are used at any time during the raising of the birds.

There is considerable controversy over the direction of U.S. policy toward animal antibiotics, but significant changes in antibiotic use in the poultry industry have occurred under current policy. We now turn to an examination of the impact of reduced STA use on practice and outcomes at broiler operations.

Prior Work on the Effects of STA Suspension on Poultry Production

We know of two prior studies of the effects of STA restrictions on broiler production. Emborg et al. (2001), analyzed the impacts of the Danish ban, while Engster, Marvil, and Stewart-Brown (2002), reported on the results of a U.S. poultry company's three-year study of withdrawing growth-promoting antibiotics from production.[4]

The Emborg analysis focused on flocks slaughtered between January 1996 and July, 1999 – before and after the Danish suspension of growth-promoting antibiotics on February 15, 1998. The authors evaluated changes in feed conversion rates, mortality, and house capacity utilization while controlling for house and farm fixed effects, as well as production cycle data (slaughter weights and age at slaughter).

The Emborg study found no significant change in mortality rates after the suspension, nor did they find a significant change in capacity utilization (broiler production per square meter). There was a small, but statistically significant, increase in feed conversion (more feed per pound produced) after the suspension – 0.016 pounds of feed per live-weight pound produced, or 0.88% of the median feed conversion rate of 1.8. Updates through July, 2002 showed continued modest trend reductions in feed conversion and mortality rates (Emborg 2009).

The Emborg study focused only on changes in production outcomes, and did not assess changes in production practices after the removal of STAs. However, feed conversion ratios, which spiked sharply upward just after antibiotic use was suspended, then trended back towards pre-

[4]*There are numerous economic analyses of STAs in hog production (Hayes and Jensen 2003; Hayes, Jensen, and Fabiola 2003; Miller, et al. 2003, Liu, Miller, and McNamara 2005; McBride, Key, and Mathews 2008; Hogberg, Raper, and Oehmke 2009).*

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suspension values during the rest of the study period as producers experimented with changes to feed formulations and production practices.[5]

Engster, Marvil, and Stewart-Brown (2002) reported on a series of controlled trials that compared production outcomes in 158 paired houses in North Carolina (NC) and the Delmarva Peninsula (DP). Trial and control houses were paired on the same farm. Trial houses used no STAs, while control houses continued to use them; otherwise, each paired house was the same size, with identical technologies, production practices, chick placements, and cycle lengths. Results were compared for 10 different trials, each covering 3-4 month periods. Unfortunately, the article, published as part of an informal symposium, reported only differences in means, and did not report tests of statistical significance. Nevertheless, the magnitudes of mean differences are interesting for purposes of comparison.

Feed conversion rates were higher in trial houses in each trial period and location. The average difference, 0.016 in DP and 0.012 in NC, was close to that found in the Danish study, and amounted to less than a 1% increase. Trial flocks had lower liveability (percentage of chicks surviving), by 0.2% in DP and 0.14% in NC.

In the first production cycle after houses were cleaned and new litter put down, trial flocks had *higher* liveability and *lower* feed conversion rates than control houses. Trial flock performance only deteriorated, compared to control flocks, during the second and third production cycles after a litter change, under poorer sanitary conditions.[6] Thus, the EMS analysis suggests that STA effectiveness may be conditional on sanitary practices, which is consistent with similar suggestions in the Emborg and Wierup papers.[7]

Sub-therapeutic Antibiotics in U.S. Broiler Production

Survey Data on Broiler Operations

We evaluate U.S. broiler grow-out operations with data from the 2006 Agricultural Resource Management Survey (ARMS). This large-scale representative survey is the USDA's primary source of data on the economics of farm businesses and farm households. The 2006 survey included a broiler version, directed to commercial producers of broilers grown for meat in the major broiler production states.[8]

[5]*The Swedish broiler industry also faced adjustment stresses, as the incidence of certain diseases, and the use of therapeutic antibiotics to fight them, increased after suspension (Wierup 2001). The industry reacted by altering practices – specifically, changing feed rations and improving sanitation and ventilation in houses.*

[6]*Just over 30% of U.S. broiler growout operations report that houses are cleaned out and sanitized after every flock removal (MacDonald, 2008). Full clean-out and sanitation is routine in the Danish industry (Emborg, 2009).*

[7]*Based on the EMS data, Graham, Boland, and Silbergeld (2007) argued that the expense of antibiotics exceeded the value associated with gains in liveability, average daily gain, and feed conversion. However, they appear to have valued added production according to the fees paid to growers, instead of the much higher value of birds to the integrator, and hence understated the value of improvements in feed conversion and mortality. Growers provide labor and capital, while integrators provide chicks, feed, and ancillary services, so grower fees will be substantially less than the full value of the bird.*

[8]*The target population consisted of all operations that produced broilers for meat and which had at least 1,000 broilers on-site at any time during 2006; this excluded farms that raised broilers for show or for private consumption, as well as egg-laying, hatchery, and broiler breeder operations. The states were Alabama, Arkansas, California, Delaware, Georgia, Kentucky, Louisiana, Maryland, Mississippi, Missouri, North Carolina, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, and Virginia.*

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In order to generate more reliable population estimates, ARMS uses stratified sampling – broiler sample selection probabilities vary with farm size and geographic location. Each sample farm then represents other farms in like geographic locations and size classes. Broiler version weights (the number of farms in the population represented by each observation) range from 3 to 40 farms.

There were 1,568 useable survey responses from the 2,100 operations in the broiler version's target sample, which reflects a 75% response rate. Once the weights were recalibrated for non-response, the useable responses represented 17,440 producers with production of 8.44 billion broilers (95% of U.S. broiler production in 2006). Farms with production contracts accounted for over 98% of operations and of broiler removals (MacDonald 2008). Because the alternatives – processor-owned and independent operations – are rare and presumably distinctive, we limit our analysis to the 1,543 sample operations with production contracts and 2006 production.

The survey collected data on production (number of birds removed, and weight at removal) and inputs. Labor includes hours worked on the farm's broiler enterprise by operators, other unpaid workers, and hired labor. For capital, respondents report the age, length, width, and technological characteristics (including tunnel ventilation, evaporative cooling, and solid walls or curtains) of each of their broiler houses.

The survey asks respondents for the quantity of feed provided during the year, but only 47% of respondents provided feed data, compared to 97% for labor and 96% for housing capital.[9] Respondents report expenses, rather than quantities, for other intermediate inputs (such as water, electricity and natural gas, or veterinarians services). We aggregate those into a single measure of intermediate expenses.

The ARMS sample is developed from a complex survey design. The sampling strata have different sampling weights, and post-survey weights are recalibrated to generate population estimates based on useable responses. In order to minimize respondent burden, farms selected for an ARMS sample in one year are less likely to be selected in a following year.[10] A screening procedure is used to screen out farms that are out of scope for the survey or out of business, and these farms are replaced in the sample.

Classical methods of statistical inference may not be appropriate for complex survey designs. An ARMS review panel has recommended that

Further information about ARMS, including downloadable copies of the questionnaires used, can be found at http://www.ers.usda.gov/Briefing/ARMS/.

[9]*Integrators provide feed, so respondents may not know how much they receive. The feed responses provided do appear to be of high quality. Agristats, an industry consulting firm, reported a 2008 feed conversion ratio of 1.93 (private communication with Roselina Angel, University of Maryland poultry nutritionist, March 20, 2009). The American Society of Agricultural and Biological Engineers used an estimate of 1.95 in their 2005 revision of standards for* Manure Production and Characteristics. *The mean among ARMS sample respondents was 1.95.*

[10]*The sample for the broiler version was drawn from a single list frame of broiler operations maintained by NASS, but other ARMS sample farms are drawn from dual frames. An area frame is used to identify farms that do not appear in USDA list frames. Most area frame farms are small. Dual frames increase survey comprehensiveness at the price of added complexity. In addition, all broiler version records are collected by paid enumerators, but the broader survey uses mixed modes, with mail-out and personally enumerated versions.*

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researchers use randomization-based inference methods, and specifically recommended the continued use of a jackknife procedure for estimating standard errors and confidence intervals for population estimates (National Research Council 2008). Jackknife estimators compute estimated standard errors by re-sampling; each of N groups of observations is dropped in turn, and the estimate of interest is recomputed (Cameron and Trivedi 2005). The resulting empirical distribution of estimates is then used to generate a standard error for the estimate, with N-1 degrees of freedom.

Because ARMS records have sampling weights, they must be reweighted to do jackknife estimates. USDA/NASS provides replicate weights in the ARMS research database, and ERS provides guides and programs to researchers if they choose to use the jackknife method.

The jackknife procedure does present problems for inference in regression models. The 2006 broiler database includes 15 sets of replicate weights (more recent ARMS databases, following other NRC recommendations, now have 30 sets of replicate weights). The parameters that can be estimated in a regression model are limited by the number of replicate weights, and the procedure therefore limits the types of models that can be used. We use jackknife methods for estimating differences in means across producer groups, and also use them for inference tests in regression models. The procedures are conservative, in that they consistently generate larger standard errors than obtained through classical inference procedures.

The Use of STAs

Survey respondents were asked, "Does your contractor, or the buyer of your broilers, require that your broilers be raised without antibiotics in their feed or water (unless the birds are ill)?" Possible answers were "yes", "no", and "don't know".

"Yes" responses (STAs were not used) covered 42.4% of operations, and 44.3% of liveweight production (table 1, columns 3 and 4). Given the media attention devoted to antibiotic use in agriculture, some operators may not want to report antibiotic use. In addition, because STAs are provided by integrators in feed, others may not be sure: 28.8% of operators reported that they didn't know if STAs were used, while 27.1% reported that they were not prohibited (table 1).

Our estimate is consistent with the levels and trends derived from other sources. According to Chapman and Johnson (2002), 33% of broiler grower diets used no STAs in 2000, compared to 2% in 1995.[11] Media reports indicate that four major integrators (Tyson Foods, Foster Farms, Gold Kist, and Perdue) had ended their use of growth-promoting antibiotics by the end of 2005 (Weise 2005). The four alone accounted for 38% of 2005 production. The extant evidence indicates that STA use has been declining since the mid-1990s, and that many growers now do without them.

We compare production practices, technologies, and outcomes across four groups identified in table 1: (1) growers who are STA users; (2) growers who don't know if they are STA users; (3) growers who forego

[11] *Chapman and Johnson (2002) relied on survey data from Agristats, a widely used industry consulting firm.*

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Table 1 Disease prevention strategies, housing features, and outcomes on broiler operations

	STA Provision Strategy			
	STAs Used (1)	**DK/ Ref (2)**	**No STAs No HACCP (3)**	**No STAs HAACP (4)**
Percentage of All Broiler Farms	27.1	30.5	10.6	31.8
Percentage of Broiler Liveweight Production	25.8	29.9	11.9	32.4
Production Practices (percent of farms):				
(a) Test flocks for avian influenza	52^{234}	40^{134}	66^{124}	92^{123}
(b) Test flocks for salmonella	40^{24}	31^{134}	48^{24}	84^{123}
(c) Test feed for salmonella	34^{24}	23^{134}	38^{24}	79^{123}
(d) Test flocks for other pathogens	38^{24}	28^{134}	36^{24}	84^{123}
(e) Clean houses after each flock	16^{234}	22^{134}	37^{124}	51^{123}
(f) Follow specific animal welfare rules	64^{234}	53^{134}	73^{124}	96^{123}
(g) Flocks are all-in all-out	86^{24}	72^{134}	87^{24}	95^{123}
(h) Feed from vegetable sources only	6^{34}	3^{34}	26^{124}	59^{123}
(i) Follow a HACCP Program	43^{234}	35^{134}	0^{124}	100^{123}
Housing features:				
Average age of houses	18.3^{4}	17.7	16.5	16.6^{1}
Percentage with tunnel ventilation	65.4^{234}	75.0^{1}	76.8^{1}	79.0^{1}
Percentage with evaporative cooling	66.8^{4}	69.3^{4}	72.6	76.0^{12}
Outcomes				
Mean feed conversion (per pound)	1.94	1.98	2.02	1.99
Mean mortality (percent)	3.95^{3}	4.22	5.01^{14}	3.95^{3}
Mean fee (cents per pound)	4.89^{4}	4.87^{4}	5.02	5.11^{12}

Note: The column headed "DK/Ref" refers to those respondents who didn't know whether STAs were prohibited, and those who did not respond to the question. Superscripts refer to outcomes of pair-wise t tests of significance for differences in means. A column entry is significantly different from entries in columns noted in the superscript at a 90% confidence level.
Source: 2006 Agricultural Resource Management Survey, version 4.

STAs, but who do not have a Hazard Analysis and Critical Control Point (HACCP) plan; and (4) growers who forego STAs, but who have a HAACP plan.[12] We are particularly interested in comparisons between our two most clearly delineated groups: STA users (1), and nonusers with HAACP plans (4).

Respondents who forego STAs tend to use a distinctly different package of production practices (table 1). The differences are large and statistically significant, and the consistency of responses across practices suggests that the STA response is meaningful. The differences are clearest when we sort STA nonusers into those who also use a HACCP plan and those who don't.

Seventy-five percent of STA nonusers also use an HACCP plan: those farms (column 4) are considerably more likely than other groups to test

[12]*HACCP is a systematic approach to the identification, evaluation, and control of food safety hazards. HACCP plans are based on a hazards analysis and an identification of critical control points in the production process. The plans establish monitoring, verification, and documentation procedures, and corrective actions should monitored outcomes range outside of critical limits.*

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flocks and feed for pathogens, to fully clean out their houses after each flock, to feed exclusively from vegetable sources, to use all-in all-out production, and to follow specified animal welfare guidelines. STA non-users who do not also have an HACCP program (column 3) are more likely to test for avian influenza, clean their houses out, and feed from vegetable sources than STA users, but the differences are not nearly as stark.

Intensified sanitation, a reliance on vegetable sources for feed, and all-in all-out production are all strategies that can reduce pathogen populations in flocks, while testing and HACCP guidelines can be used to better detect pathogen incidence. The no-STA/HAACP split appears to identify a set of farms (just under one-third of the industry), who follow a consistent set of distinct practices for animal health management.

STA Prohibition, Technology Use, and Outcomes

We summarize housing technologies and production outcomes in the lower panels of table 1. Growers who forego STAs have newer houses, on average, than those who use STAs, and they are also more likely to have tunnel ventilation and evaporative cooling in their houses. In each case, the differences between STA users and the HACCP/STA nonuser group (column 4) are statistically significant. These housing features allow farms to produce more broilers for a given capacity, and they may also improve feed efficiency and prevent disease.

We provide a comparison of outcomes in the bottom panel of table 1. Mean feed conversion among STA users is 1.94 pounds of feed per pound of liveweight production, compared to 1.99 among HACCP/no STA growers. This difference, 2.58%, is slightly larger than those reported in earlier poultry studies, but it is not statistically significant.[13] Farms that use neither STAs nor HACCP report a higher mortality rate (5.01%) than STA users, as well as STA nonusers who do use HACCP. The difference is statistically significant, but other mortality differences are not.

Users of STAs were paid 4.89 cents per pound, on average, while those who have a HACCP plan and forego STAs received 5.11 cents per pound, a 4.5% difference that is statistically significant. The price difference could reflect better performance among HACCP/STA nonuse farms, which on average have newer houses and better technology. However, it could also reflect the cost associated with management practices that replace STAs – costs that growers must be compensated for if they are to be induced to grow broilers without STAs. Given the differences in technology use and housing age between STA users and non-users (columns 1 and 4), we must control for technology and production decisions when assessing the impacts of STAs.

STAs and Production

Model

Farms that produce broilers with STAs differ from farms that abstain in several ways – in particular, they tend to have older houses, with less modern equipment. We aim to analyze the impacts of STA use on production, while controlling for other factors that may affect production, as

[13] *In more detailed regression analyses (unreported), STA use never had a statistically significant impact on feed conversion. But recall that only 47% of the sample provided feed data.*

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well as the decision to use STAs. To do so, we specify a production function for broilers, and we also specify a treatment-effect sample-selection equation (Greene 1997) to identify the factors associated with abstaining from STA use.

Consider a broiler production function with a simple Cobb-Douglas form:

$$y_i = \boldsymbol{\beta}'\boldsymbol{x_i} + \boldsymbol{\gamma}'\boldsymbol{z_i} + \delta D_i + \varepsilon_i \quad (1)$$

where y is the level of output, $\boldsymbol{x_i}$ is a vector of inputs, and $\mathbf{z_j}$ is a vector of features of production technology and operator characteristics that affect production, and D_i is a binary variable representing the operator's selection of being a non-STA user.

Output y is total liveweight pounds of broilers removed from the farm, while inputs **x** include labor (L), capital stock (K), and intermediate expenses (E) – all measured in logarithms. Labor is total labor hours, as defined above, while capital is total square footage of the operation's houses.[14] The $\mathbf{z_j}$ include the operator's education and age, and the operation's technological and operating features and geographic region.

Non-STA selection is one of the independent variables in equation (1). However, the decision to proceed without STAs may also be endogenous and can be explained by other exogenous factors shown as equation (2):

$$D_i^* = \boldsymbol{\tau}' Z_i + u_i, \quad (2)$$

where **Z**i is a vector of regressors. Di = 1 if Di* > 0, and 0 otherwise.

If some of the explanatory variables are the same as the variables in the production function, the selection problem will arise because

$$E[\delta\varepsilon] \neq 0. \quad (3)$$

The error terms in equations (1) and (2) can be assumed with a joint normal error distribution to account for the selection bias as follows

$$\begin{bmatrix} \varepsilon \\ u \end{bmatrix} \text{iid} \sim \text{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma^2 & \rho \\ \rho & 1 \end{bmatrix}\right) \quad (4)$$

Expected production by a non-STA user can be expressed as

$$E[y_i|D_i = 1] = \boldsymbol{\beta}'\boldsymbol{x_i} + \boldsymbol{\gamma}'\boldsymbol{z_i} + \delta + E[\varepsilon_i|D_i = 1] = \boldsymbol{\beta}'\boldsymbol{x_i} + \boldsymbol{\gamma}'\boldsymbol{z_i} + \delta + \rho\sigma\lambda_i \quad (5)$$

where λ_i is the inverse Mills ratio. The parameters of the treatment-effect selection model are estimated using full maximum likelihood.

Empirical findings: the selection equation

The dependent variable in the selection model is a dummy that equals 1 for operations which did not use STAs, but did use an HACCP plan.

[14] *Recall that we have feed data from less than half of the respondents. We omit feed from this analysis, imposing the assumption that it is consumed in fixed proportions with output. We found no substantive differences in results when we restricted the sample to observations with feed data.*

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Average bird weight has a statistically significant and negative coefficient (table 2). Operations specialize in producing birds of various sizes (generally, 4-8 pounds). Large birds have longer production cycles, and might therefore be more susceptible to poultry diseases. But this was the only statistically significant coefficient among the operator and operation variables, and the effects are small. Operations that grow larger birds are also more likely to use tunnel ventilation and evaporative cooling, and their houses are newer, on average.

Management practices matter, consistent with the patterns reported in table 1, and some of them have large and statistically significant effects. Specifically, testing for avian influenza, the use of specific animal welfare rules, cleaning out houses after each flock removal, and the use of feed from vegetable sources only are strongly associated with prohibitions on STAs use. Given those other features, all-in all-out production and testing for salmonella in feed are marginally associated with foregoing STAs.

Accounting for selection does not appear to affect estimates of the production function; the Heckman coefficient λ is small and not statistically significant in the production equation (table 2), and production function estimates from OLS estimation in table 3 are not materially changed from those in table 2.

Antibiotic use decisions are made by integrators. Integrators do not necessarily suspend STA use in all of their grow-out operations; instead, some may continue to use STAs for some production even when they are producing STA-free birds for most customers. As a result, selection among grow-out operations may in principle still be relevant. Nevertheless, it does not show up as important here: operator and housing characteristics have virtually no impact on the likelihood that any specific operation uses STAs. Instead, the strong indicators of STA abstention are those practices that are likely to be introduced jointly with abstention.

Empirical Findings: Production Function Estimates

We explore several production models in tables 2 and 3. Models 1 and 2 (table 2) were simultaneously estimated with a selection equation, while models 3-5 (table 3), were estimated using a single-equation production function, without selection, to allow for more degrees of freedom. We focus our discussion first on scale and technology effects, and then discuss the impacts of STA suspension.

The three production inputs (labor, capital, and intermediate expenses) all have positive and statistically significant coefficients. The sum of the coefficients provides a scale elasticity – the increase in output associated with a 1% increase in all inputs. The estimated elasticity, 1.06, suggests that there are small scale economies.[15]

Housing technology also matters. In model (1), the coefficient on tunnel ventilation is statistically significant, positive, and substantively important. For given inputs of capital, labor, and intermediate expenses, adding tunnel ventilation is associated with an 8.47% increase in annual production. The coefficient on solid wall construction, while positive, is not

[15] *An F test rejected the hypothesis of constant returns to scale–an elasticity equal to 1 – at a 95% confidence level (F = 6.01).*

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Table 2 Broiler production function with selection for STA use

Variable	*Model 1*		*Model 2*	
	Selection Equation	**Production Equation**	**Selection Equation**	**Production Equation**
		Coefficients and t statistics		
Constant	−1.5880	2.9975	−1.8441	2.7684
	(3.58)	(11.38)	(4.50)	(10.68)
Inputs (in logs):				
Capital (housing sq. feet)		0.8998		0.8897
		(31.66)		(30.50)
Labor (total annual hours)		0.0361		0.0349
		(2.54)		(2.40)
Intermediate expenses ($)		0.1253		0.1206
		(4.43)		(4.45)
Operator characteristics:				
Aged 64 or over	−0.2218	−0.0309	−0.2241	−0.0216
	(1.47)	(1.82)	(1.47)	(1.24)
Education HS grad or less	0.0562	−0.0182	0.0582	−0.0244
	(0.43)	(0.51)	(0.43)	(-0.67)
Less than 5 years in business	0.1089		0.0823	
	(0.26)		(0.43)	
Operation characteristics:				
Mean housing age	0.0003		−0.0001	
	(0.03)		(0.08)	
Houses have solid walls	−0.0157	0.0284	−0.0154	0.0246
	(0.14)	(1.19)	(0.14)	(1.04)
Tunnel ventilation	0.2625	0.0847	0.2156	0.0310
	(1.37)	(1.99)	(1.15)	(0.78)
Average bird weight (log lbs)	−0.5775		−0.3999	0.2554
	(2.04)		(1.78)	(7.95)
Region				
Northeast	−0.6771		−0.6866	
	(1.64)		(1.68)	
Southeast	−0.1666		−0.1916	
	(0.52)		(0.62)	
West	−1.1218	−0.3200	1.0977	−0.2829
	(1.39)	(3.99)	(1.41)	(3.65)
South	0.1274		0.1125	
	(0.44)		(0.39)	
Management practices:				
No STA Use		−0.0544		−0.0292
		(0.99)		(0.70)
Test flocks for avian flu	0.5487		0.5669	
	(2.20)		(2.37)	
Test flocks for salmonella	0.1661		−0.1611	
	(0.66)		(0.64)	
Test feed for salmonella	0.3288		0.3310	
	(1.68)		(1.69)	

Continued

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Table 2 *Continued*

	Model 1		*Model 2*	
Variable	**Selection Equation**	**Production Equation**	**Selection Equation**	**Production Equation**
Specific animal welfare rules	0.9328 (4.74)		0.9415 (4.83)	
Flocks are all-in all-out	0.0974 (0.80)		0.0895 (0.76)	
Houses cleaned after removal	0.3820 (3.25)		0.3717 (3.18)	
Feed vegetable sources only	1.2001 (15.05)		1.2170 (14.22)	
λ		0.0539 (1.08)		0.0330 (0.94)
ρ	0.2051 (1.11)		0.1286 (0.95)	
ln σ	−1.3228 (23.64)		−1.3557 (23.61)	
Log L		−7042.08		−7644.23
N	1371	1371	1371	1371
Scale elasticity		1.06		1.04
Constant returns to scale F test		6.01		3.28

Dependent variable in selection equations is dummy variable equal to one if the operation uses no STAs, but has an HACCP plan. Dependent variable in production equation is log of annual liveweight pounds removed.

statistically significant.[16] Operations with older principal operators realize lower production (3.09%), given inputs, than do other operations, and the effect is marginally significant.

The only statistically significant regional impact was in the west (California). Given capital, labor, and intermediate expenses, California's output was 32% lower than that in other poultry states. There do not appear to be any obvious data errors, but we have only a few California operations in the sample, and they are joint outliers – houses are much older and smaller, and reported mortality rates are higher, than in other sample broiler operations. These operations' inclusion in the sample does not affect other model estimates.

Two characteristics of the production process – bird size and the number of production cycles – have large impacts on production. We add bird size in model 2. One wouldn't necessarily expect operations with larger birds to realize greater annual production, given housing capacity, because larger birds require more space and take longer to produce. However, bird size had a large, positive, and highly significant association with production in model 2 – given capacity, labor, and intermediate expenses, a 10% increase in bird size is associated with a 2.5% increase in

[16]*Features of housing technology are correlated with one another. Houses with solid wall construction almost always feature tunnel ventilation and evaporative cooling, while houses without solid walls have those other features approximately 60% of the time. In turn, over 90% of houses with evaporative cooling also have tunnel ventilation, compared to 30% of the houses without evaporative cooling.*

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Table 3 Broiler production function without selection

Variable	*Model 3*	*Model 4*	*Model 5*
	Coefficients and t statistics		
Constant	2.7460	1.9659	0.9623
	(11.36)	(8.16)	(4.32)
Inputs (in logs):			
Capital (housing sq. feet)	0.8900	0.9337	0.9236
	(31.39)	(41.32)	(40.87)
Labor (total annual hours)	0.0338	0.0274	0.0197
	(2.42)	(2.04)	(1.36)
Intermediate expenses ($)	0.1222	0.0875	0.0552
	(4.55)	(3.95)	(3.66)
Operator characteristics:			
Age 64 or over	−0.0161	−0.0269	−0.0060
	(0.94)	(1.91)	(0.51)
Education HS grad or less	−0.0214	0.0005	−0.0127
	(0.61)	(0.02)	(0.49)
Operation characteristics:			
Houses have solid walls	0.0271	0.0403	0.0338
	(1.17)	(2.03)	(1.99)
Tunnel ventilation	0.0321	0.1205	0.0075
	(0.82)	(3.68)	(0.30)
Average bird weight (log lbs)	0.2542		0.6558
	(7.65)		(27.79)
Production cycles (log)		0.6657	0.9089
		(12.84)	(20.57)
West	−0.2738	−0.2030	−0.0792
	(3.72)	(1.98)	(1.01)
No STA use	0.0031	0.0931	−0.2839
	(0.02)	(0.51)	(1.97)
No STA use* average weight	−0.0001		0.0503
	(0.00)		(1.39)
No STA use* production cycles		−0.0646	0.0957
		(0.51)	(1.43)
R^2	0.84	0.88	0.93
N	1392	1392	1392
Scale elasticity	1.05	1.05	0.999
Constant returns to scale F test	3.28	4.52	0.01

Dependent variable: log of annual liveweight pounds removed. Variable defined as "No STA Use" is a dummy variable set equal to one for those operations reporting that antibiotics were not provided in feed or water, and who reported use of an HACCP plan.

annual liveweight production. Sample operations that produce large birds also realize greater capacity utilization (annual production per square foot of housing capacity) and less down time between flock placement and removal. Those operations also tend to have newer and larger houses, with more modern technology.[17]

[17]*Notice that the coefficient on tunnel ventilation is much smaller and loses significance in column 2. Tunnel ventilation is correlated with bird size: 56% of the houses producing small birds (less than 4.25 pounds) had tunnel ventilation, compared to 99% of those producing large birds (7.75 pounds or more).*

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On average, broilers spend seven weeks on a grow-out operation, while smaller birds are produced in five weeks and larger birds in nine. New flocks are not placed immediately, and the time between removal and new flock placement can vary widely across operations. Houses that are used more intensively ought to realize higher production, but they may also generate more disease risks. To assess the issue, we measured the number of production cycles on an operation in 2006, and entered it in model 4 (table 3).[18] The coefficient on cycles is large, positive, and highly significant in table 5, and it noticeably improves the fit of the model. When bird size and cycles are included together (model 5, table 3), each coefficient is large and significant. Given bird size and housing capacity, adding more cycles (birds) adds nearly one-for-one to annual output; given capacity and cycles, growing larger birds increases output.

Model 1 exhibited modest scale economies (a scale elasticity of 1.06). Model 5, with cycles and bird size included, exhibits constant returns to scale with an estimated scale elasticity of 0.999. The results suggest that the scale economies identified in model 1 are realized through the ability to grow larger birds, at greater capacity utilization, in larger and more technologically advanced houses.

In Census of Agriculture data (U.S. Department of Agriculture, 2009), the production midpoint where half of all broilers were removed from larger farms and half from smaller farms, was 682,000 birds in 2007. The corresponding Census midpoint sizes were 300,000 birds in 1987, 520,000 in 2002, and 605,000 in this 2006 ARMS sample. The continuing shift of production to larger operations is consistent with scale economies in grow-out, but broader elements of broiler complexes matter as well. For example, Ollinger, MacDonald, and Madison (2005) found large unexploited scale economies in broiler slaughter facilities in 1992. If true, then integrators faced strong incentives to expand grow-out operations and find growers to manage the larger operations effectively. In principle, the growers could realize larger slaughter volumes by adding more growers further from a slaughtering plant, but expansion at that extensive margin would generate increased transportation costs for feed and birds. Denser production from larger broiler operations could generate the volumes needed to realize scale economies in slaughter even in the absence of scale economies in grow-out.

Empirical Findings: The Impacts of STA Suspension on Production

When estimated with the selection equation (table 2, model 1) the coefficient on STA suspension is negative. The point estimate indicates that farms that do not use STAs realize a 5.3% drop in liveweight production for a given commitment of capital, labor, and intermediate expenses. However, the estimate is not statistically significant.

We added bird size and the number of production cycles in models 2-5 because we wanted to evaluate whether the impact of STAs varied with production decisions. When bird size is added in model 2, the point

[18] *We don't have direct data on cycles, but instead calculated it by dividing the total number of birds removed in 2006 by the peak inventory on the operation. Another reason to account for cycles is that some operations may not have produced for the full year (operations that were opened, closed, or reconstructed during 2006).*

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estimate on STA suspension falls by nearly half, and it is still not significantly different from zero.

STA use may have different impacts on production under different production routines. In models 3-5, we explored interactions between STA suspension, bird weight, and production cycles. There is no hint of any impact in model 3 when we interact STA suspension with bird size: the coefficients on STA suspension and the interaction are quite small, and are not statistically significant. When STA suspension is interacted with cycles (model 4), the coefficient estimates are larger, but are again not significant. However, when interactions are entered with both average bird size and with cycles (model 5), the coefficient on STA use is marginally significant ($t = 1.97$). Those on the two interaction terms are not. The point estimates suggest that production is reduced by 4.3% at mean values for birds and cycles. The production impact ranges from a 2% decline for operations at a 90th percentile value of one variable and a mean value for the other, to 6-7% declines for operations at a 10th percentile value of one variable and a mean for the other.[19] This pattern is suggestive, but not conclusive, since an F-test for the joint significance of the three coefficients failed to reject the hypothesis of zero impact (an F statistic of 1.59, compared to a critical value of 2.60 for 95% confidence).[20]

STA Restrictions, Grower Fees, and Grower Costs

We find no statistically significant difference in output, given inputs, operator characteristics, and operation characteristics, between growers who use STAs and those who do not. However, we also know that other production practices may substitute for STAs, and that some of those practices, such as following an HACCP plan or more extensive cleanout, impose costs on growers. We also know, from table 1, that growers who forego STAs receive higher fees, on average, than growers who use STAs.

Most growers receive fees that vary with performance (feed conversion and mortality), measured relative to other growers in tournament settings. Housing technology and bird size affects performance, but fee revenue also varies with a number of other clauses that may appear in production contracts (MacDonald, 2008). Each of these features may also be associated with STA use, so we look more closely at the association between fees and STA use in table 4.

We measure fees as a unit value – total contract fees received in 2006, divided by total liveweight pounds removed. In the model reported in column 1 of table 4, we regressed the log of fees per pound on contract characteristics reported in the survey.

Some contracts include clauses that link fees to energy prices, while others require growers to purchase their energy from a specific dealer.

[19]*Bird size and cycles are inversely associated with one another ($r = -.40$), so estimates when each are at extreme values aren't useful.*

[20]*This analysis compared operations that suspended STAs, and also instituted HACCP plans, to all other operations. We also compared only to operations that used STAs – excluding those that did not know, as well as those that suspended STA use but did not use an HACCP plan. In addition, we compared all operations that suspended STAs to all other operations. Our findings remained robust to changes in comparison groups: there were no statistically significant differences in output, given capital, labor, and intermediate expenses, between farms that suspended HACCP use and other farms, although the point estimate on STA suspension was consistently negative.*

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Table 4 Effects of Antibiotics Restrictions on Broiler Contract Fees

Variable	*Model 1*	*Model 2*
	Coefficients and t-statistics	
Constant	1.570	1.993
	(128.35)	(15.47)
No STA Use	0.027	0.021
	(3.06)	(2.36)
Energy price clause in contract	0.038	0.024
	(2.38)	(1.50)
Energy dealer clause in contract	0.068	0.041
	(2.03)	(1.49)
Contractor pays fuel expenses	−0.091	−0.061
	(5.45)	(3.31)
Contractor pays custom expenses	0.009	0.024
	(0.93)	(1.96)
Contract duration of 5 years or more	0.051	0.038
	(5.29)	(3.52)
Number of birds removed (log)		−0.041
		(4.19)
Tunnel ventilation		0.066
		(2.70)
Evaporative cooling		0.030
		(1.38)
Houses have solid walls		−0.002
		(0.08)
Average age of houses (years)		−.003
		(3.26)
Birds are less than 4.26 lbs		0.160
		(5.44)
Birds are 4.26-6.25 lbs		0.087
		(3.23)
Birds are 6.26-7.75 lbs		0.071
		(3.02)
R^2	0.08	0.14
N	1,476	1,388

Dependent variable: log of fee per pound. All explanatory variables are (0-1) dummies except for age and number of birds removed. Variable defined as "No STA Use" is set equal to one for those operations reporting that antibiotics were not provided in feed or water, and who reported use of an HACCP plan.

Each clause is associated with higher fees, and each is statistically significant. Contractors may pay for some expenses – for example, energy in some parts of the country, and custom services in others. Growers receive lower fees where contractors pay for energy. Finally, a few growers have long-term contracts, of five years or more, and they also receive higher fees.

In model 2 of table 4, we added variables representing farm size, bird size, and housing characteristics. Smaller birds, smaller farms, newer houses, and tunnel ventilation generate higher fees, with coefficients that are statistically and substantively significant. While the coefficients on contract terms fall when we add those variables, they keep their signs and remain statistically significant.

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Growers who forego STAs receive higher fees, and the effects remains positive and statistically significant when we control for contract features, farm and bird size, and housing characteristics (table 4).[21] The average difference, 4.4% in the simple comparison in table 1, falls to 2.7% in model 1 when we control for contract features, and to 2.1% in model 2 when we add other controls.

Conclusions

Broiler producers reduced their use of antibiotics for disease treatment and growth promotion after 1995, and we find that farms accounting for 44% of production were no longer providing STAs in 2006. We also find that STA non-users tend to follow a consistent set of production practices that are quite distinct from STA users. Non-users are much more likely to have an HACCP plan, and nonusers with HACCP plans clearly follow stricter sanitation practices and different feeding and testing regimens.

If feed conversion and mortality rates were to rise in the absence of STAs, then integrators would realize increases in the costs, per liveweight pound delivered, of broiler production. These costs would be direct, in the form of more feed required per pound delivered, and indirect, in the form of higher fees required to attract growers to invest in capital facilities that were delivering less production per unit of capacity. But our estimates indicate that growers and integrators can adapt to STA suspensions without declines in production.

We found no statistically significant effects of STA suspension on production when we compared those farms to other broiler grow-out operations, while controlling for labor and capital inputs and intermediate expenses. The term "statistically significant" matters here. Our point estimates tie STA suspension to 2-7% production declines, depending on the comparison. But the estimates have relatively large standard errors, and we cannot conclude that the true effects differ from zero. The large standard errors on STA suspension do suggest a range of outcomes among farms: some operations can institute practices that compensate for the loss of STAs, while others struggle.

The alternative practices are not free. Growers who forego STAs receive higher contract fees, on average, than those who do not, and higher fees likely compensate growers for the increased costs associated with production without STAs. In a simple comparison, growers who forego STAs and institute an HACCP program receive 4.4% more per pound than growers who use STAs, and 2.1% more when we control for relevant contract, housing, and operation features. With growers receiving fees of 5 cents per pound, on average, in 2006, then a 2.1% non-STA premium paid to growers would have cost integrators an additional $22.5 million for foregoing STAs on 44% of the 48.6 billion pounds produced in 2006.

Even in the absence of production effects, STA suspensions could raise integrator costs, aside from an increase in grower fees. Because integrators provide feed and veterinary supplies to growers, integrators would forego

[21] *Survey respondents also reported the average fee that they received in 2006. The results remain the same when we use that variable in place of our unit value (fee revenues divided by pounds). They are also robust to alternative functional forms and to the inclusion of other operator, contract, and operation characteristics.*

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the expense of STAs, but bear any added costs of feeds reformulated for STA-free operations. STA suspension may also lead to increased therapeutic provision of antibiotics, which would impose added materials and labor costs on integrators (Emborg and Hannerum 2008; Grave, et al. 2006; Emborg et al. 2001; Wierup 2001).

These additional integrator costs cannot be effectively gathered in the grower survey that we rely on, nor can we assess the demand impacts, if any, of an STA suspension. As noted above, broilers that do not receive STAs in grow-out cannot be labeled as antibiotic-free or grown without antibiotics. However, this study does provide new evidence on how grow-out operations adjust to production without STAs, which is a key component of the broader evaluation.

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References

American Society of Agricultural and Biological Engineers. 2005. Manure Production and Characteristics. OASAE D384.2.

Cameron, A. Colin, and Pravin K. Trivedi. 2005. *Microeconometrics: Methods and Applications*. Cambridge, UK: Cambridge University Press.

Chapman, H.D., and Z.B. Johnson, 2002. Use of Antibiotics and Roxarsone in Broiler Chickens in the USA: Analysis for the Years 1995 to 2000. *Poultry Science* 81(3):356–364.

Emborg, Hanne-Dorthe, and Anette M. Hammerum 2008. *DANMAP 2007: Use of Antimicrobial Agents and Occurrence of Antimicrobial Resistance in Bacteria from Food Animals, Foods, and Humans in Denmark*. The Danish Integrated Antimicrobial Resistance and Monitoring Program. National Veterinary Institute, Technical University of Denmark, and National Food Institute, Technical University of Denmark.

Emborg, Hanne-Dorthe, Annette Kjaer Ersboll, Ole Eske Heuer, and Henrik Caspar Wegener. 2001. The Effect of Discontinuing the Use of Antimicrobial Growth Promoters on the Productivity in the Danish Broiler Production. *Preventive Veterinary Medicine* 50(1): 53–70.

Emborg, Hanne-Dorthe. Personal communication. November 20, 2009.

Engster, H.M., D. Marvil, and B. Stewart-Brown. 2002. The Effect of Withdrawing Growth Promoting Antibiotics from Broiler Chickens: A Long-Term Commercial Industry Study. *Journal of Applied Poultry Research* 11(4): 431–36.

Graham, Jay P., John J. Boland, and Ellen Silbergeld. 2007. Growth-Promoting Antibiotics in Food Animal Production: An Economic Analysis. *Public Health Reports* 122(1): 79–87.

Grave, Kari, Vibeke Frøkjaer Jensen, Kristina Odensvik, Martin Wierup, and Marit Bangen. 2006. Usage of Veterinary Therapeutic Antimicrobials in Denmark, Norway, and Sweden Following Termination of Antimicrobial Growth Promoter Use. *Preventive Veterinary Medicine* 75(1): 123–132.

Greene, William H. *Econometric Analysis*.1997. 3rd ed. New York: Prentice Hall.

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Hayes, Dermot J., Helen H. Jensen, and Jay Fabiosa. 2002. Technology Choice and the Economic Effects of a Ban on the Use of Antimicrobial Feed Additives in Swine Rations. *Food Control* 13(1): 97–101.

Hayes, Dermot J., and Helen H. Jensen. 2003. Lessons from the Danish Ban on Feed-Grade Antibiotics. *Choices: The Magazine of Food, Farm, and Resource Issues*. 3rd Quarter, pp. 1–6.

Hays, V.W. 1991. "Effects of Antibiotics." In *Growth Regulation in Farm Animals*. Advances in Meat Research. Vol 7. A.M. Pearson, and T.R. Dutson, eds, pp. 299–320. New York: Elsevier Applied Science.

Hogberg, Michael G., Kellie Curry Raper, and James F. Oehmke. 2009. Banning Subtherapeutic Antibiotics in U.S. Swine Production: A Simulation of Impacts on Industry Structure. *Agribusiness* 25(2): 314–330.

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

MacDonald, James M. 2008. *The Economic Organization of U.S. Broiler Production*. U.S. Department of Agriculture, Economic Research Service. EIB-38.

Mathew, Alan G., Robin Cissell, and S. Liamthong. 2007. Antibiotic Resistance in Bacteria Associated with Food Animals: A United States Perspective of Livestock Production. *Foodborne Pathogens and Disease* 4(2): 115–133.

McBride, William D., Nigel Key, and Jr.Kenneth H. Mathews 2008. Sub-therapeutic Antibiotics and Productivity in U.S. Hog Production. *Review of Agricultural Economics.* 30(2): 270–288.

Miller, Gay Y., Kenneth A. Algozin, Paul E. McNamara, and Eric J. Bush. 2003. Productivity and Economic Effects of Antibiotics Used for Growth Promotion in U.S. Pork Production. *Journal of Agricultural and Applied Economics* 35(3): 469–482.

Miller, Gay Y., Paul E. McNamara, and Randall S. Singer. 2006. Stakeholder Position Paper: Economist's Perspectives on Antibiotic Use in Animals. *Preventive Veterinary Medicine* 73(2): 163–168.

National Research Council. 2008. *Understanding American Agriculture: Challenges for the Agricultural Resource Management Survey*. Panel to Review the USDA's Agricultural Resource Management Survey. Committee on National Statistics, Divison of Behavioral and Social Sciences and Education. Washington, DC. The National Academies Press.

Ollinger, Michael, James M. MacDonald, and Milton Madison. 2005. Technological Change and Economies of Scale in U.S. Poultry Processing. *American Journal of Agricultural Economics* 87(1): 116–129.

Phillips, Ian, Mark Casewell, Tony Cox, Brad De Groot, Christian Friis, Ron Jones, Charles Nightingale, Rodney Preston, and John Waddell. 2004. Does the Use of Antibiotics in Food Animals Pose a Risk to Human Health? A Critical Review of Published Data. *Journal of Antimicrobial Chemotherapy* 53(1): 28–52.

U.S. Congress. House of Representatives. Committee on Energy and Commerce. Hearing on "Antibiotic Resistance and the Use of Antibiotics in Animal Agriculture ". July 12, 2010.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2009. Unpublished data from the Census of Agriculture.

Weise, Elizabeth. 2006. 'Natural' Chickens Take Flight. *USA Today*. January 23, p. D5.

Wierup, Martin. 2001. The Swedish Experience of the 1986 Year Ban of Antimicrobial Growth Promoters, with Special Reference to Animal Health, Disease Prevention, Productivity, and Usage of Antimicrobials. *Microbiotic Drug Resistance* 7(2): 183–190.

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