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Economic Effects of a Ban Against Antimicrobial Drugs Used in U.S. Beef Production

Kenneth H. Mathews, Jr.

Economic effects for three scenarios of antimicrobial drug use in livestock production—a no-ban scenario and two levels of bans—are examined through cost minimization and a partial equilibrium analysis. Results indicate that regulating antimicrobial drug use in livestock production would increase per-unit costs of producers previously using drugs and reduce beef supplies in the short run, reducing consumer surplus. Producers not previously using drugs would benefit from short-run price increases.

Key Words: antimicrobial drug, ban, beef production, cost minimization, feed efficiency, growth function, growth promotant

JEL Classifications: C61, D21, D41, I18, Q11, Q12, Q18, R38

Specific production technologies gain attention when food safety or human health is affected or when livestock production costs or returns are affected. Feeding low, subtherapeutic levels of antimicrobial drugs (LLADs) to livestock to increase growth rates and improve feed efficiency is one such technology that has drawn criticism since its first use in the 1940s. That microbes can develop resistance to LLADs when fed to livestock has been known since the practice began (Ensminger). This fact has continually stimulated concerns that the practice of feeding LLADs to livestock may result in diseases resistant to antimicrobial drugs that could be passed from livestock to humans, through animal-derived food products, with the drug resistance intact. Concerns about resistant diseases include the

potential for increased treatment costs and loss of productivity, even life, in both humans and livestock. Although precise estimates of the share of foodborne illnesses attributable to foods of animal origin are lacking, a large share of foodborne illnesses are attributed to foods of animal origin. It is estimated that 76 million foodborne illnesses and 5,000 deaths occur in the United States annually from all foods, including those from animal-derived foods (Mead et al.).

Fear of human health consequences from the development of resistance to LLADs has motivated legislative proposals in Congress banning the low-level use of some antimicrobial drugs in livestock production (U.S. House of Representatives [H.R.] 3266, introduced November 9, 1999; H.R. 3804, introduced February 27, 2002; and U.S. Senate S. 2508, introduced May 13, 2002). These legislative proposals followed earlier Food and Drug Administration moves affecting drug approval (U.S. Department of Health and Human Services). Conversely, not feeding LLADs in-

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creases the probability of disease outbreaks in animals and/or humans from pathogens that may or may not have originally been resistant to antimicrobial drugs, especially in confinement operations. LLADs are also known to reduce foodborne pathogens (Committee on Drug Use in Food Animals).

Several previous studies have dealt specifically with the issue of banning LLADs in livestock production (Allen and Burbee; Brorsen et al.; Dworkin; Gilliam et al.; Hayes et al.; Henson; U.S. Department of Agriculture [USDA] 1978; Wade and Barkley). The heuristic approach taken in those analyses of antimicrobial drug bans was to assume (1) which, if not all, drugs would be banned from low-level, subtherapeutic feeding; (2) changes in output levels; and (3) changes in feed costs and feeding periods, and then to present some aggregate economic effects from various drug-ban scenarios.

The present article extends this earlier work in three important ways. First, a growth model reflecting recent feeding conditions allows output per animal to vary. Second, an optimal framework is used to further determine changes in output levels per year by allowing feeding periods to vary. These two extensions mean that final cattle weights can vary and the number of cattle fed per year can vary, resulting in an aggregate supply shock that is endogenous to the model rather than an assumption imposed on the model, as in previous studies. As a further extension along related lines, optimal feeding costs are also made endogenous. The third way the present study extends earlier work arises from the additive treatment in earlier studies of LLAD effects on feed efficiency and effects on growth rates. Specifically, these earlier studies failed to consider the effects on production and costs of the drug-induced interactions between feed efficiency and growth-rate effects that are incorporated into the current article.

We proceeded as follows. The next section briefly summarizes the literature on livestock drug bans. Next, a series of economic models is developed, beginning with (1) a growth function incorporating the interaction between

growth rates and feed efficiency that sets the stage for (2) a firm-level model that minimizes the cost of feeding cattle to final output weights for base, full ban, and partial scenarios. Under the assumption that these firms are identical, these firm-level results (3) can be aggregated across firms to reach aggregate supply for the base, full-ban (banning all growth-promoting antimicrobial drugs), and partial-ban (banning selected drugs) scenarios. Then, (4) a model of the effects of aggregate supply shocks is developed that can be used to examine the differences between aggregate results of the base model and the ban scenarios.

Next comes a section of Results and Discussion, which begins with an overview of the sequence of model estimations. Then follows a discussion of assumptions, data considerations and sources, and some preliminary results necessary for further empirical model estimation. The section then proceeds with a discussion of the estimation of the growth model used in the analysis and an alternative specification. The results from the growth model set up estimation of the firm-level cost minimization in the following section. In the absence of data from actual incidents of antimicrobial drug bans, a baseline situation in which the use of LLADs is unconstrained is simulated. Two departures from the baseline are then examined: a complete ban and a partial ban. The minimum-cost, feeding-simulation model allows endogenous determination of changes in output and feeding periods. Results from the growth and cost-minimization model estimations are expanded to represent aggregation of effects at the national level. The aggregate analysis of market-level effects that follows is a simple partial equilibrium model in which supply shocks at the firm level are aggregated to account for supply shocks at the aggregate market level. The analysis considers in depth the direct effects on the cattle feeding industry. Given the simulation nature of the empirical work, some discussion of sensitivity analyses follows. Implications for the cow-calf sector, as well as effects on other livestock markets, follow the sensitivity

analysis but are only briefly discussed. The final section of the article is a discussion of the implications of a drug ban with reference to the cattle feeding experiment reported herein.

Previous Studies of Livestock Drug Bans

Results from earlier studies (Allen and Burbee; Brorsen et al.; Dworkin; Gilliam et al.; Hayes et al.; Headley; Henson; USDA 1978; Wade and Barkley) have uniformly demonstrated higher costs to producers and general price increases for consumers as the result of partial or total bans on feeding LLADs to livestock. In those studies, losses were higher under the assumption of no substitutes for the antimicrobial drugs banned than under partial bans. Only Wade and Barkley showed aggregate gains to both producers and consumers from a ban on antimicrobial drugs used in swine production, but their positive results depend on an assumption of increased willingness to pay for drug-free pork.

Brorsen et al., Gilliam et al., Mann and Paulsen, and Wade and Barkley assumed full bans of all antimicrobial drugs in feed. Dworkin, Headley, and Henson investigated banning only selected antimicrobial drugs. Allen and Burbee and the USDA (1978) considered both full and partial-ban scenarios. Hayes et al. considered a ban against over-the-counter livestock drugs.

The full-ban scenario can be considered somewhat extreme, because there are several antimicrobial drugs used as growth promoters in livestock production that are not related to antimicrobial drugs used in human health care. These unrelated drugs would not be expected to be targeted in precautionary regulatory actions aimed at protecting human health care technologies.

The commonly used antimicrobial livestock drugs fed at low levels to cattle are tylosin, chlortetracycline, oxytetracycline, combined chlortetracycline/sulfamethazine, tetracycline, combined sulfamethazine/sulfadimethoxine, neomycin, and virginiamycin (USDA 2000b). Other antimicrobial drugs approved for use in cattle production as

growth promoters are ampicillin, dihydrostreptomycin, and the ionophores¹ lasalocid and monensin. Only tylosin and virginiamycin appear to be fed for the duration of the feeding period (USDA 2000b). Tylosin is fed to 40% of cattle arriving at feedlots weighing less than 700 pounds and to 45% of cattle arriving at over 700 pounds (USDA 2000b). Ionophores are fed to virtually all cattle fed in feedlots (USDA 1995, 2000a). Other antimicrobial drugs are approved for other livestock species, some of which are also related to antimicrobial drugs used in human health care. Tylosin and virginiamycin are the only drugs fed to cattle long-term that are also used in human health care, although bacitracin, dihydrostreptomycin, chlortetracycline, oxytetracycline, tetracycline, sulfamethoxine, sulfamethazine, and ampicillin are approved as growth promotants in cattle and are used in or related to antimicrobial drugs used in human health care (USGAO). Because there is no apparent human conflict with ionophores used in livestock production, the partial-ban scenario is more in line with regulatory objectives to address the stated criticisms of antimicrobial livestock drug use.

An Economic Model of an Antimicrobial Ban

This section presents a model of a single-species livestock operator (in this case a cattle feeder) who makes input decisions with and without constraints on access to antimicrobial drugs fed as growth-enhancers. This simple model allows an evaluation of the economic effects of feeding and not feeding LLADs on production at the firm level. By aggregating firm-level effects, supply effects can be estimated.

The model presented herein allows for variable feeding periods, final weights, and, as a consequence, the number of head fed per time period. The model contains an additional innovation with respect to the form of the

¹ Ionophores are a type of antibiotic that depresses or inhibits the growth of specific rumen microorganisms (Stock and Mader).

growth function used to estimate the final weight of fed cattle from information known when the feeding period begins. The model is dynamic in a limited sense because final weight depends on exogenous information from the previous feeding period (average daily gain [ADG], final weight [OutWeight], feed conversion [CONV], and cost of a pound of gain [COG]).

Suppose there exists a cattle feeder whose objective is to minimize the cost of feeding livestock. The cattle feeder expects to feed steers to some final weight, q_{it} , based on a growth function that is dependent on information that is currently available and some of which comes from the most recent feeding period,

$$(1) \quad q_{it} = q(\mathbf{y}_{it} | \Omega_t),$$

where \mathbf{y}_{it} is a vector of variables that affect growth and Ω_t represents the information set at t .

This expected final weight is used to determine specific nutrient minima and maxima important in the feeding process and used in a subsequent cost-minimization model. Additional constraints that deal with a number of digestive and growth-related issues are also included in the model. Thus, the cattle feeder's constrained optimization problem is

$$(2) \quad \min \{\text{cost of producing } q_{it}\} = \min_{\mathbf{x}_i} \{\mathbf{p}_i' \mathbf{x}_i; q_{it}\}$$

subject to $\mathbf{r} \leq g(\mathbf{z}_{ikt}), \quad \mathbf{s} \geq h(\mathbf{z}_{ijt}).$

In Equation (2), q_{it} is the weight to which the i th animal is to be fed (the growth function) and is estimated separately from the cost-minimization model from information known at time t about the initial weight of the animal, recent costs of gain, recent ADGs, and other exogenous information. Input prices at time t are represented by the price vector, \mathbf{p}_t , and \mathbf{x}_t is a vector of inputs. For simplicity, the input vector, \mathbf{x}_t , is limited to two classes of inputs (nonantimicrobial inputs $[\mathbf{x}_{it}, i \neq a]$ and an antimicrobial feed additive input $[x_{at}]$).

Constraints ensuring that maximum limits

on feed inputs are not violated are represented by $\mathbf{s} \geq h(\mathbf{z}_{ijt})$, where \mathbf{s} is a vector of maximum limits and $h(\mathbf{z}_{ijt})$ is a matrix of input characteristics. Examples of these maximum constraints would be upper limits on the amounts of wheat and cottonseed meal that can be safely fed and the maximum roughage content of the ration. Constraints ensuring that minimum limits on feed inputs or nutrients are not violated are represented by $\mathbf{r} \leq g(\mathbf{z}_{ikt})$, where \mathbf{r} is a vector of minimum limits and $g(\mathbf{z}_{ikt})$ is a matrix of input characteristics. An example of a minimum constraint would be minimum protein levels required to reach a particular level of growth and minimum energy levels required for a steer to reach q_{it} . In these constraints, \mathbf{z}_{ikt} , for $k = \{\text{protein content, net energy for maintenance, net energy for growth content, } \dots\}$, represents characteristics of each x_{it} input. For example, characteristics of feedstuffs include protein content of corn, net energy content of alfalfa, fiber content of cottonseed meal, and so on.

The growth function enters the programming model through the protein constraint and days fed used in the cost-minimization model. The objective function (Equation [2]) then appears as

$$(2') \quad \min_{\mathbf{x}} \text{cost} = \mathbf{p}_i' \mathbf{x}_i + \lambda_1(K_0 - K(\text{OutWeight}))$$

$$+ \lambda_2(D_0 - D(\text{OutWeight}))$$

$$+ \sum_j \lambda_j(\mathbf{r}_j - h(\mathbf{z}_j))$$

$$+ \sum_k \lambda_k(\mathbf{s}_k - g(\mathbf{z}_k)).$$

Variables are as defined above, except some vectors have been replaced by variable notation, λ_i , ($i = 1, 2, j, k$) are shadow prices of constrained variables, and K_0 and D_0 are, respectively, protein required and days required to reach the OutWeight. $K(\cdot)$ and $D(\cdot)$ are functions that determine protein and days fed. From the solution to this model, minimum feeding costs for the expected level of production, q_{it} , can be estimated.

Two points about the growth function should be kept in mind. First, the ideal growth function would incorporate all of the

effects of the LLADs, including any interaction effects between growth rate and feed efficiency and any other interactive effects. In general, the interaction effect is believed to reduce the combined effects of each single enhancing effect so that the combined effect is less than a simple additive result. Testing for the interaction effect is one of the nested hypotheses of the model presented in this article. The second point is that q_{ii} is not an optimal solution to the minimum cost problem. It is an expectation that sets the stage for a minimum cost solution. It could be an optimal expectation, given the factors that determine its level.

The individual feeder's production decisions determine the quantity of livestock supplied at the market level when aggregated across all firms. The following equations represent a simple analytical expression of the aggregate relationship:

$$(3) \quad Q^s = Q^s(p^s, u) = \sum_{i=1}^N q_{ii}$$

$$(4) \quad Q^d = Q^d(p^d)$$

$$(5) \quad Q^s = Q^d.$$

In these equations, Q^s represents aggregate supply, which is the sum of individual production, q_{ii} , from the solution to Equation (2'). Supply is a function of the price at which the product is supplied, p^s , and a supply shock, u . This supply shock is similar conceptually and in the manipulations that follow to demand and other shocks observed in simple textbook treatments of market equilibrium and other models (Intriligator; Russell and Wilkinson; Samuelson). In this case, the supply shock is from the LLAD ban. Market-level quantity demanded, Q^d , is a function of p^d , the market price.² At the

market equilibrium represented in Equation (5), $p = p^s = p^d$. Taking the total derivative of Equation (5) with respect to price and the supply shock, which in the present case is the supply change from banning LLADs, gives (following Holthausen; Intriligator; Russell and Wilkinson; Samuelson)

$$(6) \quad \frac{\partial Q^d}{\partial p} dp = \frac{\partial Q^s}{\partial p} dp + \frac{\partial Q^s}{\partial u} du.$$

Rearranging and multiplying the left-hand side by p/p and u/u and the right-hand side by Q/Q , and then again rearranging,

$$(7) \quad \frac{dp}{p} = \frac{\frac{\partial Q^s/\partial u}{Q^s/u}}{\left(\frac{\partial Q^d/\partial p}{Q^d/p} - \frac{\partial Q^s/\partial p}{Q^s/p} \right)} \frac{du}{u}.$$

Equation (7) can be readily expressed in terms of supply and demand elasticities and percentage changes

$$(8) \quad \% \Delta = \frac{E_u}{E_d - E_s} \% \Delta,$$

where E_d is the own price elasticity of demand for cattle, E_s is the own price elasticity of supply of cattle, and E_u is the elasticity of the supply shock for cattle. This analytical model provides a method for estimating the percentage change in livestock prices associated with a given percentage change in supply quantities, which in this case is caused by a ban on LLADs in livestock feeding.

Empirical Model Specification

Three drug-ban scenarios are examined in this article: (1) a baseline case reflecting cur-

² Beef imports and exports are excluded from consideration in this model. Net beef trade accounts for about 2% of total beef supplies, and with the exception of some Canadian and Japanese imported beef, most imported beef is not fed beef. Although recognizing that there could be some net trade effect on total supplies from a ban on antimicrobial drug use, including imports and exports would complicate the simple mod-

el presented in this article with little likely effect on final estimates. Net imports of calves and feeder cattle are included in the results because, once imported, they would go through the production process described in this paper. More important is the exclusion from this model of other livestock species that would be affected by a drug ban. These other livestock species would have effects in terms of both their own supplies and as substitutes. It may also be that trade effects on supplies of these other livestock species would be more important as well.

rent practices, in which LLADs are used to enhance growth and feed efficiency; (2) a full ban on the use of LLADs; and (3) a partial ban on the use of LLADs. In the empirical model, a producer minimizes feeding costs for each of the three production scenarios.

The cost-minimization model presented herein (Equation [2']) is similar to the model used by Epplin and Heady.³ In their model, feed costs and days on feed were minimized subject to (1) days fed to reach a given weight gain on the basis of protein level and (2) given weight gain as a function of corn, silage, and supplement. In the present analysis, the growth function is used to estimate a final (finished) steer weight (OutWeight) that is, in turn, used to determine the minimum protein requirement for the steer and to calculate the number of days the steer is fed.

Next, the averages of these minimum-cost solutions over the 11-year study period are used in a partial equilibrium framework to estimate supply and price effects in the livestock sector. Finally, aggregate effects on producers and changes in consumer surpluses are calculated.

Assumptions and Data

Data needs are different for the growth model, the cost-minimization model, and the aggregate model. This section describes the data necessary for estimating each of these models and some of the supporting considerations.

The Growth Model

The growth model sets the stage for the cost-minimization model and forms the "dynamic" link to the impacts of recent feeding experi-

ences. The empirical growth function for an animal is specified as follows:

$$\begin{aligned} (9) \quad \text{OutWeight}_t &= q_t(\text{seasonal dummy variables}_t, \\ &\quad \text{InWeight}_t, \text{OutWeight}_{t-1}, \text{ADGL}, \\ &\quad \text{CONVL}, \text{COGL}, \text{ADGL} \times \text{CONVL}, \\ &\quad \text{OKSTR800}). \end{aligned}$$

The growth function is estimated using 169 monthly observations from cattle feeding data for the High Plains of Texas from February 1978 through February 1992. These data can be found in monthly feedlot reports in *Feed-stuffs* magazine and are referred to herein as "the Hoelscher data."

A maintained hypothesis is that growth for the current set of steers will be similar to the most recent set of steers (naive expectations) but modified by current information for the current feeding period and steer starting weight. Growth enhancement is captured in lagged average daily weight gain in pounds (ADGL). Feed efficiency is captured in lagged pounds of feed fed on a dry-matter basis per pound of weight gained (CONVL). For the simulation in time t , lagged variables (OutWeight _{$t-1$} , ADGL, CONVL, and COGL) were taken from the cost-minimization solution in the previous period ($t - 1$), except for the first feeding period. Lagged values for the first-period estimation came from the Hoelscher cattle feeding data for the previous feeding period. The interaction effect is represented by ADGL \times CONVL. The price for Oklahoma City Medium and Large No. 1, 800–850-pound steers (OKSTR800) was also included, to represent the steer input cost.

The Cost-Minimization Model

The cost-minimization model finds the minimum cost for feeding a steer to the final weight estimated from the growth function for each of the 45 feeding periods used to generate the average base scenario results. The protein constraint and the length of feeding period needed for each cost-minimization solu-

³ Other possible specifications of growth functions and physical relationships exist, and it is possible that other specifications could improve results reported in this article. However, experiments aimed at generating the data necessary for tests of alternate specifications for growth functions and other physical relationships are long-term and expensive. The functions used in the model outlined in this article are the results of previous experiments that have been reported in the literature.

tion depend on the final weight estimated previously from the growth function.

Data from Appendix Table 10 in the National Research Council's *Nutrient Requirements of Beef Cattle* (1984 edition) were used to estimate minimum protein requirements for steers

$$(10) \quad \text{protein} = K(\text{weight}),$$

where weight is the weight of the steer at the midpoint of its gain

$$(11) \quad \text{weight} = (\text{estimated OutWeight} + \text{InWeight})/2.$$

Specifically, data for weight and percentage of protein for both gains of 3 pounds per day (medium-framed steer calves) and 3.5 pounds per day (large-framed steer calves and compensating medium-framed yearling steers) were used to estimate parameters for a minimum protein requirement equation. The parameter estimates for determining the minimum protein requirements for steers of a given weight are as follows (t statistics in parentheses below parameter estimates):

$$(12) \quad \begin{aligned} \text{minimum \% protein} &= 29.45 - 0.03824 \times \text{weight} \\ &\quad (41.49) \quad (-16.9256) \\ &+ 0.00002 \times \text{weight}^2. \\ &\quad (11.2756) \end{aligned}$$

This model ($R^2 = 0.99$) is used to calculate the protein required for each quarterly General Algebraic Modeling System (GAMS) run of the cost-minimization program.

The number of days the cattle were fed was estimated by dividing estimated weight gain by the ADGL and then used to set the minimum number of days a steer would be fed:

$$(13) \quad \text{days fed} = \frac{(\text{outweight} - \text{inweight})}{\text{ADGL}}.$$

The total days fed was used to determine yardage costs estimated in the model.

To simulate the cattle feeding series, it was

assumed that steers were placed on feed at 750 pounds (InWeight) and that no therapeutic uses of antimicrobial drugs were banned, even when drug use was at low levels to treat specific symptoms. In the partial-ban scenario, substitute antimicrobial drugs were assumed to be functionally equivalent to and (arbitrarily) twice as costly per unit of drug to use (approximately \$0.036 per day fed) as antimicrobial drugs used in the base scenario (approximately \$0.018 per day fed; Sewell). Functional equivalence is loosely considered to mean drugs currently used that are related to human antimicrobial drugs and that would be most likely banned and have the same or similar effects on growth and feed efficiency as substitute drugs (Sewell; Stock and Mader).

In reality, full functional equivalence is elusive—there are slight differences in the ways antimicrobial drugs function to promote growth and feed efficiency, so they are not likely to be perfect substitutes in practice. These differences in pharmacology would also likely alter cost dynamics between drugs. Data on these cost aspects are not available. However, livestock producers likely use the current drug regimen because it is the most cost effective and substitutes are more costly. The assumption of arbitrarily doubled costs was intended to capture an extreme, in the sense that because other drugs are used less commonly, they must have some disadvantages that make them less desirable. This often translates into higher costs. Most substitutes would not generally be expected to exceed twice the current costs unless there were offsetting advantages to using them.

Estimates for improvements in feed efficiency and growth rates range from no effect to 8% (e.g., Buttery; Preston et al.; Rogers et al.; Stock and Mader; Stock et al.). In this article, the isolated growth rate effect of feeding LLADs to cattle was assumed to be 6% (Ensminger) and was assumed to be captured in ADGL. Feed efficiency effect was assumed to be 4% (Ensminger) and was assumed to be captured in CONVL (Ensminger). Because other estimates could have been justified (Buttery; Preston et al.; Rogers et al.; Stock and Mader; Stock et al.), some sensitivity analysis,

discussed below, was included in the analysis. In estimating the parameters for the growth function imbedded in the cost-minimization model, it was assumed that interactions between growth rate and feed efficiency are captured in the parameter estimated for their cross product ($ADGL \times CONVL$). Prices for Medium No. 1, 800–850-pound feeder steers at Oklahoma City were also included as a regressor (OKSTR800), reflecting input demand aspects.

Price data for grains and other feedstuffs and interest rates used in the actual cost-minimization simulations were obtained from the *Livestock, Dairy, and Poultry Situation and Outlook* (USDA). Feed ingredients used in the cost minimization were grain sorghum, corn, wheat, cottonseed meal, silage, and alfalfa hay. Time series for average prices for silage are virtually nonexistent, so silage prices were calculated on the basis of the price of corn, modified to reflect prices in the range feedlots are known to pay

$$(14) \quad \text{silage price per ton} \\ = \{[(\text{corn price in \$ per bushel}/56) \\ \times 2000]/0.9\} \times 0.2,$$

plus a handling charge of \$30 per ton. The original source for this formula seems to be lost, but it does reflect relative feeding values (e.g., net energy for maintenance) between silage and corn. By algebraically manipulating this equation, a simple silage price equation can be obtained in which

$$(14') \quad \text{silage price in \$ per ton} \\ = 7.9365 \times \text{corn price in \$ per bushel}.$$

As a check, silage price data from Washington (Hasslen and McCall) for 1980–1991 regressed on Washington corn prices (no intercept) yielded a coefficient of 7.9674, which is quite close to the multiplier from the above equation. Yardage costs were assumed constant at \$0.22 per day for the analysis.

Aggregate Analysis

Data needs for the aggregate analysis were minimal. Average annual all-cattle prices for the period 1975 through 1990 were obtained from *Agricultural Statistics* (USDA, National Agricultural Statistics Service). The all-cattle price was used to reflect the fact that aggregate beef production consists of fed steers, fed heifers, cows, and bulls. Fed steers and heifers account for about 85% of total beef production, with the remainder made up of cows, bulls, and other classes of cattle (USDA *Cattle and Cattle on Feed*). These prices were deflated to 1984 dollars per hundredweight (cwt) using the Consumer Price Index (USDA *Agricultural Statistics*).⁴ Average annual commercial beef production for the period 1975 through 1990 was also obtained from *Agricultural Statistics* (USDA).

Rather than estimate elasticities from a more integrated model of the cattle-beef sectors, previous elasticity estimates were relied on for the aggregate analysis. A fed cattle supply elasticity of 0.606 (Marsh 1994) and a Choice slaughter beef demand elasticity of -0.66 (Marsh 1991) were used. In the absence of estimates of a supply shock elasticity, an elasticity of 1.0 was assumed. This choice of a unit elasticity is arbitrary. However, there is some evidence that suggests a tendency for some supply elasticities to converge toward unity in the longer run (Houck). Furthermore, previous studies of livestock supplies have suggested that elasticities (actual or implied), especially in the short run, are generally less than one (absolute value) but are often near one (Aadland, Von Bailey, and Feng; Arzac and Wilkinson; Hayes et al.; Mann and Paulsen; Marsh 1994, 1999; Tryfos; Wade and Barkley). The magnitude of full and partial-ban responses depends on the assumptions made about shock elasticities and some sensitivity analysis was carried out and is discussed below.

⁴ Prices were deflated to 1984 dollars for ease of comparison to the results reported in the CAST analysis.

Results and Discussion

In this section, results for the growth, cost-minimization, and aggregate models are presented and discussed. Some alternative growth models were estimated, to examine the specific impact of the interaction term between growth rate and feed efficiency. In addition, some sensitivity analysis was done to examine the impacts that assumed the effects of drugs on growth and feed efficiency might have on days on feed, OutWeight, and COG. The sensitivity of the results to the supply shock elasticity was also examined. These sensitivity analyses are also presented in this section. The last subsection is a discussion of impacts on the cow-calf sector.

Estimation of the Growth Function

The growth function is specified as an OLS regression with no intercept (below), because if no animal is placed on feed, there will be no meaningful OutWeight, the seasonal dummy variables notwithstanding. Monthly average final finished weights of steers were regressed onto seasonal dummy variables, monthly average feeder steer weights as they went on feed, lagged OutWeight, ADGs for the previous month, dry-matter feed conversion, and average cost of a pound of gain for the previous month. The estimated growth function was

$$\begin{aligned}
 (15) \quad \text{OutWeight,} \\
 &= 20.69189596 \times \text{DSUM} \\
 &\quad (6.527) \\
 &+ 14.93149395 \times \text{DFSPR} \\
 &\quad (4.926) \\
 &+ 0.4362440733 \times \text{INWT} \\
 &\quad (8.732) \\
 &+ 0.5149798668 \times \text{OUTWTL} \\
 &\quad (8.554) \\
 &+ 101.383028 \times \text{ADGL} \\
 &\quad (4.226) \\
 &+ 22.29370642 \times \text{CONVL} \\
 &\quad (3.591)
 \end{aligned}$$

$$\begin{aligned}
 &- 11.42379022 \times (\text{ADGL} \times \text{CONVL}) \\
 &\quad (-4.008) \\
 &- 0.2643742885 \times \text{OKSTR800} \\
 &\quad (-2.928) \\
 &+ 0.8297839118 \times \text{COGL} \\
 &\quad (3.746)
 \end{aligned}$$

The R^2 is 0.761, and the t statistics are in parentheses below parameter estimates. DSUM is a dummy variable designating that the feeding period begins in July. DFSPR is a dummy variable designating that the feeding period begins in April or October. ADGL and COGL are as defined above. As noted above, this model has the added advantage of including an interaction effect between growth and feed efficiency, an effect not seen in previous studies. The interaction parameter estimate is negative and significant, as expected, implying that the combined effects from feeding LLADs are less than the sum of each effect.⁵

One curious note pointed out by a reviewer is the positive coefficient on COG. A direct examination of the Hoelscher data showed a positive correlation coefficient of 0.2847 between COG and OutWeight. There are at least two possible explanations: first, InWeight and OutWeight are also positively correlated ($r = .550$), so heavier cattle are fed to heavier final weights. High COG may reflect the fact that heavier cattle generally gain less efficiently, which tends to raise COG. Also, when feed-stuff prices are high, COGs are high, and often heavier cattle are placed on feed for shorter periods but to heavier final weights.

Some alternative specifications of the growth model were estimated, primarily to see how much effect the interaction term had on the model. The alternate specifications were specified as first- or second-order McLaurin series expansions that served as approximations to observed growth. Among the alternate specifications estimated was one without the interaction term between ADGL and CONVL:

⁵ The estimated model does not exhibit as good a fit as one would like (R^2 statistic), but feeding cattle is fraught with random events, including, but not limited to, weather effects from heat, cold, ice, and mud; disease and injuries; and input price changes during the feeding period.

Table 1. Change in Production Scenarios under Two Antimicrobial Drug Policy Alternatives

	Base "No Ban" Scenario	Full Ban Scenario	Partial Ban Scenario
Average days on feed (days/head)	155.75	168.91	155.75
Average final weight (pounds/head)	1,230.84	1,214.12	1,230.84
Average annual number of pen turnovers	2.34	2.16	2.34
Average annual pounds of finished cattle per head unit of pen space	2,884.47	2,623.61	2,884.47
Percentage change in pounds of production per unit of pen space from base scenario		-9.04	0
Average cost of feed and yardage (\$/head)	233.71	239.96	246.17
Average daily gain (pounds/day)	3.09	2.75	3.09
Average cost per pound of gain (cents/pound of gain)	48.61	54.61	51.19

(16) OutWt

$$\begin{aligned}
 &= 25.91055001 \times \text{DSUM} \\
 &\quad (8.572) \\
 &+ 18.01025978 \times \text{DSPFL} \\
 &\quad (5.874) \\
 &+ 0.4555840894 \times \text{INWT} \\
 &\quad (8.762) \\
 &+ 0.634879069 \times \text{OUTWTL} \\
 &\quad (11.622) \\
 &+ 22.6733202 \times \text{ADGL} \\
 &\quad (1.574) \\
 &- 1.167009998 \times \text{CONVL} \\
 &\quad (-0.541) \\
 &- 0.09606241774 \times \text{OKSTR800} \\
 &\quad (-1.149) \\
 &+ 0.5378000889 \times \text{COGL} \\
 &\quad (2.459)
 \end{aligned}$$

The R² for equation (16) is .737.

Although the R² value changed little between the models with and without the cross product term, ADGL, CONVL, and OKSTR800 were not significant without the cross product, adding credence to the value of the cross product in describing the combined effects of growth and feed efficiency.

Estimating Minimum Costs

GAMS (Brooke, Kendrick, and Meeraus) software was used to solve for minimum cattle feeding costs per head for each quarter over an 11-year period for the base scenario. Forty-

five observations over an 11-year period were felt to be sufficient to obtain some sense of an average ration, especially given that the period (January 1990–January 2001) included record high grain prices, the low grain prices observed more recently, and both low and high points of a cattle cycle.

Given the parameter and final weight estimates from the growth model, it was possible to determine the minimum feeding costs for the three scenarios (base, full ban, and partial ban). These costs are estimated as indicated above by solving Equation (2') through a GAMS feed cost-minimization algorithm.

Impact at the Feedlot Level

Results for the base, full-ban, and partial-ban scenarios at the feedlot level are summarized in Table 1. In the base scenario, cattle are on feed for 155.75 days and are sold at 1,230.84 pounds. Pen space is turned over 2.34 times a year.⁶

Full Ban. A full ban resulted in feeding pe-

⁶ A reviewer pointed out that the turnover rate in this study implies instantaneous space turnover. The same reviewer also pointed out that feedlot occupancy rates of 85% or less are not uncommon. Turnover rates reported herein were intended to imply only that occupancy rates are likely to remain more or less constant. With excess capacity, it is not necessary to instantly refill each pen. It is only necessary to replace cattle sold with new feeder cattle, not an uncommon practice among larger cattle feeders.

riods 8.4% longer and final weights that were 1.4% lower than those for the base scenario. The effect of the lower final weights per head overshadows the effects from the longer feeding periods, with the result that total production per year is lower by just over 9% with the full ban. These results are counter to the increased beef supplies reported in USDA (1978) but are consistent with Mann and Paulsen's results.

Partial Ban. The partial-ban scenario is characterized by increased LLAD costs but essentially no other changes—most notably, no changes in feed efficiency or growth rate. The partial-ban scenario was implemented by doubling the daily cost of the drugs. This was accomplished in the model by increasing daily yardage costs by the increased amount of daily antimicrobial drug costs (discussed above). Not surprisingly, there was no change from the base solution except an increase in total costs for the feeding period. As a practical matter, this means that substituting more costly drugs in a given feeding regime results in an upward shift in the cost function where, initially, the optimal quantities and finished steer weight at the firm level are unchanged from the base solution. In the present study, the method of implementing higher costs for substitute drugs does not allow for substitution of other inputs. Input substitution was thought to be minor for the increased drug costs in the partial-ban scenario, given the relatively high returns to feeding drugs.

Aggregate Effects of the Firm-Level Model

In the aggregate analysis that follows, the firm-level results are expanded to reflect total supplies and adjusted to reflect both the USDA's (1999) estimate that 54.7% of cattle in feedlots are fed LLADs and that about 85% of beef production is from fed cattle. Costs and production for producers in the base scenario are such that both sets of producers, the 54.7% feeding LLADs and the 45% not feeding LLADs, are at equimarginal equilibria, both individually and collectively. That is, both sets of producers are producing where their marginal costs are equal to the market

price for fed cattle. Thus, the only production that is adversely affected initially by a full or partial ban is that produced by those feeding LLADs. In the longer run, producers not currently feeding LLADs will likely expand their production until marginal costs again equal the increased prices. Feedlots generally are not fully stocked at any time, so any adjustments from ban effects could result in some changes in occupancy rates but not any changes in the number of feedlots.

The relationships among supply, demand, and shock elasticities shown in Equation (8) were used to examine the aggregate effects of optimal cattle-feeding strategies under the different scenarios. In this simple partial-equilibrium model, the supply shock from the drug ban, measured as percentage change in quantity of beef produced, generates market responses that affect prices. Estimates of marketwide departures of full- and partial-ban scenarios from the base scenario, based on supply and demand shock elasticities discussed above, are presented in Table 2.

Full Ban. The result for the full-ban scenario, reflecting the USDA's (1999) estimate that 54.7% of cattle in feedlots are fed LLADs, is a 4.21% decrease in aggregate quantity of beef produced. This 4.21% decline in production results in a decline in aggregate beef production from an average of 24.34 to 23.32 billion pounds for 1990 through 1998 with the full-ban policy scenario.

This decline in beef production yields, through Equation (8), a 3.32% increase in the price of cattle from \$45.60 (1984 dollars) per cwt to \$47.12 per cwt. This price increase, in turn, results in a decline of \$113.6 million (1984 dollars) in the aggregate value of live cattle production (Table 2). The loss in consumer surplus, measured as the average of the Paasche and Laspeyre measures, is about \$361 million (1984 dollars).⁷

Although results in the present study are qualitatively consistent with most previous

⁷ Change in consumer surplus = $-(\text{Old price} - \text{New price}) \times (\text{Old quantity} + \text{New quantity})/2 = -(\$0.4560 - \$0.4712) \times (24,343,900,000 - 23,319,930,524)/2 = -\$361,066,286$.

Table 2. Changes to Producers and Consumers under a Full Ban and a Partial Ban Against Low-level Feeding of Antimicrobial Drugs to Livestock^a

	Base Situation	Full Ban Scenario	Partial Ban Scenario
Aggregate average annual quantities			
Baseline (million \$)	24,343.90	24,343.90	24,343.90
Equilibrium with policy (million \$)		23,319.93	24,191.54
Changes in quantities (million \$)		-1,023.97	-152.36
Percentage change		-4.21	-0.63
Prices			
Baseline price (\$/pound)	0.4560	0.4560	0.4560
Equilibrium price with policy (\$)		0.4712	0.4660
Price change (\$)		0.0152	0.0023
Percentage change		3.32	0.49
Aggregate value of production			
Baseline (million \$)	11,100.82	11,100.82	11,100.82
Equilibrium with policy (million \$)		10,987.20	11,085.88
Difference (million \$)		-113.62	-14.94
Percentage change		-1.02	-0.13
Change in consumer surplus (million \$)		-361.07	-54.71

^a Values for this table are in 1984 dollars for ease of comparison with results from earlier studies.

studies, they show less of an effect for cattle than many previous studies have shown for beef. One reason for this difference in results is that many of the previous studies expressed results in terms of higher values of beef observed at the wholesale level compared with live cattle values used here. Another reason for the lower results observed here stems from the expected reduction in effects on feed efficiency and growth rate that comes from the interaction effect incorporated into the model estimated herein. Comparing results in this study with the first-year estimates reported in the Council for Agricultural Science and Technology (CAST) summary of early studies (CAST Table 45), which they present in 1979 dollars, only Mann and Paulsen found a smaller change in consumer surplus (\$193 million) compared with results herein (\$252 million in 1979 dollars). Other higher results from the CAST report ranged from \$749 million to a high of \$3.7 billion (1979 dollars), although most estimates from the studies were in the range of just over \$1 billion.

Consistent with most other authors, constant consumer demand functions—that is,

movements along the demand function, rather than shifts in the demand function—were assumed in the present study. However, Wade and Barkley assumed that demand for meat would shift to the right because of perceived health benefits derived from not feeding LLADs. To the contrary, one could expect more diseases to infect livestock herds and more product contamination from livestock produced under a ban on LLADs (USDA 1999).

Partial Ban. Using the same general methods to estimate the economic changes for producers and consumers from a partial ban on LLADs fed to livestock as enhancers of growth and feed efficiency requires the following modifications. First, quantities supplied are assumed to adjust, to be consistent with an equilibrium price that reflects the increased cost. Thus, for the partial ban, the change in price is attributed directly to the estimated change in cost, and from the percentage change in price a percentage change in the market-clearing quantity of beef produced is calculated. This is accomplished by inverting Equation (6) and solving for the percentage

change in quantity of beef produced. Performing this inversion and inserting assumed and estimated values yields a quantity change of -1.29% for a 0.49% change in price.

In the partial-ban scenario, producers' aggregate income decreases by almost \$15 million (Table 2). Income decreases only to those producers who are restricted in their use of antimicrobial drugs. Other producers not using antimicrobial drugs in the first place gain because they reap the full benefit of the higher prices. Consumer surplus decreases by \$54.7 million. Mann and Paulsen also observed a relatively small price increase (\$0.93/cwt initially) and higher costs to consumers. Aggregate effects observed in other studies ranged from no significant effects (Allen and Burbee) to a decline of 15% (USDA 1978).

Sensitivity Analysis

Because aggregate results of this analysis depend on assumed values for growth at the firm level, feed efficiency, and the aggregate supply shock elasticity, some sensitivity analysis was carried out with respect to these assumptions. These results are presented in Tables 3 and 4. For growth and feed efficiency (Table 3), the average results from the runs for the full ban were run iteratively, using the initial base run as the lagged values with one iteration. Because of this iterative procedure, results in Table 3 do not match exactly the results presented earlier for 4% growth enhancement and 6% feed efficiency gain. Differences in OutWeight and COG were minor. Days fed appeared to increase from low feed efficiency enhancement values, peak, then decline, being lowest for either no enhancement effects or for high feed efficiencies, where they approached the base value. Aggregate results (Table 4) changed with the size of the assumed supply shock elasticity but remained below a billion dollars until elasticities reached a magnitude three times the value assumed for the main analysis.

Impacts on the Cow-Calf Sector

The positive price changes for fed cattle in response to the reduced supplies due to a ban

would imply increased prices for feeder cattle (Marsh 1994). The initial response by cow-calf producers to increases in feeder cattle prices would be cow herd expansion by retaining some heifers that would have gone to feedlots. Initially, holding heifers would decrease supplies of fed cattle more, contributing to further price increases (Aadland, Von Bailey, and Feng; Jarvis). On the basis of an intermediate-term elasticity of 1.167 (Marsh 1994), the quantity of feeder cattle demanded would increase by 3.87% in response to the 3.32% fed-cattle price rise observed in the present study. This 3.87% increase in feeder cattle demand would not be burdensome to a feeding infrastructure already below capacity.

Ramifications could extend from the feeder-cattle sector into the cow-calf sector, especially in the shorter run. With 92% calf crops (USDA 1998), the cow herd would need to expand by 4.2% to be able to meet the extra 3.87% of feeder cattle demanded in the intermediate run. Marsh's long-term elasticity was large, 3.12, which implies the potential for quite an adjustment in the cow herd. Once heifers retained for expansion began contributing to future calf crops, the effects would reverse, and cattle supplies would increase.

However, there are two responses to a ban because there are two sets of cattle feeders—those feeding antimicrobial drugs before the ban and those not feeding drugs before the ban. Each set of cattle feeders would view the drug ban differently. To the extent that the response of LLAD feeders would be moderated by the response of non-LLAD feeders, the long-term response would likely be less than Marsh's long-term elasticity would imply. As the first group of cattle feeders (those who saw their input costs increase because of the ban) reduced their demand for feeder cattle, those feeders who had not fed antimicrobial drugs before the ban would observe increasing prices for their fed cattle, because they would incur no ban-induced changes in either their production technologies or their production costs. Thus, demand for feeder cattle from the no-drug cattle feeders would increase in response to higher prices for their products. In the longer run, feeder cattle demand from the first

Table 3. Sensitivity of Selected Feeding Output to Assumed Drug Effects on Growth and Feed Efficiency

Drug Effect on Growth (%)	Drug Effect on Feed Efficiency (%)				
	0	2	4	6	8
Days on feed					
0	155.75				
2		157.29	160.03	156.50	155.53
4		163.72	162.78	161.84	160.90
6		169.37	168.47	167.56	166.71
8		175.40	174.54	173.67	172.81
Out weight					
0	1,230.84				
2		1,216.77	1,224.90	1,214.42	1,211.53
4		1,217.33	1,214.65	1,211.96	1,209.27
6		1,215.39	1,212.90	1,210.41	1,208.07
8		1,214.28	1,211.99	1,209.70	1,207.41
Cost of gain (feed, handling, and yardage: \$/cwt)					
0	48.61				
2		50.55	50.55	50.55	50.55
4		52.55	52.55	52.55	52.55
6		54.59	54.59	54.59	54.59
8		56.67	56.67	56.67	56.67

group, facing higher post-ban costs, could return to preban levels as these cattle feeders adjusted to the new production paradigm or were replaced by feeders not feeding drugs. Because about half of fed cattle now receive antimicrobial drugs in feed and half do not, the overall effect on the cow-calf industry

could actually be small or ambiguous in the longer run.

Conclusions and Implications

The potential for antimicrobial-resistant diseases to pass between animals and humans in-

Table 4. Sensitivity of Aggregate Results to Assumed Supply Shock Elasticity

Assumed Supply Shock Elasticity	Price Effects (% Change)	Changes from Base Quantities (Million Pounds)	Producer Effects (Million \$1984)	Consumer Effects (Million \$1984)
0.2	0.69	-213.41	-21.12	-76.53
0.4	1.38	-426.81	-43.59	-152.38
0.6	2.08	-640.22	-67.40	-227.57
0.8	2.77	-853.62	-92.57	-302.07
1.0 ^a	3.46	-1,067.03	-119.08	-375.91
1.2	4.15	-1,280.43	-146.94	-449.07
1.4	4.85	-1,493.84	-176.14	-521.55
1.6	5.54	-1,707.24	-206.70	-593.37
2.0	6.92	-2,134.05	-271.85	-734.97
3.0	10.39	-3,201.08	-458.31	-1,077.19

^a Elasticity assumed in this study.

creases with the aggregate use of antimicrobial drugs in livestock production. Incorporating LLADs in livestock feeds is thought to be a leading factor stimulating the development of antimicrobial-resistant bacteria and other pathogens found in livestock. Enough evidence has accumulated that the practice of incorporating LLADs in livestock feeds has been outlawed in several countries, and bans have been seriously considered in the United States as a precautionary measure against the spread of resistant, zoonotic pathogens. The Food and Drug Administration has recently tightened antibiotic testing measures by adopting a framework for evaluating and assuring the human safety of the antimicrobial effects of new animal drugs intended for use in food animals (Bernick). In addition, several groups in the United States have recommended that LLADs be banned (e.g., Richwine), and legislation to that effect has been introduced in the U.S. Congress on more than one occasion (H.R. 3266, introduced November 9, 1999; H.R. 3804, introduced February 27, 2002; and Senate 2508, introduced May 13, 2002). To proceed with these policy alternatives, it is important to understand the ramifications of each policy. This article contributes to that understanding by updating and extending previous studies by allowing output, costs, and feeding periods to vary and by more appropriately modeling drug-feed-growth relationships.

In this analysis, livestock production costs increase through increased feed costs due to reduced feed efficiency and lower growth rates or higher drug costs. Costs could increase in other ways as well. For instance, increased management and labor requirements aimed at preventing disease outbreaks and increasing animal performance without antimicrobial drugs could increase costs. Costs for physical plants could increase as less intensive technologies like pasture systems for hogs, range-fed cattle, and other more dispersed production methods, some of which are older technologies, are used under ban scenarios.

If a ban against using low-level antimicrobial drugs in livestock production as growth promotants were imposed, it is unlikely that the fed cattle sector would be the only sector

subjected to the ban. It is likely that a drug ban would be imposed on antimicrobial drugs used for all livestock species simultaneously. All livestock species would face similar economic effects, with some livestock sectors being more affected than others. Estimates of cross-price (demand) elasticities between beef and other livestock commodities are generally low (Hahn), and low cross-elasticities and near-zero homogeneity effects on all livestock species would suggest relatively minor changes in quantities substituted among livestock commodities.

Hayes et al. described the situation in Sweden, where antimicrobial drugs have been banned since 1986. In Sweden, "[t]he prevalence of [swine] influenza is very low, and there is virtually no salmonellosis . . ." (Hayes et al., p. 18). Even though there are other factors that contribute to these results in Sweden, these observations suggest that banning drugs, although having some locally severe short-term consequences, might have little or no effect on livestock production in the long run. Even in U.S. beef production, only about 45% of production is from feedlot cattle fed (or watered with) antimicrobial drugs at low levels. Other studies support the possibility that partial drug bans would have little effect on at least some livestock sectors (Algozin, Miller, and McNamara; Emborg et al.). Studies that have examined longer-term effects show declining annual effects from drug bans due primarily to assumed intra-sectoral adjustments (Allen and Burbee; Dworkin; Gilliam et al.; Hayes et al.; Headley; Mann and Paulsen; USDA 1978).

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