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Economic Impacts of Banning Subtherapeutic Use of
Antibiotics in Swine Production

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*Paper presented at the Western Agricultural Economics Association Annual
Meetings, Logan, Utah, July, 2001.*

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Economic Impacts of Banning Subtherapeutic Use of Antibiotics in Swine Production

Public health officials and physicians are concerned about possible development of bacterial resistance and potential effects on human health that may be related to the use of antimicrobial agents in livestock feed. The focus of this research is aimed at determining the economic effects that subtherapeutic bans of antimicrobials would have on both swine producers and consumers. The results show that a ban on growth promotants for swine would be costly, totaling \$242.5 million annually with swine producers sharing the larger portion in the short run and consumers sharing about 75% in the long run. If a ban affected poultry as well as pork production, the total costs would expand to \$586 million per year with swine producers sharing about the same as in bans for swine only and consumers sharing significantly more than the swine only case.

Key words: banning subtherapeutic use, feed efficiency, mortality rate, sort loss at marketing.

Food animal production in the United States uses antimicrobial agents to promote animal welfare and to enhance the efficiency of livestock production. Of the total antibiotic production for both human treatment and animal purposes, approximately 25% is used in food animals and 90% of that portion has been reported as being used in subtherapeutic concentrations for disease control and as growth promotants.

Antimicrobial agents have been added to feed and used extensively in swine production since their introduction in the early 1950's (Radostits). Swine performance is potentially improved by using subtherapeutic concentrations of any of the 12 currently available antibiotic or chemotherapeutic drugs that are approved for use in hogs with claims for increased rate of gain or improved feed conversion (FDA). Because of the economic benefit to producers, antimicrobial drugs are used in about 90% of the starter feeds, 75% of the grower feeds, and over 50% of the finisher feeds (Cromwell).

Growth promotant or subtherapeutic use of antimicrobials administered in animal feeds has been strongly criticized as a serious public health threat causing life-threatening

infections that are resistant to antimicrobial therapy (Angulo; Witte). This concern has developed around the following issues: (1) subtherapeutic use of antimicrobials in animal feeds creates antimicrobial-resistant bacteria; (2) if subtherapeutic use were eliminated, the level of resistance of bacteria harbored by animals would be reduced; and (3) reduced resistance to antibiotics in animals would improve human health because the potential for transmitting antibiotic-resistant bacteria from animals to humans would be reduced (National Research Council 1998). However, in spite of these claims, which have been considered more speculation than fact, there appears to be no clear-cut, definitive answer regarding whether subtherapeutic use causes resistance and adverse effects on human health. Nonetheless, it appears that human health officials are moving towards the withdrawal of antimicrobials that are used for growth promotants in animals if these drugs are also used for human therapeutics (Herrick).

The Animal Health Institute has estimated that growth promotants save hog producers an estimated two billion dollars in annual production costs. However, not all swine producers rely on these compounds to the same extent. Responses to subtherapeutic uses of antimicrobials tend to be more positive when pigs are raised under less than ideal conditions. Therefore, it is likely that producers who have good management practices would not be as greatly affected by a ban as producers with less desirable management systems. It has been suggested that a ban on subtherapeutic drug use could ultimately improve animal care and improve industry efficiency, but the process to achieve that result could be painful for those producers who are unable to adopt improved management practices and are forced out of business. The overall effect of a ban on antimicrobial drugs used as growth promotants, including the need to adopt

technological improvements to obtain equal levels of production, would likely be an increase in costs and higher meat prices.

Earlier studies on the economic impacts of bans on antimicrobial use in swine production were conducted in the 1970's and indicated an increase in the market price of pork and a 4 to 20% reduction in the quantity of pork supplied to the market (Burbee; Gilliam). Shifts in technology and changes in management systems would likely alter these results that were obtained more than 20 years ago.

In two of the more recent economic studies dealing with the ban on subtherapeutic antimicrobials in swine production, a basic assumption was made that would appear to seriously flaw the results of these reports (Manchanda; Wade and Barkley). Both of these studies assumed that there would be an increase in the demand for pork of 5% because of perceived improvements by consumers that pork produced under these bans would be more wholesome and less likely to contain antibiologic residues. This assumption seems to be unfounded because further decrease in the extremely low level of current antibiotic residue rates would be unlikely. Because of this assumption, the study by Wade and Barkley reported net economic gains for both producers and consumers due to the proposed ban on antibiotics.

The most recently published economic evaluation (National Research Council 1998) of the effects of a ban on subtherapeutic use of antimicrobials in swine production also included some assumptions and methods that were questionable. This study assumed that there would be no change in consumption with a concomitant increase in the market price of meat. No elasticity measurements were included in this study that would make adjustments for changes in consumer demand due to price increases and provide for

economics changes related to substitution effects among competing goods, such as beef or poultry.

The current climate of increased regulatory pressures by health officials and notable deficiencies or flaws in previously reported studies on the economic impact of restricted antimicrobial use policies indicate the need to obtain better quality information about this potential economic problem facing the U.S. pork industry.

The objective of this study is to develop useful economic estimates of the impact of potential restricted-use policies for antimicrobial agents used in swine production as growth promotants. By using a model similar to that used by Wohlgenant, the economic impacts of banning antimicrobials agents in swine production are measured by the changes in producer's and consumer's surplus.

Estimation of the Surplus Changes from the Bans of Antimicrobials

A model used by Wohlgenant allows for feedback effects between the beef and pork markets, and can be used to measure the changes in producers' and consumers' surplus due to the shifts in both demand and supply curves. Our purpose is to measure the changes in producers' and consumers' surplus in the three commodity markets due to the bans of antimicrobials in swine production. We thus need to modify the model in two dimensions: we extend the two commodity model to a three commodity model; we set the parameters corresponding to the shifts in demand curves equal to zeros and only consider the effects of the shifts in the supply curves due to the bans. Explicitly, our modified model is

$$Q_j^* = \eta_{j1}P_1^* + \eta_{j2}P_2^* + \eta_{j3}P_3^* \quad (1a)$$

$$P_j^* = S_j W_j^* \quad (1b)$$

$$X_j^* = -(1 - S_j) \sigma_j W_j^* + Q_j^* \quad (1c)$$

$$W_j^* = (1/\varepsilon_j) X_j^* - k_j \quad (1d)$$

$$j = 1, 2, 3.$$

where asterisks denote approximate relative changes (i.e. $X^* = dX/X$), subscript 1, 2, and 3 denote beef, pork, and poultry respectively, Q represents quantity of retail product, P is retail price, X is quantity of farm product, W is farm price, η_{ji} is the elasticity of demand for the j th retail product with respect to price of the i th product, σ_j is the elasticity of substitution between the farm product and marketing inputs in producing the j th product, S_j is the farmer's cost share of the j th retail product, ε_j is the elasticity of supply of the j th farm product, and k_j is the relative decrease in production cost for the j th farm product.

Once the parameters in (1) are given, the values of the variables with asterisks can be determined by solving the equations simultaneously. Using the total farm revenue and total consumer expenditures, changes in producers' and consumers' surplus can be calculated as

$$\Delta PS_j = W_j X_j (W_j^* + k_j) (1 + 0.5 X_j^*) \quad (2a)$$

$$\Delta CS_j = -P_j Q_j P_j^* (1 + 0.5 Q_j^*) \quad (2b)$$

$$j = 1, 2, 3$$

where ΔPS denotes the change in producer's surplus, ΔCS denotes the change in consumers' surplus. The total farm revenue $W_j X_j$ and total consumer expenditures $P_j Q_j$ are predetermined.

All parameters necessary to apply the equations in (1) and (2), except the parameter representing the change in production costs, will be from other researchers' results

(Wohlgenant, Brester and Schroeder). The production cost change parameter k is determined by simulations illustrated as follows.

Production Cost Changes Due to Banning Use of Growth Promotants

The production cost changes due to banning use of growth promotants are measured indirectly by the net benefits from using growth promotants. Three key components were identified as the most important for contributing potential economic advantages for growth promotant use at the producer level: a) improved feed efficiency over drug cost, b) reduced mortality rate, and c) reduced sort loss at marketing. The net economic benefit for growth promotants in swine production is the sum of these components. The per animal net benefits are then used to calculate the net benefit at the industry level.

Economic Benefit from Improved Feed Efficiency Over Drug Cost

The stochastic relationship between the economic benefit per pig and the improvement in feed to gain conversions (F/G) in swine production is modeled as

$$\text{Economic Benefit} = \alpha + \beta(\text{Improvement in } F/G) + \varepsilon \quad (3)$$

where α and β are the parameters to be estimated, ε is a random variable with zero mean. Improvement in F/G is a random variable with a probability distribution to be determined.

Scientific literature was reviewed to determine the probability distribution of the improvement in F/G , and the parameters α and β . This literature search provides the data shown in Table 1. Reports were restricted to feeding trials using antimicrobial compounds that are presently available for use in swine; reports on those compounds

under development or not yet approved for use by FDA in swine feed were excluded. Data from feeding trials limited to extremely brief periods of the production cycle, such as those associated with segregated early weaning programs, and from the report based upon producer surveys instead of actual feeding trials were excluded from calculations.

Improvements in feed-to-gain ratio (F/G) for subtherapeutic levels of antimicrobials were reported as ranging from -1% (a decrease) to 5% or greater for grower/finisher hogs. The mean improvement in F/G was 2.74% with a standard deviation of 1.88% based upon 16 different values in the literature from feeding trials covering significant periods of the grower/finisher phase of swine production. These data best fit a normal distribution compared to alternative distributions (see Figure 1). Thus F/G is assumed to follow a normal distribution with 2.74 as the mean and 1.88 as the standard deviation.

A linear regression is used to determine the parameters α and β . Economic values derived from drug use during extremely brief periods of the production cycle or from therapeutic dose rates were excluded from the regression analysis. The regression based on the data in Table 1 shows the following estimated equation.

$$\text{Economic Benefit} = 1.68 + 0.66 (\text{Improvement in } F/G) \quad (4)$$

(0.42) (0.14)

$$R^2 = 0.85$$

This result is used to estimate the economic benefit per pig from the improvement in F/G .

Economic Benefit from Reduced Mortality Rate

Subtherapeutic use of antimicrobials affects mortality rates, especially on younger pigs, although these effects are not well documented. Unpublished data from 67 experiments

conducted on swine farms over a 23-year span indicated an overall improvement in mortality rates of 2% for pigs receiving antibiotics as growth promotants (Zimmerman 1986). Only two of the published reports in Table 1 provided data about differences in mortality rates associated with the use of antimicrobial agents. Walter, Holck, and Wolff (1999) evaluated therapeutic levels of tiamulin and chlortetracycline fed from 11 weeks of age for a period of 16 weeks to more than 1,000 modern crossbred lean genotype barrows in a commercial swine production system. Treatments were divided among continuous delivery of medication in feed, “pulse” delivery of medication for seven days administered every two or three weeks, and a nonmedicated control group. Mortality rates for pigs in these groups were 0.55, 1.92, and 5.22% respectively, with both medication groups having significantly less mortality than controls. Gourley (1998) evaluated low-level continuous and high-level “pulse” (one week out of four) medication regimens for delivering chlortetracycline in feed to 576 grower/finisher pigs from a lean genotype, high health swine herd. The third treatment was a nonmedicated control group. The mortality rates for the three treatment groups were 2.60, 2.08, and 3.13% respectively. Although there was an advantage for pigs receiving medication, none of these mortality differences in this study was significantly different. In view of the fact that, from the two published reports, the average mortality difference between the treatments is 1.43%, we model the mortality benefit associated with growth promotants as a symmetric triangular distribution with minimum 0, most likely 0.75, and maximum 1.5%.

The market price used for hogs is \$45.00 per cwt. This price is based on an approximate ten-year average market hog price (Walter 1999). Then market price of hogs

is used indirectly to establish value of 40 lb feeder pigs needed to calculate benefits associated with reduced mortality rates. Using current feeder pig pricing schedules as a guideline (USDA Iowa Department of Agricultural Market News at http://www.ams.usda.gov/mnreports/NW_LS255.txt), we also assume that heavier feeder pigs are worth \$0.45 per pound for additional weight over 40 pounds. Weights of pigs associated with the risk of dying that could be reduced due to feeding growth promotants is modeled as with minimum value 40, most likely value 60, and maximum value 80 lb respectively.

Economic Benefit from Reduced Sort Loss at Marketing

When the weights of market hogs fall outside of the packer' specified weight range, pricing discounts are applied, especially for lighter hogs, based on price schedules or "grid" pricing. The term "sort loss" has been used by the swine industry to describe the dollar loss related to these market hogs, which receive price discounts. Growth promotants improve the uniformity of average daily gain, and, therefore, reduce the ending weight variability and associated sort loss for market hogs (Tillman 1996; Gourley et al. 1997; Gourley 1998). The size of the sort loss benefit would vary according to the type of feeding management. Production systems using targeted days on feed would achieve potentially greater benefits related to reduced sort loss compared to targeted marketing weight management systems because the time schedule for a targeted days system would typically provide less opportunity for delayed marketing to allow additional gain for lighter weight pigs. A report by Tillman (1996) provided data on average ending weight and standard deviations for the effect of a growth promotant on

reducing sort loss in market hogs compared to a control group based on a targeted days on feed production system. The normal distribution function was used to determine cumulative proportions within each group as inputs for calculating differences in distributions between these two groups. Sort losses at slaughter were based on grid pricing discounts announced by Farmland for underweight hogs (Table 2). These data provide an overall mean value of \$1.39 with standard deviation of \$0.15 per hog benefit for growth promotants in reducing sort loss for targeted days production systems. It is assumed that this benefit would be only one-third as much, i.e. mean \$0.46 with standard deviation \$0.05, for hogs produced under targeted weight production systems because of increased opportunity to allow longer feeding periods to achieve desired market weights, which would reduce the chance of price discounts. No benefits were included for any reduction in days on feed associated with the use of growth promotants.

Estimating the Total Net Economic Benefits at Industry Level by Simulation

As outlined before, the total net economic benefits from using growth promotants are from three random sources, i.e. normally distributed improvement in F/G , triangularly distributed reduced mortality rate, and normally distributed reduced sort loss at marketing. To estimate the total economic benefits, we need convert the scale from producer level to industry level.

The number of market barrows and gilts slaughtered per year is extrapolated from annual USDA livestock slaughter summary reports for years 1994-2000 (National Agricultural Statistics Service, Agricultural Statistics Board, USDA). These summaries report figures ranging from 86.5 to 96 million head for years 1996 and 1999 respectively.

Based on these data, an annual production of 100 million market barrows and gilts is assumed for the simulation.

The proportion of grower/finisher pigs receiving antimicrobials as growth promotants and the proportion of grower/finisher pigs managed as all-in/all-out are based on population estimates from the Swine '95 project (USDA, APHIS, VS, CEAH 1995) (see Table 3). We project that 85% of grower/finisher pigs would receive growth promotants in feed and that 55% of hogs would be raised in an all-in/all-out grower/finisher system.

Once the probability distributions of three sources of economic benefits at industry level are given, the total net economic benefits are estimated Monte Carlo simulations on each of the three components and summarizing them together. The expected net benefit could have been approximated with analytical methods by assuming normality. The Monte Carlo method accommodates nonnormal distributions and provides a convenient way of calculating the uncertainty of the estimate.

Results

Based on a 5,000 iteration simulation, the total estimated net benefit for subtherapeutic use of antibiotics in swine production was calculated as $\$2.76 \pm \0.56 per hog as determined by the previously described components. Although a wide spread in the value of this benefit was possible, the majority of values most likely to occur would range from $\$2.37$ to $\$3.11$ per hog (Figure 2). The average benefit of $\$2.76$ per hog was used to calculate the proportional change in production costs for the swine industry and the resulting impact on economic values related to changes in supply and demand of pork in

the U.S., if the use of subtherapeutic antibiotics in feed were banned. If the resulting change in cost of pork production is lower or higher than assumed, all numbers change proportionately. The calculated average increased cost of production of \$2.76 per hog due to loss of the net benefits associated with growth promotants was considered to be the best estimate for figuring the cost change listed in Table 4. The number of hogs marketed per year is estimated as 100 million heads. All price elasticities in Table 4 are Marshallian.

Given all parameters and data in Table 1, the variables with asterisks in equation (1), i.e. the retail products, retail prices, farm products, and farm prices for the three commodities, are obtained by solving the simultaneous equations (1). Substituting the solution for (1) into (2), we obtained changes in producer's and consumers' surplus. By setting specific parameters equal to zeros, the changes in producer's and consumers' surplus obtained are the ones due to banning subtherapeutic antibiotics in swine only or both swine and poultry production.

The total annual loss in short run would be \$242.5 million (the sum of the first row in Table 5) if the ban on antimicrobials as growth promotants were on pork alone and \$673 million (the sum of the second row in Table 5) if the ban were applied to pork and poultry. Table 5 shows that in the short run, the estimated loss borne by swine producers would \$153.5 million if the ban were only on swine production and \$149.6 million if the ban is across pork and poultry. In the long run, the total losses will be similar, \$242.4 million and \$586 million respectively, but consumers would bear more of the cost. In the long run the swine producer surplus lost will be \$62.4 million if the ban is only on pork and \$59.7 million if the ban is across pork and poultry. Because of the low price elasticity

between pork and poultry, it does not make much difference to swine producers as to whether the ban included swine only or also included poultry.

Conclusion

A ban on the use of antimicrobial agents as growth promotants for swine would be costly, totaling \$242.5 million annually with swine producers bearing \$153.5 of the cost in the short run. In the long run, consumers would bear about 75% of the total cost. If a ban affected poultry as well as pork production, the total losses would expand to about \$586 million per year with larger portion of the cost bear shifted from the producers in the short run to the consumers in the long run. Based on a 30-year planning horizon and a 4% discount rate, the net present value of these increased costs would be \$8.4 billion and \$11.6 billion, respectively, for a ban that would affect pork or both pork and poultry production.

It should be noted that wide ranges of published elasticity estimates were available. The elasticity estimates determined whether producers or consumers incurred the cost of the ban. Because neither pork nor poultry production uses many resources that are specialized and fixed in the long run, their supply curves are likely very elastic in the long run.

The estimates of the total cost of banning subtherapeutic antimicrobial use in swine and poultry were roughly half of that estimated by Committee on Drug Use in Food Animals (National Research Council 1998). The main difference was that they assumed that marketing cost would increase proportionately to any change in production cost while this model held marketing costs constant.

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Table 1. Reported Effects of Growth Promotants Fed to Swine on Feed Efficiency and the Associated Economic Benefits.
(F/G = feed to gain; NR = not reported)

Drug	% Improve-ment in F/G ratio	Net economic advantage (\$/pig)	Comment	Used to estimate improve-ment in F:G ratio?	Author & year
Carbadox Tiamulin + Chlortetracycline	5.60	1.36	Early weaning period only	No ^c	Anderson, Campbell J, and Walter D (1997)
Carbadox	7.50	2.66		No ^c	
Tiamulin	6.90	NR	To 35 kg	No ^d	Cromwell and Stahly (1985)
Tiamulin	5.70	NR	To 30 kg	No ^d	
Tiamulin	3.10	NR	To 57 kg	Yes	
Chlortetracycline	1.72	2.17 ^a	Grower/finisher	Yes	Gourley (1998)
Chlortetracycline	4.50	NR	Historical data	Yes	
Chlortetracycline	1.03	2.12 ^a	Dose: 50g/ton	Yes	Gourley and Wolff (1997)
Chlortetracycline	0.34	1.86 ^a	100g/ton	Yes	
Bambermycin	3.74	NR	Five different locations	Yes	Hagsten et al. (1980)
Tylosin	2.30	NR		Yes	
Chlortetracycline	-6.42	NR	Producer survey	No ^e	Losinger (1998)
Tylosin	5.00	4.88 ^a	Commercial farms	Yes	Mackinnon (1987)
Carbadox + Virginiamycin	5.47	NR	NRC diet	Yes	Schwartz (1997)
Virginiamycin	3.51	4.85 ^a	High density diet	Yes	
Chlortetracycline	-0.67	NR	Seven-state study	Yes	Speer (1982)
Various	-0.33	NR	Six-state study	Yes	

Tylosin	4.57	NR	Dirt lots	Yes	
Bacitracin	3.30	NR	Analysis of 85 trials	Yes	Tillman (1996)
methylene disalicylate	2.40	NR	High lean genetics	Yes	
Tiamulin + Chlortetracycline	3.80	3.87 ^b	Lean genotype pigs	Yes	Walter, Holck, and Wolff (1999)

^a Economic data that was used to develop association with corresponding improvements in F:G ratio.

^b Economic data was not used because antimicrobials were fed at therapeutic rates.

^c Data was limited to early weaning period

^d Data was limited to only a portion of the grower/finisher phase.

^e Data was developed from a producer survey and not based upon feeding trials.

Table 2. Sort Loss Discounts for Underweight Hogs and Differences in Distributions Between Market Hogs for Growth Promotant Use Based Upon Targeted Days (All-In/All-Out) Production System.

Estimated Live Weight Range	Hot Carcass Weight Range	Carcass Midpoint Used for Calculations	“Sort Loss” (Discount) ^a	Estimated Distribution of Market Hogs by Use of Growth Promotants ^b (%)		Difference in Distributions (%)	Difference in Carcass Discounts(\$)
				Without	With		
under 190	under 140	137.0	(\$13.50)	7.61	3.59	4.02	0.743
191-200	141-148	144.5	(\$13.50)	6.14	4.27	1.87	0.365
201-210	149-155	152.0	(\$9.76)	8.87	7.31	1.56	0.231
211-220	156-163	159.5	(\$6.00)	11.42	10.82	0.60	0.058
221-229	164-169	166.5	(\$1.26)	11.77	12.34	-0.58	-0.012
230-240	170-177		BASE PRICE				
Totals:						7.47	1.385

^a Per scalded carcass cwt using grid pricing discounts for underweight hogs from America’s Best Pork[®] Carcass Merit Program (Farmland) [effective 7/16/2001].

^b Distributions were based upon data for average ending weights and standard deviations (232.1 ± 29.40 lb and 236.7 ± 25.94 lb for control and growth promotant groups, respectively) reported by Tillman (1996). The normal distribution function was used to determine cumulative proportions for each weight range within each group as inputs for calculating differences in distributions.

Table 3. Management of Swine Farms Related to Growth Promotant Use in Grower/Finisher Pigs and Prevalence of All-in/All-out Production System.

Swine '95 report		
	Mean	s.e.
Growth Promotant Use		
Percent of swine operations	91.3	2.0
Percent of grower/finisher hogs on those operations	92.7	1.5
Percent of pigs receiving growth promotants	84.6	
Input used for simulation model	85.0	2.0
Grower/Finisher Management		
Percent hogs, all-in/all-out production system	51.0	2.2

Sources: U.S. Animal and Plant Health Inspection Service, Veterinary Services, Centers for Epidemiology and Animal Health. *Swine '95*. Part 2: Reference of 1995 U.S. grower/finisher health & management practices and Part 3: Changes in the U.S. pork industry, 1990-1995. Fort Collins, CO: Centers for Epidemiology and Animal Health, USDA, 1995.

Table 4. Estimates of Parameter Values for the U.S. Beef, Pork and Poultry Industries

	Value		
	Beef	Pork	Poultry
Price elasticity of demand for beef (η_1)	-6	.1	.21
Price elasticity of demand for pork (η_2)	.14	-.35	.04
Price elasticity of demand for poultry (η_3)	.05	.07	-.3
Elasticity of substitution (σ)	.72	.35	.35
Elasticity of farm supply, short run (ϵ_{SR})	.15	.2	.2
Elasticity of farm supply, long run (ϵ_{LR})	.70	1	1
Farmer's share of consumer's dollar (S)	.49	.4	.4
Increase in production costs ^a (k)	0	.02023	0 ^b
Total farm revenue (WX)	\$35 bil.	\$12 bil.	\$17 bil.

^a The proportional change in production costs was calculated as:

- increased production cost per hog due to growth promotant ban = \$2.76
- \$2.76*84.6% utilization of growth promotants = \$2.33 per hog for industry
- weight of one pig = 256 lb. = 2.56 cwt
- market value per pig = \$45/cwt*2.56 = \$115.20
- production cost increase = \$2.33/\$115.20 = 2.023%

^b When a ban is assumed to affect both pork and poultry, the increase in production costs is .02023.

Table 5. Change in Producer and Consumer Surplus from Increase in Production Costs Due to Banning Subtherapeutic Antibiotics in Swine Only or Both Swine and Poultry Production (\$ Million)

Situation	Producers			Consumers		
	Beef	Pork	Poultry	Beef	Pork	Poultry
Ban, short run						
Pork only	14.3	-153.5	7.0	-14.3	-89.0	-7.0
Pork & poultry ^a	42.7	-149.6	-206.0	-42.7	-92.9	-137.6
Ban, long run						
Pork only	16.1	-62.4	5.5	-16.1	-180.0	-5.5
Pork & poultry ^a	49.3	-59.7	-79.3	-49.3	-182.7	-264.3

^a The same percentage increase in cost for pork was assumed for poultry. No change in cost of beef production was assumed.

Figure 1. Distribution of Improvement in Swine Feed Efficiency Due to Growth Promotants

