The Complexity of Food Safety Regulation

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Food safety regulation and policy involves a complex network of issues. Roberts and van Ravenswaay (1989) state that the United States Department of Agriculture (USDA) now considers cost and benefit information essential for effective food safety policy evaluation and development. However, this information alone may not be enough for the development of socially optimal policies. Issues such as the market structure in the input and output markets, the opinion formulation process of consumers, and the administrative costs and technical problems with food safety regulations must also be considered. These issues need incorporation into food and safety policy. Policies formulated on incorrect assumptions or incomplete information could actually lead to reductions in the safety of the food supply.

An example of this complexity is antimicrobial usage in food animal production. Potential food safety and public health effects related to antimicrobial usage by livestock producers are of concern to the public. This debate continues through television documentaries, newspaper and magazine articles, and research reports from governmental agencies. An accessible, well-balanced example is a recent article by Karen Wright in the journal *Science* (Wright). However, the extensive reports and studies have not yet yielded expert consensus on hazards posed by antimicrobial usage in livestock production (Institute of Medicine). The prevalence of antimicrobial usage in livestock production (Hays, Batson, and Gerrits; Hagstad and Hubbert; Institute of Medicine), shows that it is regarded as an effective method of boosting productivity and a necessary complement to other disease control measures. A goal of this paper is an improved general understanding of complex policy interactions involved in food safety issues. We discuss the effectiveness and efficiency of various policy alternatives regarding the technical, biological, financial, and institutional relationships in the livestock production and animal pharmaceutical industries. The issues covered in this paper fall into two main areas—antimicrobial residues and antibiotic resistance.[1] We present a different set of policy alternatives for each issue.

Antimicrobial Residues

An antimicrobial residue can be defined as the presence of an antimicrobial compound in animal tissue. If the residue is at a level higher than an established tolerance level (a scientifically documented level of concern), it is a violative residue. The residue rate of one antimicrobial, sulfamethazine, as reported by the USDA-Food Safety and Inspection Service (USDA-FSIS), has declined from 13 percent in 1978 down to 0.3 percent in 1989 (McKean, DeWitt and Honeyman; Anon). Sulfamethazine, because of its persistence, has accounted for most antimicrobial residue violations. Sulfamethazine residues in pork carcasses have been the most frequently detected of any tested residue in meat products.

The Food and Drug Administration (FDA) established a tolerance level of 0.1 ppm for sulfamethazine in muscle, kidney, and liver tissues to provide a margin of safety for consumers. They randomly monitor swine and cattle carcasses at slaughtering plants for the detection of violative sulfamethazine residues. Under current regulations, the detection of carcasses with violative residues may prompt a temporary marketing embargo on the producer. These embargoes, of two to four week duration, have several significant financial impacts upon producers including interference with orderly production-unit scheduling, decreased feed efficiency in heavier livestock, and reduction in the per hundredweight price of overweight livestock.

To study the question of sulfamethazine residues in pork, the USDA-FSIS began a two phase program of residue testing and control. In Phase I, the program restricted detection of sulfa residues to low sampling levels. During this monitoring phase it was not the intent that testing be at a high enough level to influence producer behavior. The FSIS designed the level of sampling to get a statistically significant sample size (large enough to produce a 95 percent confidence interval) for detecting a 1 percent violation rate. In 1987, this sampling level amounted to testing about 1500 swine carcasses of the 80 million swine slaughtered in the United States (McKean).

More recently, under Phase II of the residue prevention program the FSIS incorporated the sulfa-on-site (SOS) screening test into the 100 largest United States pork slaughter plants. The SOS test uses a card impregnated with specific antibodies to sulfamethazine using ELISA (Enzyme Linked ImmunoSorbent Assay) procedures. Under the new program, they screened six swine per shift/plant/day. At that rate, they monitored the equivalent of all the 1987 samples screened in approximately 2 1/2 days. Based on current USDA-FSIS policies, the SOS screening rate will remain at present levels. If residue violations trend upward, the USDA will increase the Phase II testing rate or issue rules to allow

the screening of representative swine in order to determine the disposition of entire lots of market swine.

The FDA is now evaluating potential regulatory action for sulfamethazine use in livestock feeding. The four actions under consideration are: a) doing nothing; b) banning sulfamethazine use in swine as it represents an imminent hazard to human health; c) lowering the tolerance level for sulfamethazine in tissues from 0.1 ppm to 0.025 ppm and implementing increased testing at point of production and at other points in the slaughter process; and d) beginning the formal procedure for removal of sulfamethazine as an approved drug. Although the FDA has signalled that it has begun the administrative procedure for registration removal, the third alternative represents a more flexible course of action. Increased testing would place additional pressure on pork producers and their suppliers to address the contamination problem at the production-unit level. Lower tolerance levels are attainable with current production practices when using good production management, animal control, and feed handling procedures (McKean, DeWitt, and Honeyman).

Sulfamethazine residue prevention activities benefit both producers and consumers. The livestock producer benefits directly by avoiding temporary marketing embargoes and indirectly through reduced negative perceptions of tainted meat and meat products. Additionally, the management intensity needed to eliminate residues will spill over into other facets of management. Consumers would benefit from the continued, but safer use of sulfamethazine as it does improve production efficiency and lowers prices for pork and pork products. Furthermore, associated actions taken by producers necessary to minimize sulfamethazine residues may reduce or eliminate other currently unknown food safety problems as well.

The implementation of residue prevention activities through on-farm quality assurance programs will be necessary to enhance product quality and to gain a larger market for meat products. Branded meats products can take advantage of increased testing and quality assurance activities to differentiate their products. The potential for market segregation, through quality assurance programs and differentiated products, can act to increase consumer confidence improving demand for all meat and meat products.

In summary, the successful implementation of quality assurance programs will depend upon on-farm testing technologies which are reliable and cost-effective. The introduction of field screening tests has provided the capability to identify animals which are likely to produce violative carcasses and to identify sulfamethazine contamination sources. These tests include the SOS test developed by USDA-FSIS and other new chemical or microbiologic analytical technologies.

Economics of Testing and Enforcement of Residue Standards

Adjustments to improve food quality and safety are not usually free goods. Improvements incur costs. In a setting free of any regulatory policy, individual producers who misuse antimicrobials do not internalize the external costs of violative residues. Since residues are indistinguishable, the selling price of meat is identical and there is no direct economic incentive to the individual producer. However, rational consumers will recognize that meat may include antimicrobial residues and respond by demanding less meat and meat products. Thus, the external costs of violative residues are borne by the entire pork production industry.

An alternative to this setting involves the introduction of a regulatory policy which forces the internalization of the costs due to improper use of antimicrobials (Cornes and Sandler; Baumol and Oates). Cost-effective, accurate, and rapid testing makes it possible to either assess a tax on an externality or to impose a penalty for a violation of an accepted quality standard. For antimicrobial residues, a penalty for violating one specific standard is the practical alternative.

Analytical conclusions about the expected effectiveness of a regulatory policy from a simple two-stage economic model can be derived. These are shown in the appendix. In the first stage, a representative producer faces a tradeoff between costs of changing the production system to lower the chance of violation and the expected cost of violating of residue standard. The probability of producing a violative carcass is a variable which is under control of the producer. The producer's response is a function of the financial parameters and the probability of detection under the enforcement and testing system.

In the second stage, the producer's response is incorporated into a social cost minimization problem. Thus, for socially optimal policy, a social planner must consider the optimizing decisions of producers under the institutional framework, as well as all costs and benefits to society. Following Stigler, the costs to society of uncertain violations includes not only the cost of reducing the probability of violations and value of the harm done by the violation but the costs of the testing and enforcement system.

Therefore, the current system could include a fine to pay for costs of increased testing and as compensation for the harm done by a violation of a residue standard. The prospect of a high fine, regardless of the probability of detection, may be enough to influence some producers. However, there are several considerations in the imposition of higher financial costs through an added fine. First, a high fine may induce other non-productive tactics targeted specifically at avoiding the impact of the fine if residues occur. Second, a high fine with a low probability of detection raises certain questions of fairness as there is extremely severe punishment on only a few violators. Third, consumer confidence in the

inspection system depends on the probability of detection. While increased testing is necessary to increase the probability of detection of violative carcasses, recent advances in testing have greatly lowered the cost and time required for testing.

This model does not address the issue of varying demands by different consumers for different levels of food safety assurance. Higher levels of food safety imply higher costs of production as well as higher costs of testing. It should be clear that completely eliminating the freedom of consumers to choose their own level of food safety and imposing the concurrent higher costs on every consumer would not be socially optimal. A solution may be to segregate the market into two markets — one with high level testing (and higher cost) and another with a lower level.[2]

Market Segregation

Food safety and antimicrobial use issues can lead to conditions favorable to a divided or segregated market for meat and meat products. The current market can be divided according to the use of certain compounds, such as antimicrobials, during livestock production. Markets could also be segregated according to the stringency of quality assurance systems. Higher levels of food safety and quality verified through public testing and certification programs could be a critical part of a marketing strategy for labeled or branded meat and meat products.

Consumers assess many food safety and quality attributes of meat and meat products such as certified food safety programs. Another important consideration for some consumers is the use of various compounds during the production of livestock. Both consumers and producers can gain from segmented markets if there is enough demand to support each market. However, substantial additional marketing costs occur in segmented markets. Monitoring identity of products produced with given production standards is not a costless venture.

Market segregation and resulting product differentiation would allow consumers to assess information, to place their own value on the possible risks involved, and to pay for improvements in food safety. So, producers could see a direct price-differential according to consumers attitudes and values placed on those possible risks. In the segregated marketplace, more information about both production systems or quality assurance programs would be available to consumers so they could better weigh the risks and costs. Ostensibly, groups with interests in each system would collect, organize, and disseminate information for consumers. Better-informed consumers would be able to trust the products safety when warranted and refuse to purchase products when it was not.

There can be adverse effects from market segmentation. If the attempt to segment the market raises doubts about the general safety of both products, then producers and consumers alike will not benefit by market segregation. When consumers perceive market segregation as the creation of an inferior product, then both consumers and producers are worse off. Although the gradual restoration of confidence would eventually eliminate this institutional uncertainty effect, it could produce deep short-term losses. If market segregation is to be successful, consumer preferences and the opinion formulation process must be understood. Appropriate informational campaigns should precede the market segregation implementation.

Market segregation is a potential policy alternative for consideration. The elimination of attribute uncertainty can produce welfare gains for both producers and consumers. However, segregation of the market involves high institutional fixed costs of setting up the separate markets and the testing and certification necessary for operating the two markets. Market segregation entrepreneurs may not be able to charge producers or consumers to cover these costs and the risks involved. Public involvement may be necessary to aid with the start-up and certification costs needed for product identification. An auxiliary benefit of a public market segregation experiment would be the data provided on consumer reaction to uncertain information and hidden food safety risks. This information could lead to improvements in future food safety policy decisions.

Antibiotic-Resistance

Antibiotic-resistance is a significant food safety and public health concern. The transfer of antibiotic resistant disease microorganisms can occur through food products including foods of animal origin, as well as fruits and vegetables (Hagstad and Hubbert). The transfer of resistance is important because effective antibiotics must be available to treat those diseases. This is especially true for individuals with weakened immune systems. Any process that potentially damages that effectiveness is cause for concern. This development and spread of antibiotic resistance involves complex issues and must be understood and incorporated to properly address policy measures.

Development of resistance to any agent which threatens an organism is a phenomenon which occurs naturally as a necessary mechanism for species survival. Antibiotics kill sensitive bacteria and in the process bacteria which have effective mechanisms of resistance survive. Researchers have pointed out that through this process of natural selection, antibiotic usage increases the percentage or prevalence of resistant bacteria (Frappaolo and Guest; Hagstad and

Hubbert; Hays, Batson and Gerrits; Holmberg et al.; Holmberg, Wells and Cohen; Institute of Medicine; Langolis et al.; O'Brien et al.; Walton).

Another area of concern mentioned in the literature on antibiotic resistance is that bacterial resistance to antibiotics may develop in a step-wise fashion (Institute of Medicine). The hypothesis is that each progressive generation of moderately resistant bacteria has the evolutionary opportunity to become more resistant to a given antibiotic or to develop multiple resistance to other antibiotics. A further concern is that resistant bacteria survive and evolve to develop other mechanisms of increased virulence (Wright). Increased virulence combined with increased drug resistance can lead to serious problems in combatting these diseases. Added virulence in an antibiotic-resistant disease reduces the time available to find effective antibiotics or other means of treatment.

There are two opposing views about whether the use of antibiotics creates new health hazards. According to one view, an increase in prevalence is not necessarily equivalent to an increase in the population of antibiotic-resistant bacteria. Although the prevalence of the resistant bacteria after the use of antibiotics would be greater than before, antibiotic-resistant bacteria were in existence prior to the use of antibiotics. Therefore, antibiotic use does not necessarily lead to a new or larger population of resistant bacteria so there are no new health hazards created. In contrast, if there is an effective upper biological or physical limit on the size of the entire population of all bacteria, then a resistant population can increase. This occurs as resistant bacteria multiply and fill the void created by the deaths of those bacteria sensitive to antibiotics. A new or larger population of resistant bacteria is a new hazard.

The development of multiple antibiotic resistance, increases in populations of drug resistant bacteria, and other changes in disease bacteria associated with livestock concern public health officials. Some argue that microorganisms associated with livestock and humans are a linked ecosystem in which the resistance acquired by any segment of the system could be transferred to other segments (Frappaolo and Guest; Institute of Medicine). According to this view, foods of animal origin may serve as a medium of transferring resistance from animal disease bacteria to their human counterparts. However, it is unclear whether the transfer of resistance from animal sources adds significantly to the level of antibiotic resistance within human diseases (Langolis et al.; Walton; Watanube; Zimmerman).

Antimicrobial Regulation

Policy options available to address the food safety concerns related to antimicrobial residues in the meat supply and antibiotic resistance are numerous. One

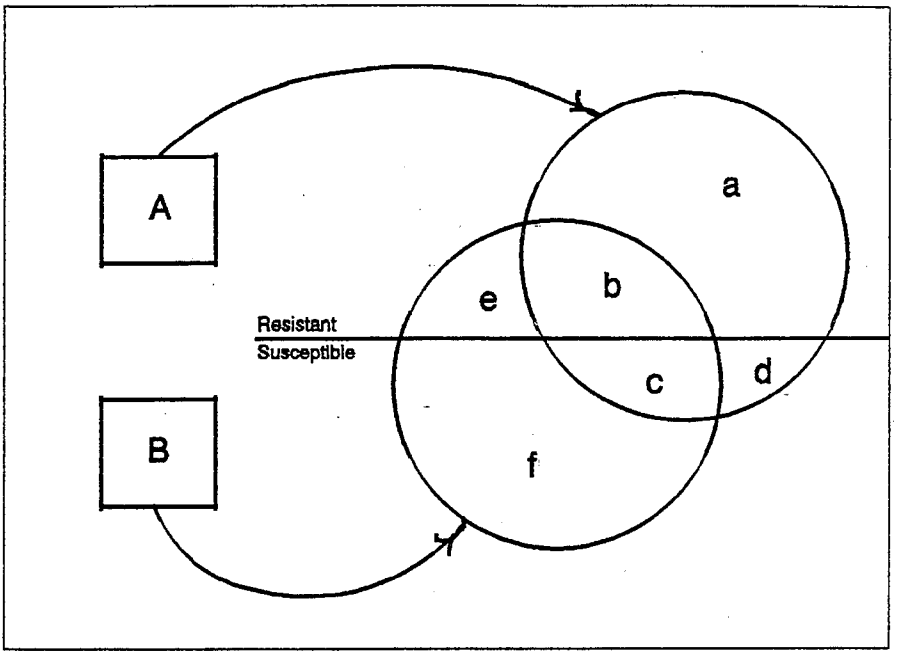
measure includes consumer educational programs focusing on kitchen sanitation and proper preparation procedures for meats, fruits, and vegetables. Beyond this, there are policies which regulate the level of use of antimicrobials. At one end of the policy spectrum is a complete ban on all uses of the product. At the other end is a policy which provides little regulation and relies on consumer reaction in the open market to dictate the level of use by producers. Between these measures are taxes on product use and a variety of restrictions according to quantities or types of use. Although several groups have sought a ban on the use of antimicrobials in animal agriculture, some have expressed doubt whether this measure would successfully accomplish a noticeable reduction in antibiotic resistance. Evidence collected during a 13-year ban on antibiotic use in a secluded swine herd at the Kentucky Agricultural Experiment Station at Princeton, Kentucky and a 16-year imposition of subtherapeutic-use restrictions in the United Kingdom shows that removing all antibiotic use or even subtherapeutic use in animals did not end or significantly reduce antibiotic-resistant bacteria (Langolis et al.; Walton).

Others argue that antimicrobials should not be used in animal agriculture. According to this view, reductions in production costs do not offset the public health risks. However, this view ignores the positive impacts on animal welfare. Furthermore, it would be unusual if the additional demand for antimicrobials by the livestock production industry did stimulate added research and development of new antimicrobials, as well as new compounds for combating antibiotic resistance. It is not clear that a more restrictive policy on the use of antimicrobials would have produced fewer instances of bacterial disease (in humans).

The current relatively open policy on antibiotic use, Policy A, (Figure 1) has lead to a given set of deaths and illnesses (shown by areas a + b + c + d). In this diagram, the areas above the line are deaths and illnesses due to resistant diseases. The areas below are due to diseases susceptible to antibiotic treatment. A policy featuring a complete ban, Policy B, would have lead to another set (e + f + c + b). We do not know conclusively which set of illnesses and diseases would have been greater. Some restrictive assumptions are necessary to make quantification of areas b, c, e, or f possible. As shown by the Institute of Medicine study, although it is possible to produce precise quantitative estimates of specific risks under the current policy, we cannot accurately perform a comprehensive comparison between an open-use policy and a complete ban.

Economic theory allows for some important insights into the antibiotic use and resistance issue. If we believe a class of compounds, such as antibiotics, causes negative external effects, we can impose either quantity restrictions or excise taxes on that class of compounds (Baumol and Oates; Cornes and

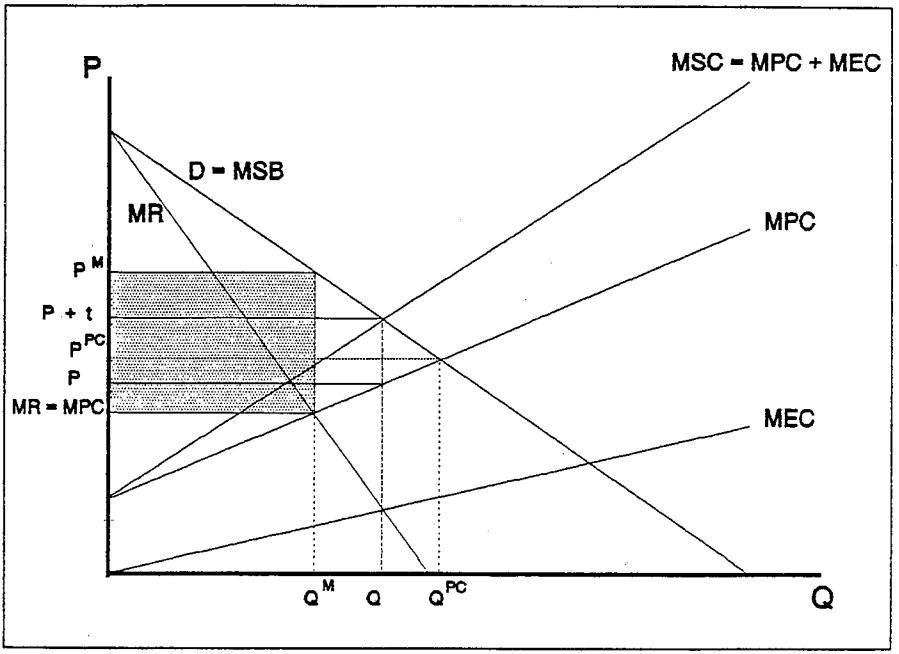
Figure 1:
Instances of Disease Under Alternative Policy Measures



Sandler). Either policy will accomplish the purpose of limiting use of the compounds. For practical reasons, the product manufacturer pays the excise tax or complies with the quantity restriction on the compound.

Figure 2 shows the economic situation faced by the manufacturers of the product. In a market characterized by perfect competition, the price, P^{PC}, and quantity, Q^{PC}, are where marginal private cost, MPC, of producing the compound is equal to demand, D, for the compound. The compound's demand, D, is equivalent to its marginal social benefit, MSB. The competitive equilibrium quantity, Q^{PC}, is optimal when external effects are not present. If externalities are present the socially optimal quantity, Q, is where the marginal social benefit, MSB, is equal to the marginal social cost, MSC, of the product. The marginal social cost, MSC, is the vertical addition of marginal private cost, MPC, and marginal environmental cost, MEC. The marginal environmental cost is another way of referring to the hidden cost of the negative external effect not internalized by the market price of the compound. In a perfectly competitive

Figure 2:
Market for Externality Causing Product



market, we can establish an excise tax, t, on the product that would internalize the externality. With the tax, the marginal social cost of the compound is equal to the market price for consumers, P + t. A different but equivalent measure to a tax is a restriction that the quantity produced be no greater than Q. As one might infer from examination of Figure 2, it is quite difficult to specify the size of the excise tax or to accurately specify an exact quantity restriction, to reach a social optimum. Such policy measures usually require substantial, perhaps even prohibitive, amounts of information.

Restrictions in use or impositions of excise taxes are not necessarily appropriate in situations where the input is a product of firms which exercise considerable market power. For example, in a market where firms have market power, a tax based on the assumption of perfectly competitive markets will result in quantity demanded and produced lower than the social optimum. If the market is a monopoly where one firm has complete market power (Figure 2), then market price, P^M and quantity, Q^M are where marginal revenue (MR) is equal to

marginal private cost (MPC). The monopolist's price, P^M, is higher than the purely competitive price, P^{PC}, and its quantity, Q^M, is lower than the purely competitive quantity, Q^{PC}. As shown in Figure 2, the firm's choice of the quantity, Q^M, is below the level, Q, the socially optimal considering externalities. In a real market, Q^M is not necessarily either equal to, above, or below Q, although it will necessarily be below Q^{PC}.

Pharmaceutical firms which produce antimicrobials enjoy considerable market power created by the patent on a given drug. Pharmaceutical firms, by the nature of the market within which they operate, produce at levels below that of a perfectly competitive market. To maximize the firm's total value to its stockholders, a large portion of the excess profits due to this market power (shown by the shaded area in Figure 2) is re-invested in research and development of new antimicrobials and other compounds which may prolong the effectiveness of a antimicrobial. Only through continued research and development can the pharmaceutical firm gain or hold its market power into the future.

The firm's restriction in output of a given compound will only last as long as the firm can protect its market power for that compound. As the market becomes more perfectly competitive, the firm will move toward the point where its marginal private cost is equal to market price. This price is where the marginal private cost curve intersects the demand curve. The privately provided quantity exceeds the socially optimal quantity. Deterioration of patent protection destroys market power and the ability to charge higher prices which restrict consumption. In this institutional setting, conditional reinforcement of market power by through patent protection may lead to more socially optimal levels of compound use. In this instance, conditions on patent protection might pertain to levels of investment in research and development of new antimicrobial and compounds to attack the externality problems of issues such as drug resistance. Thus, regulation of patent protection has far-reaching consequences for social optimality.

Other animal health policy alternatives which impact upon this issue are available to reinforce the efforts of producers to provide safe, high-quality meat and meat products. Certainly production practices which are stressful or excessively promote and transfer livestock disease from farm to farm need restrictions. For example, Walton mentions the spread of disease through very young calves intended for beef production which are sold and often resold in livestock sale barns.

Rather than the heavy use of antimicrobial, livestock producers recognize that sound animal husbandry, careful management, and the reduction of stress lessen disease problems. Other forms of protective technology might represent efficient and effective substitutes for antimicrobials in the future. However, the

development and implementation of the alternative technologies do not occur instantaneously and costlessly. Implementation of these technologies as a longer term solution needs evaluation. In the intermediate term, the availability of antimicrobials will help producers in coping with disease problems and in reducing food costs for consumers of meat and meat products.

Conclusions

Issues involved with food safety and antimicrobial usage in livestock production illustrates the complexities of developing effective food safety policies. Economic cost and benefit information is necessary but not sufficient for effective and meaningful evaluation of food safety policy alternatives. In addition to information on the market structure in product and input markets, the processes consumers use to gather information and form opinions, biological and technological barriers to effective policy implementation, and a host of other items specific to the food safety issue needs consideration. The paradox of food safety regulation is that unless these issues properly consider the complete set of diverse, complex factors, regulation can lead to a deterioration in the variety, quality, and safety of the food supply rather than the desired improvement. Development and analysis of food safety regulation requires a multidisciplined, multifaceted approach.

Notes

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1. Antibiotics and sulfa compounds such as sulfamethazine are two subsets of the set of all antimicrobials.
2. This analysis does not address two modes of behavior by monopolists: (1) introductory marketing efforts to acquaint consumers with new products; and (2) circumvention of the product testing process and regulations on the product's intended or labelled use by encouraging experimentation and off-label use of broad-spectrum products. Discussion of these practices and the policies which might address them is beyond the scope of this paper.

References

Anon. 1990. *Food Chemical News.* 32(14):58.

Baumol, W. J. and W. C. Oates. 1987. *The Theory of Environmental Policy.* 2nd edition, Englewood Cliffs, NJ: Prentice-Hall, Inc.

Cornes, R. and T. Sandler. 1986. *The Theory of Externalities and Public Goods, and Club Goods.* New York: Cambridge University Press.

Frappaolo, P. J. and G. B. Guest. 1986. "Regulatory Status of Tetracyclines, Penicillin and Other Antibacterial Drugs in Animal Feeds." *J. Animal Sci.* 62 (Suppl. 3).

Hagstad, H. V. and W. T. Hubbert. 1986. *Food Quality Control: Foods of Animal Origin.* Ames, Iowa: Iowa State Press.

Hays, V. W., D. Batson, and R. Gerrits. 1986. "Public Health Implications of the Use of Antibiotics in Animal Agriculture." J. *Animal Sci.* 62 (Suppl. 3).

Holmberg, S. D., M. T. Osterholm, K. A. Senger, and M. L. Cohen. 1984. "Drug Resistant Salmonella from Animals Fed Antimicrobial." *New England J. Medicine.* 311:617-622.

Holmberg, S. D., J. G. Wells, and M. L. Cohen. 1984. "Animal-to-Man Transmission of Antimicrobial-Resistant Salmonella: Investigation of U.S. Outbreaks (1971-1983)." *Science.* 225:833-835.

Institute of Medicine. 1989. *Human Health Risks with the Subtherapeutic Use of Penicillin or Tetracyclines in Animal Feed, the report of the Committee on Human Health Risk Assessment of Using Subtherapeutic Antibiotics in Animal Feeds.* Washington, D.C.: National Academy Press.

Langolis, B. E., K. A. Dawson, G. L. Cromwell, and T. S. Stahly. 1986. "Antibiotic Resistance in Pigs Following a 13 Year Ban." *J. Animal Sci.* 62 (Suppl. 3).

McKean, J. D. 1988. "Swine Sulfamethazine Residues: A Problem-Solving Approach Is Needed." *Agri-Practice.* 9(5):15-20.

McKean, J. D., D. L. DeWitt, and M. S. Honeyman. 1989. "Management Factors Affecting Sulfamethazine Depletion Rate in Swine." *Agri-Practice.* 10(2):27-34.

O'Brien, T. F., J. D. Hopkins, E. S Gilleece, A. A. Medeiros, R. L. Kent, B. D. Blackburn, M. B. Holmes, J. P. Reardon., J. M. Bergeront, W. L. Scheel, E. Christensen, M. L. Bissett, and E. V. Morse. 1982. "Molecular Epidemiology of Antibiotic Resistance in Salmonella from Animals and Human Beings in the United States." *New England J. Medicine.* 307:1-7.

Roberts, T. and E. van Ravenswaay. 1989. "The Economics of Safeguarding the U.S. Food Supply." Washington, D.C.: *USDA-ERS Agriculture Information Bulletin 566.*

Stigler, G. J. 1970. "The Optimal Enforcement of the Laws." *J. Pol. Econ.* 78:526-536.

Walton, J. R. 1986. "Impact of Antibiotic Restrictions in Animal Productions on Public Health." *J. Animal Sci.* 62 (Suppl. 3).

Watanube, T. 1963. "Infectious Heredity of Multiple Drug Resistance in Bacteria." *Bacteriology Rev.* 27:87.

Wright, K. 1990. "Bad News Bacteria." *Science.* 249:22-24.

Zimmerman, D. R. 1986. "Role of Subtherapeutic Levels of Antimicrobial in Pig Production." *J. Animal Sci.* 62 (Suppl. 3).

Appendix

In this model, a representative producer is faced with a tradeoff between costs of changing the production system to lower the probability of violation,

$C(P_v)$, and the expected cost of violating a residue standard, $E\{F\}$. The producer's objective (for each animal or hundredweight of meat produced) is represented by

$$\text{Min } C(P_v) + E\{F\} \tag{1}$$

The cost $C(P_v)$ of reducing P_v is given by

$$C(P_v) = c(1 - P_v^{\beta}) \tag{2}$$

where β is the responsiveness of the probability of violation to changes in the production system. β is restricted to being greater than 0 and less than or equal to 1. The cost parameter, c, is the cost of reducing P_v to zero. On the other hand, if $P_v = 1$, then $C(P_v) = 0$.

The expected financial cost, $E\{F\}$, to the producer of violating a sulfamethazine residue standard is the product of *f*, a financial parameter (i.e., a per animal fine if a violation is detected); P_d, the probability of detection; and P_v, the probability of violation, or

$$E\{F\} = f \times P_d \times P_v \tag{3}$$

The probability of producing a violative carcass, P_v, is the only variable controlled by the producer. Hence, the solution to the producer's cost minimization problem for P^*_v is given by

$$P^*v = \left[\frac{fP_d}{\beta c}\right]^{\frac{1}{\beta-1}} \tag{4}$$

Hence, P*v (chosen by the producer) is a function of the financial parameter, *f*, or the probability of detection, P_d. The social planner (an expression for an omniscient regulatory system) uses this functional relationship in determining the socially optimal Pd and *f*.

In this model, the social planner controls the parameters under control of the regulatory system. The probability of detection, P_d, relates to testing procedures and the level of testing. The social planner raises (lowers) the probability of detection by increasing (decreasing) the level of testing. The financial parameter *f* is also within the control of the social planner. The social planner can raise or lower this parameter by changing the level of financial penalties. Market embargoes in the current penalty structure impose costs on producers but these embargoes yield no revenue to the regulatory system. Market embargoes are necessary because animals from farms which have produced violative carcasses are highly likely to also yield violative carcasses. Except for this important practical matter in the enforcement of policy, market embargoes are not

necessarily a socially efficient method for influencing producer behavior. Although the financial parameter, *f*, in this model may not capture exactly the specific nature of market embargoes it does demonstrate the general principles involved with financial penalties in enforcement systems.

The social planner's objective is the minimization of both the cost of reducing the probability of producing violations and the expected social cost of violations. E{SC}, or

$$\text{Min} \quad C(P_v) + E\{SC\} \tag{5}$$

The expected social cost, E{SC} of uncertain violations includes the value of the harm done by the violation, $H(P_v)$, and the costs of testing and enforcement, $T(P_d)$. For simplicity $H(P_v) = h \times P_v$ and $T(P_d) = t \times P_d$. To account for the actions of the optimizing producer from (4), P^*_v is substituted for P_v. The full minimization problem of social planner is now

$$\text{Min} \quad c - c\left[\frac{fP_d}{\beta c}\right]^{\frac{\beta}{\beta-1}} + h\left[\frac{fP_d}{\beta c}\right]^{\frac{1}{\beta-1}} + tP_d \tag{6}$$

To simplify the form of the solution, $\alpha = 1/(\beta - 1)$. The first order condition is

$$J = P_d^{\alpha} + \frac{h}{f}P_d^{\alpha-1} + \frac{t(\beta-1)(c\beta)^{\alpha}}{f^{\alpha\beta}} = 0 \tag{7}$$

From (7) the socially optimal P^*_d can be determined by the social planner given the exogenous parameters in the model. It is necessary that the following second order conditions is satisfied for cost minimization.

$$h(2-\beta) \geq fP^*_d \tag{8}$$

This model may be extended in several ways. For example, a social benefit (e.g., consumer confidence) may be derived from increasing the probability of detection. This effect would show up in the social planner's objective function. Whatever extension is considered, the basic process of analysis will apply — the social planner must take into account the optimizing decisions of producers under the institutional framework under examination, as well as all costs and benefits to society.