ECONOMIC IMPLICATIONS ASSOCIATED WITH PHARMACEUTICAL TECHNOLOGY BANS IN U.S. BEEF PRODUCTION

A Dissertation

by

ISAAC DANIEL OLVERA

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Chair of Committee,	Andy D. Herring
Committee Members,	Jason E. Sawyer
	David P. Anderson
	William L. Mies
Head of Department,	H. Russell Cross

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ABSTRACT

Sustainability in agricultural production has become a large point of emphasis for consumers in the United States. Despite pharmaceutical technologies being used to increase production efficiency and cost effectiveness, their use remains questioned by the general public, particularly regarding antibiotics within the livestock sector. Therefore, the objectives of this study were to determine the economic effects of a removal of certain technologies from the U.S. beef cattle production system.

A whole system structural econometric model was used to determine effects of: (1) a removal of feed-grade antibiotics as growth-promotant technologies, and (2) the removal of all growth enhancing technologies from the U.S. beef cattle industry as possible future policy. One year after implementation, the loss of feed grade antibiotics is predicted to reduce fed cattle inventories by 270,000 animals and reduce carcass beef by approximately 227.6 million lb. Additionally, beef production and consumption are estimated to decrease by approximately 1% five years post ban. The loss of all growth enhancing technologies predict much larger implications, with one-year post-ban reductions in fed cattle inventories estimated to be 3.1 million animals and a corresponding 2.2 billion lb reduction in carcass beef. At five years post ban, beef production and beef consumption are projected to decrease by 10.5% and 8.2%, respectively while beef imports are projected to increase by 9.1%.

Additionally, an equilibrium displacement model was used to further investigate the effects of a removal of feed-grade antibiotics used to control liver abscesses in U.S.

feedlot cattle. In this model the largest first year change, as expected, is within the slaughter cattle sector with a 4.45% reduction in quantities supplied and an 11.13% increase in slaughter cattle price. The 10-year net change for retail beef is estimated to be a 6.31% reduction in total quantity, and a corresponding 1.13 billion lb loss in total beef supplied at the retail level.

The term “sustainability” in agricultural production is often interpreted to mean natural or free of certain technologies. This study has shown that the removal of technological advances poses a significant economic concern to beef producers and consumers alike.

DEDICATION

To my family, for always praying and supporting me along the way.

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CHAPTER I

INTRODUCTION

Antimicrobials used in agricultural production as growth-enhancing technologies have largely been blamed for increases in antimicrobial resistant bacterial strains in both humans and animals. Although the relationship is not largely understood, it is speculated that the use of antibiotics administered in feed and/or water leads to a selection pressure that fosters antibiotic-resistant pathogens. As consumers become more distant from agricultural production, alternative beef production systems have become increasingly popular. Following suit with similar bans across the European Union, the United States Food and Drug Administration (FDA) will begin imposing bans on certain antibiotics deemed medically important in human medicine. Despite observation of unintended negative results stemming from antibiotic bans in Denmark, there is a belief that banning the use of feed grade antibiotics in U.S. livestock production may help alleviate increasing levels of microbial resistance. Among the affected pharmaceuticals, antibiotics used to suppress *Fusobacterium necrophorum*, the primary pathogen responsible for liver abscess formations, will now require a veterinary prescription.

Therefore, the objectives of this dissertation were to determine the economic effects of a removal of specific technologies from U.S. beef cattle production. A whole systems structural econometric model was used to predict the effects of a removal of feed-grade antibiotics as growth-promotant technologies. Additionally, the model was expanded to include a removal of all growth promoting technologies as a likely next policy facing U.S. beef cattle production. The proposed model assumes that feed-grade antibiotics impact productivity by adding additional pounds of carcass beef, therefore making production more efficient and aiding in maintaining a lower cost across all marketing levels. The removal of these products will have a negative effect throughout the industry, altering key model output variables: cattle price, cattle supply, total beef, and beef demand, which will iteratively alter production until a new equilibrium is established. Furthering the investigation on feed-grade antibiotics, an equilibrium displacement model was created to analyze the effects of a removal of feed-grade antibiotics used to control feedlot cattle liver abscesses, specifically. An exogenous shock to the fed cattle sector was implemented, causing a transmission effect between all levels of beef cattle production, as well as across market sectors pork and poultry.

By reducing certain parameters associated with efficiency in beef cattle production consumers are faced with higher retail prices, while beef cattle production loses operational efficiency and potentially increases negative environmental effects. The term “sustainability” in agricultural production is often interpreted to mean natural or free of certain technologies. This study has shown that the removal of technological advances poses a significant economic concern to beef producers and consumers alike, moving against the foundation of sustainable production.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Sustainability regarding agricultural production often takes on different meanings depending on where individuals place value between social, environmental and economic considerations (Cooprider et al., 2011). Satisfying all three of these goals while meeting both producer and consumer needs is often exceedingly difficult. Technological advances in beef cattle production have been catalysts to increases in efficiency, cost effectiveness, and product consistency across all segments of beef cattle production. A vast majority of these technologies revolve around meeting consumer demands for a safe, wholesome, and quality product while maintaining an affordable, consistent price point.

As consumers continually become more distant from agricultural production while maintaining progressive ideologies it has been concluded that they, not producers, will dictate how animals are raised (Norwood and Lusk, 2011). This notion has led to an increasing trend in consumer preferences towards products labeled “USDA Organic” or “naturally-raised” which denotes limited to no use of certain technologies. Consumers have even demonstrated willingness-to-pay price premiums for products they have deemed healthier, sustainable, or environmentally friendly (Umberger et al., 2002; Lusk et al., 2003; Hughner et al., 2007; Abidoye et al., 2011; Olynk, 2012). Therefore, the objectives of this dissertation were to survey literature regarding the economic and environmental effects of pharmaceutical technologies used in the U.S. beef industry, and model the potential national impacts of a removal of these technologies from U.S. beef production. Specifically, Chapter III investigates the impact of the removal of feed-grade antibiotics at the feedlot level, as well as an implementation of a European Union style full ban on growth enhancing technologies in the beef cattle sector. Chapter IV analyzes the effects from a removal of feed-grade antibiotics at the feedlot level, but specifically quantifying the effects of an antibiotic removal that would be associated with liver abscess controls.

Feed-grade antibiotics

The terms antibiotic and antimicrobial are often used synonymously, when in fact they are somewhat different. An antibiotic is a substance produced by a microorganism that is intended to kill another microorganism while an antimicrobial is a substance that inhibits the growth of, or kills, a microorganism without causing harm to the host (USDA, 2012). There are two main uses of antibiotics in livestock production, therapeutic and "subtherapeutic". Therapeutic use of antibiotics is generally classified as the treatment of sick cattle, sickness prevention for cattle deemed high-risk for illness, or control of an outbreak resulting from cattle exhibiting clinical illness. The often-used term "subtherapeutic treatment" is the use of antibiotics at low levels, not intended for the treatment of sick cattle, but to promote feed efficiency and rate of gain. Many medicated feeds included labels for growth promotion and increases in feed efficiency.

The use of antibiotics for growth promotion began with streptomycin in poultry feed in 1946 during a dynamic time of change in production agriculture (Elam and Preston, 2004). Feed-grade antibiotics typically change the microflora of the intestinal tract in ruminants resulting in greater digestion, metabolism, and absorption of nutrients. The results of increased efficiencies from sub-therapeutic treatments are a need for less feed and the production of less waste. Antimicrobial feed additives are administered to animals at low levels to prevent disease, as well as increase growth and feed efficiency. Approximately 83% of U.S. feedlots have been reported to use some form of sub-therapeutic, feed-grade antimicrobial (USDA, 2013). The use of feed-grade antimicrobials has been shown to increase average daily gains by approximately 3.37% as compared to non-supplemented animals (Lawrence and Ibarburu, 2007), and increase feed efficiency by approximately 7% (Elam and Preston, 2004). Antimicrobials with labels for use in feed or water include: aminoglycosides, lincosamides, macrolides, penicillins, and tetracyclines (FDA, 2012c).

Mode of action

Antibiotics can be classified as either bactericidal or bacteriostatic, where the former kills an organism and the latter inhibits growth. In a USDA (2012) publication, Antimicrobial Drug Use and Antimicrobial Resistance on U.S. Cow-calf Operations, antimicrobials were outlined to work via six main mechanisms listed and described as follows:

1) Inhibitors of bacterial cell wall synthesis. Without the ability to create cell wall, an essential component of a microorganism, the organism dies.

2) Inhibitors of bacterial protein synthesis. Proteins are generally the building blocks of the cellular structure, without the ability to synthesize proteins the cellular structure becomes weak and the organism dies.

3) Inhibitors of nucleic acid synthesis. DNA and RNA are essential for cell survival, without DNA the cells cannot replicate and without RNA gene expression is not possible.

4) Inhibitors of cell metabolism. Different classes of antimicrobials disrupt common metabolic pathways such as cell respiration or folic acid synthesis.

5) DNA destruction. Certain classes of antimicrobials actively break down bacterial DNA.

6) Increase membrane permeability. As cells become more permeable, molecules escape from the cell, causing death.

Liver abscesses and antibiotics

Livers have a significant by-product value in the beef cattle industry, with downgraded and condemned livers representing a substantial economic consideration to both packers and feedlots. The 2011 National Beef Quality Audit reported nearly 21% of slaughter cattle possessed a condemned liver, while only 69% of livers were deemed acceptable for human consumption. Losses due to U.S. beef liver abscesses have been estimated to be $15.8 million (Hicks, 2011). Livers are discounted based on the classification of abscesses and may be suitable for human consumption, pet food, or condemned based on abscess severity. Liver abscesses are ranked on a scale of 0, A, and A+ correlating to abscess severity (Elanco, 2014). Livers classified as 0 have no abscess and are classified as healthy livers, “A” livers display one or two small abscesses, or up to two to four well-organized abscesses which are generally under one inch in diameter, and “A+” livers exhibit multiple large abscesses often with collateral tissue damage (Elanco, 2014).

Condemned livers due to abscesses are generally the result of intensive grain feeding protocols, but condemnation rates have been shown to be reduced by up to 73% through the use of medicated feeding regimens (Laudert and Vogel, 2011). The presence of abscesses on cattle livers can reduce daily gains by up to 5.2% and may reduce dressing percentages by up to 1.7% (Hicks, 2011). Even with the use of feed grade antibiotics such as tylosin, the 2011 National Beef Quality Audit revealed that 9.9% of fed cattle had livers scored A+ compared to only 2% in 1999. As of January 1, 2017, the use of medicated feeds, particularly tylosin, will require a veterinary feed directive, effectively limiting the widespread use of preemptive feeding applications for liver abscess control (FDA, 2013).

Microbial resistance

Increases in public preference against routine antibiotic use in livestock production coupled with shrinking supplies of cattle have forced U.S. beef producers to constantly look for ways to increase individual animal outputs while utilizing fewer resources. There have been mounting public concerns over the use of certain pharmaceuticals within production. It has been hypothesized that the addition of feed-grade antimicrobials in livestock production are catalysts for the development of antimicrobial resistant bacteria, both in humans and animals. This notion has prompted much debate surrounding the use of human derivative antibiotics in livestock production. As well, these concerns have prompted many countries to place bans on antibiotics and growth promotant feed additives in livestock production (Johnson, 2011). The leading argument behind the ban is the notion that bacteria and other microbes are developing a resistance to human drugs based on uses of derivatives in animal agriculture.

Dating back to the early 1960's there have been multiple committees all over the world designated to investigate the use of antibiotics and human health. The Agriculture and Medical Research Council Committee of Great Britain in 1960, the Netherthorpe Committee in 1962 (Great Britain), the Committee on Veterinary Medical and Non-Medical Uses of Antibiotics in 1966 (United States), The Joint Committee on the Use of Antibiotics in Animal Husbandry and Veterinary Medicine in 1968 (Great Britain), and The FDA Task Force on the Use of Antibiotics in Animal Feeds 1970 (United States) are just a few of the early research committees designated to investigate the use of antibiotics in agriculture and their effects on human health. One of the more influential investigations into the use of antibiotics as growth promotion was from England in the 1969 "Swann Report" (Swann et al., 1969). This report centered on concerns over the use of antibiotics used in both human medicine and livestock production. The Swann Report identified penicillin, tylosin, and tetracyclines as primary agents of importance in human medicine, and recommended a committee be formed to review and evaluate antibiotic use in human and animal medicine, as well as in horticultural production. Since this report, there have been countless investigations and reports, committees and focus groups dedicated to researching the cause and effect relationship of antibiotics and resistance in livestock production.

Often times ionophores (classified as an antimicrobial) are grouped into the antibiotic debate. Traditional feed grade antibiotics are fed to approximately 83% of all feedlot cattle; with more than 90% of all cattle in feedlots receiving ionophores in their rations, opponents of the use of feed additives include ionophores as “medicated feed additives” (USDA, 2013). Including ionophores in the debate increases the number of affected cattle, strengthening the argument that this broad classification of feed additives furthers the spread of antibiotic resistant bacteria. Alexander et al. (2008) investigated the use of multiple antibiotics fed for increases in animal efficiency, and their effect on the prevalence of antibiotic resistant strains of *E. coli*. Regarding ionophores, the authors concluded that removing ionophores from the diet did not significantly alter the shedding of tetracycline or ampicillin resistant *E. coli*, and speculated that resistance to antibiotics might be related to additional environmental factors, including diet type. Increases in antibiotic resistant bacteria as a direct result of ionophores are not well supported based on a number of reasons: (1) ionophores are not available for antimicrobial use in humans, (2) ionophores do not act in the same manner as therapeutic antibiotics, and most importantly (3) *Escherichia coli,* a gram negative bacteria, is insensitive to the addition of ionophores (Teuber, 2001; Callaway et al., 2003; Russell and Houlihan, 2003). For these reasons, ionophores will not be considered in the discussion on feed-grade antibiotics in this research.

Specifically pertaining to feed-grade antibiotics, the Preservation of Antibiotics for Medical Treatment Act (PAMTA) was first introduced in 2011 as House of Representatives Bill (H.R.) 965, then reintroduced as H.R. 1150 in 2013. This bill stated that nearly 80% of all antibacterial drugs sold in the United States in 2009 were solely for use on food animals, rather than being used for human health (FDA, 2012a). Additionally, the bill claimed that nontherapeutic use of antibiotics in livestock might contribute to the development of antibiotic-resistant bacteria in humans. The FDA later released a briefing outlining several considerations that must be made before attempting to compare human and food animal drug use including: population size differences, physical characteristics of animals as compared to humans, dosing differences, and intended use (therapeutic or feed efficiency). After briefly describing each consideration they concluded “that is difficult to draw definite conclusions from any direct comparisons between the quantity of antibacterial drugs sold for use in humans and the quantity sold for use in animals” (FDA, 2012b).

The PAMTA aimed to ban all nontherapeutic antibiotics, growth-promoting agents, and human derivative antimicrobials from livestock production, but failed to pass. Less severe alternatives, such as the Guidance for Industry (GFI) #209 “The Judicious Use of Medically Important Antimicrobial Drugs in Food-Producing Animals” (Judicious Use Guidance) and GFI #213 “New Animal Drugs and New Animal Drug Combination Products Administered in or on Medicated Feed or Drinking Water of Food-Producing Animals: Recommendations for Drug Sponsors for Voluntarily Aligning Product Use Conditions with GFI #209” implement a program aimed at promoting more appropriate uses of medically important human antibiotics in food animals, while phasing out the use of medically important antibiotics for growth promotion. Drugs that fall on the medically important antibiotics list are:

aminoglycosides, liaminopyrimidines, lincosamides, macrolides, penicillins, streptogramins, sulfas, and tetracyclines (FDA, 2012c).

The GFI #209 platform still allows the use of antimicrobials, but under a prescription, or veterinary feed directives (VFD). Veterinary feed directives are specifically for the use of treating illness rather than increasing the feed efficiency of livestock. A VFD can be obtained under one of many circumstances, including the prevention of illness for susceptible cattle, control of illness in groups of animals, and treatment of clinically sick animals. The Guidance for the Industry #209 aims to reduce the overall level of antibiotic use in animal agriculture, and applies only to antibiotics administered in feed or water; the guidance does not apply to injectable forms of the aforementioned drugs. Guidance for Industry #213 allows companies with products on the medically important list to withdraw growth promotion claims and submit applications for relabeling products as therapeutic. Companies must resubmit data showing safe, efficient use of their products as therapeutic agents.

Proponents of banning the use of antibiotics for growth promotants often argue that stopping "off-label" product use forces producers to improve management practices and even opens the door for new, innovative, products and protocols. Recently, large food corporations such as SUBWAY, McDonald's, and Chipotle have come forward in the fight against antibiotics. These corporations have policies in place regarding the use of antibiotics in food animals, outlining how producers should responsibly use antibiotics, with SUBWAY and Chipotle having already phased out antibiotics, or outlining plans to phase out antibiotics in the near future. Restaurant chains are attempting to capitalize on the emerging consumer trends surrounding organic and natural production, with Chipotle touting these measures as “food with integrity”, further implying that the use of antibiotics in production is in some way harmful (Chipotle, 2016). Subway has vowed to remove all antibiotics in their animal proteins by 2025, starting with chicken by the end of 2016 and turkey following within 2-3 years. SUBWAY’s executive vice president of the company’s independent purchasing cooperative stated “today’s consumer is ever more mindful of what they are eating, and we’ve been making changes to address what they are looking for... we hope that this commitment will encourage other companies in our industry to follow our lead, and that, together, this will drive suppliers to move faster to make these important changes for consumers” (SUBWAY, 2015). This statement implies that the new policies implemented by SUBWAY are not rooted in foundational science, but instead in favor of consumer perception. McDonald’s has taken a unique approach to antibiotics in production. The company acknowledges the benefits of antibiotics to both the environment and animal welfare, and outlines a policy that promotes the judicious use of antibiotics in production committing to sensible changes that lead to overall reductions in antibiotic use (McDonald’s Corporation, 2015).

Effects of the EU ban on growth enhancing technologies

In 1986, Sweden was the first country to impose a ban on all growth promoting antibiotics in food animal production. The rest of the European Union followed suit in 1997, banning avoparcin, then bacitracin, spiramycin, tylosin and virginiamycin in 1999 (Casewell et al., 2003; Phillips, 2007). In 1998 Denmark imposed an antibiotic ban in pork production only at the finishing stage. Upfront, this ban was deemed a relative success. As the restrictions were implemented further upstream, at the weaning stage, producers began encountering more health related issues and larger production costs (Hayes and Jensen, 2003). According to Hayes and Jensen (2003), approximately 80% of the benefit was achieved at 20%of the production cost when the ban was initially imposed but when the full ban was implemented producers received 20% of the benefits at 80% of the cost.

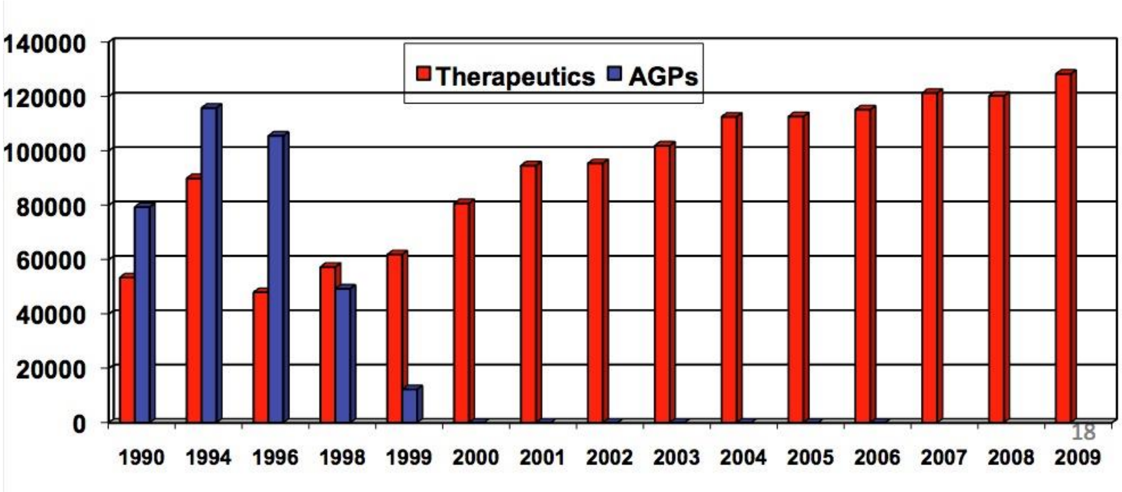

Figure 2.1. Kilograms of use of antibiotics for therapeutic purposes as compared to antibiotics used as growth promoters in Denmark, pre and post ban 1990-2009 (DANMAP, 2009).

Since the full ban was imposed by the European Union, there has been chasm between research supporting and condemning the precautionary ban. Two clear conclusions have emerged: 1) the overall use of antibiotics has been reduced. Total antibiotic use has declined 26% from 1998 to 2009, and 2) the banned antibiotics had an important subclinical activity in livestock production. Quantities of antibiotics used for therapeutic purposes have increased 223% from 1998 to 2009 (AHI, 2015).

As seen in Figure 2.1, the therapeutic uses of antibiotics increased sharply post (1998) ban. Despite considerably higher therapeutic use in 2009, total use of antibiotics (therapeutic and growth promotion combined) was roughly 65% that of 1994. It is important to note that a majority of the increases in therapeutic antibiotics used were those classified as medically important to human health such as tetracyclines, aminoglycosides, macrolides and lincosamides (Casewell et al., 2003).

Overview of the beef production system in the United States

The United States is the largest beef producing country in the world, despite ranking fourth in total cattle and calf inventory (Lowe and Gereffi, 2009). Although the United States produces the most beef, it is still a net importer of live cattle and beef, importing both largely from Canada and Mexico. In the United States, cattle production ranks first among all commodity sales, accounting for approximately 19% of the total market value of agricultural production (USDA NASS, 2012). Being the largest single sector of production agriculture, cattle and calf sales generated $76.4 billion in 2012; this number is all-inclusive, encompassing beef cattle ($29.6 billion), feedlot cattle ($36.4 billion), and dairy cattle ($4.5 billion) (USDA NASS, 2012). Beef contributes considerably to the U. S. food supply, with an average per capita consumption of 56.3 lb (USDA ERS, 2015).

Commercial beef cattle production in the United States can be classified into three distinct phases: cow- calf, stocker, and feedlot, as shown in Figure 2.2.

Additionally, dairy steers and cull dairy cows contribute approximately 18% of the total beef and veal production in the United States (Lowe and Gereffi, 2009). Including dairy calves, approximately 27 million animals are finished each year making up 80% of total U.S. beef production (Matthews and Johnson, 2013; Rotz et al., 2013).

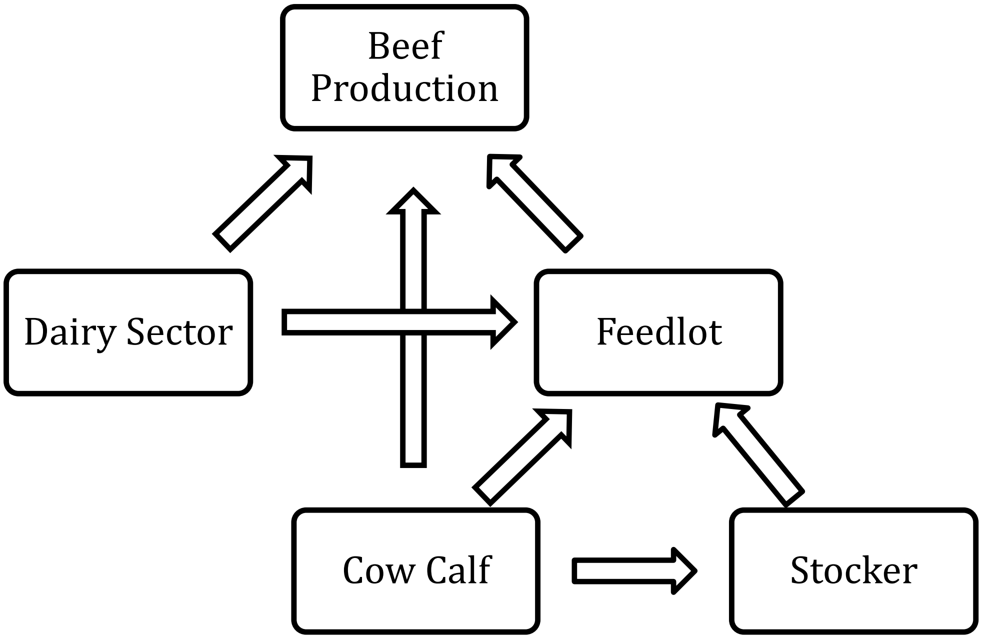

Figure 2.2. General overview of the U.S. beef production system

During the cow-calf phase breeding animals are maintained throughout gestation and calving, and calves are kept until weaning. Calves are generally weaned between 6 and 9 months of age, weighing approximately 400-700 lbs. Cow-calf production occurs in every state, and of the 2.2 million farms in the United States, approximately 35%

(approximately 765,000) maintain a beef cow inventory, with almost 90% of those operations housing fewer than 100 breeding females (McBride and Matthews, 2011; USDA NASS, 2012).

The stocker production phase is generally focused on adding additional pounds of gain to weaned calves over a 3-8 month feeding period. Calves in this phase may be backgrounded and given a series of vaccinations or medicated feeds in order to condition them for an easier transition into the feedlot segment. Finally, the feedlot, or finishing phase places animals on a high concentrate diet in order to meet a specified slaughter weight between 1,000-1,500 lb. Approximately 80-85% of all animals coming off ranches are fed in one of roughly 2,200 feedlot operations (Abidoye and Lawrence, 2006; Matthews and Johnson, 2013). The remaining animals may either be classified as cull animals going straight to processing, or animals finished in a non-traditional manner (grass-fed or forage finished). About half of U.S. beef cattle operations can be categorized as cow-calf only, with the remaining 50% conducting activities in two (cow-calf/ stocker, stocker/ feedlot) or all three of the phases of beef cattle production (USDA, 2009; McBride and Matthews, 2011).

Growth enhancing technologies and alternative production systems

Cattle production can be further broken down into two subcategories: conventional production systems and alternative production systems. Alternative production encompasses grass-fed, organic, and naturally raised systems. Within conventional production, cattle producers routinely utilize pharmaceutical technologies throughout an animal’s life to quell illness, improve individual animal performance, aid general productivity, and enhance overall profitability and operational sustainability. Ionophores, implants, antibiotics, beta agonists, and parasite control are among the most common pharmaceutical technologies employed to achieve these goals. Many of these technologies have been broadly classified as growth-enhancing technologies based on their inherent ability to increase individual animal production. Lawrence and Ibarburu (2007) estimated that the cost savings from the use of all five growth-enhancing technologies listed above were approximately $360 over the lifetime of the animal. These technologies have been a catalyst to the increases in overall U.S. beef productivity over the past 50 years.

Despite higher prices observed from alternative production systems, alternative systems are estimated to account for approximately 3% of total beef and have seen growth of approximately 20% annually (Matthews and Johnson, 2013). Organic labeling in the United States is a USDA certified program, meeting certain minimum requirements: 1) animals must be raised under organic management for the third trimester of gestation, 2) animals may not be given any antibiotics or growth promoting hormones, 3) all feedstuffs must be 100% organic, and not treated with pesticides or synthetic fertilizers, 4) at least 30% of an animal’s diet must be met via pasture during grazing seasons (Matthews and Johnson, 2013). Likewise, grass fed production must meet certain standards specified by the USDA, Agricultural Marketing Service. Grass and forage must be the only feed consumed by the animal aside from milk consumed prior to weaning. Cereal grain crops in the vegetative (pre-grain) state may also be consumed. In the case of any incidental supplementation due to accidental exposure to non-forage feedstuffs or to ensure an animal’s well being during adverse environmental or physical conditions, all supplementation must be fully documented including the amount, frequency, and the supplements provided (USDA AMS, 2008).

Sustainability

Sustainability in livestock production should balance social, environmental and economic goals. Social goals include: population, labor, health, education, income, and preference. Economic considerations include: technologies in production, governmental regulations, production, income, and investments. Environmental considerations may include: land use, water use, energy requirements, and emissions. Producers and consumers differ widely on acceptance of growth-enhancing technologies, such as antibiotics and ionophores, but these pharmaceuticals can help merge these economic and environmental objectives while scientifically satisfying the social implications associated with antibiotic treatments. Most importantly, livestock production needs to focus closely on the sustainability of production for future generations by supplying consistent products as economically, humanely, and efficiently as possible. Many of the decisions regarding the use of antimicrobials in livestock production revolve around a cost-benefit relationship.

The USDA (2007) has defined sustainable agriculture as “the efficient production of food that meets the current generations’ needs for food and quality of life, enhances the environment and natural resources, and does not compromise the productive capability of future generations.” Often, this definition of sustainability is interpreted as enhancing human health through all natural, unadulterated food products without regard for global quantities produced or overall price implications.

As the world's population increases livestock producers are faced with the challenge of producing more meat with fewer natural resources at a competitive price. According to the Food and Agriculture Organization of the United Nations (FAO, 2009), the global population will increase 34% by 2050, necessitating 70% more total food production. Of that 70%, annual meat production will have to exceed 200 million metric tons to meet increased food demands. As a result of increases in productivity, total beef production in the United States had nearly doubled in 50 years while operating with similar national herd size (Elam and Preston, 2004). Increases in productivity and overall animal efficiency are necessary to maintain a lower global price while utilizing fewer natural resources.

Continually improving production practices will allow beef producers the ability to meet this goal; from 1977 to 2007 the U.S. beef industry has reduced necessary resource inputs and waste outputs, largely through the use of pharmaceutical technologies (Capper, 2011). The ability for cattle producers to remain sustainable is key to the success of future production. Another definition of sustainability suggests "food systems and practices should maintain a balance by being ethically grounded, scientifically verified and economically viable" (Arnot, 2008). Perhaps sustainability could be more closely defined by combining both definitions, improving productivity to meet global food demands through environmental and economic efficiencies while reducing the resources necessary to produce one unit of protein.

Cooprider et al. (2011) reported that the use of growth promotants in livestock production resulted in a 34% increase in feedlot average daily gains over "never ever" therapeutic technology cattle. Conventionally raised cattle grew faster and reached target weights 42 days sooner than the control group. There was a 21% lower associated cost of production on the conventional cattle, which yielded additional environmental gains as well. Fernandez and Woodward (1999) showed even greater differences when conventional and organic production systems were compared. Fewer days on feed, higher average daily gains, greater feed efficiencies, heavier ending weights and decreased feed costs were all observed in the conventionally raised cattle. The associated cost of production was 39% lower for conventionally raised cattle. The additional cost of production, or premium, to feed non-additive cattle included: increased feed costs, yardage and sourcing of natural stockers came to approximately $142.52 per animal. Capper and Hayes (2012) modeled beef production in the United States that did not utilize growth promotants and concluded that within ten years, U.S. beef production would decline by 17.1% forcing greater reliance of imports from Canada and Brazil.

The removal of growth enhancing technologies would significantly reduce productivity and subsequently increase cattle populations necessary to meet current beef demands. Capper and Hayes (2012) estimated an additional 385,000 animals would be necessary to meet current beef demands. This population increase would heighten demands for feedstuffs, land and water by 2,830,000 tons, 265,000 ha, and 20,139,000 additional liters, respectively. This degree of loss of production appears to go against USDA's definition of sustainability: "the efficient production of food that meets the current generations' needs for food and quality of life, enhances the environment and natural resources, and does not compromise the productive capability of future generations" (USDA, 2007).

Policy modeling in agriculture

Whole system modeling in agricultural production has widely been used to assess the impact of technological changes, policy implications, or trade regulations (Taylor et al., 1993). Generally, whole system models can offer a quantitative method to evaluate a change in the production landscape without physically altering the production environment. Forecasting models can be used by decision makers to effectively evaluate multiple scenarios in an effort to select the best possible outcome. Models can be constructed for multiple purposes: descriptive, causal, exploratory, forecasting, or decision analysis (Rausser and Just, 1981). The latter are generally used with policy analysis in mind.

The process of modeling beef cattle systems is not a new practice. Models are often constructed to simulate production cycles or biological processes, with the earliest models investigating the nutrient requirements necessary to maintain a particular level of animal performance (Shafer et al., 2005). Deterministic models have been used to evaluate the impacts of removal of technologies within in beef cattle production systems, and even evaluate the interactions across species (USDA ERS, 1978). Most recently, whole system models are being developed to investigate interactions across multiple segments of agricultural production including crop management to feed systems, from feed systems to animal production, and animal production into the retail segment (Shafer et al., 2005; Rotz et al., 2013; Maisashvili, 2014; Lacminarayan et al., 2015). The crossfunctional analysis provided by whole system models gives a much more holistic approach to rapidly changing production landscapes.

Equilibrium displacement models

Equilibrium displacement models have been demonstrated as a valuable tool in assessing the effects of exogenous shocks in “raw material-oriented industries”, where each material source can be treated as a separate industry within a vertically related marketing chain for a given commodity (Muth, 1964; Pendell et al., 2010). Sumner and Wohlgenant (1985) were the first to title Muth’s formulation as “equilibrium displacement modeling.” Lemieux and Wohlgenant (1989) used an equilibrium displacement model to estimate the potential impacts of growth hormones on the U. S. pork industry. Wohlgenant (1993) extended Muth’s formulation to multistage industries, modeling U.S beef and pork markets simultaneously.

Recently, equilibrium displacement models have been used to analyze projected market impacts of policy changes or technological impacts in production (Hanselka et al., 2004; Lusk and Anderson, 2004; Balagast and Kim, 2007; Pendell et al., 2010; Schroeder and Tonsor, 2011). Hanselka et al. (2004) modeled the industry costs of implementing country-of-origin labeling, as wells as the magnitude of industry demand necessary to offset new regulation costs. Additionally, Lusk and Anderson (2004) used an equilibrium displacement model to investigate the costs of country-of-origin labeling and how these costs would be distributed across the livestock sector’s farm, wholesale, and retail markets. Schroeder and Tonsor (2011) estimated the short and long run effects of the adoption of Zilmax in cattle feeding, and the pass through effects of increases in production of beef on the pork and poultry sectors. Balagtas and Kim (2007) developed a multi-market equilibrium displacement model to analyze the effects of producer-funded advertising across milk and multiple dairy product markets. Pendell et al. (2010) examined the impacts of adopting animal identification systems on the U.S. meat and livestock industries. Johnson (2016) created a stochastic equilibrium displacement model to assess the short and long run industry impacts of a removal of beta adrenergic agonists. Each of these studies utilized a similarly formatted equilibrium displacement model, but in a unique analytical approach, to investigate the effects policy and technological changes in various livestock sectors.

Elasticities

Elasticity estimates are necessary to determine the relative changes between prices and quantities within a market, but also between market segments in the same industry (retail, wholesale, slaughter and feeder), and even between separate industries (beef, pork, and poultry). Econometric estimations of elasticity values can be difficult due to the large number of necessary equations as well as identifications problems in in jointly estimating supply and demand relationships (Brester et al., 2004). Pendell et al. (2010) published an appendix including a list of elasticity estimates from multiple previously published sources. The Pendell elasticity estimates were used in some of the aforementioned publications, but the full list of elasticities is the first compilation of elasticity estimates and transmission elasticities for beef, pork and poultry.

Summary

As the global population continues to increase, farmers are tasked with producing more food with fewer resources. In the diverse U.S. beef cattle production system, continually producing a sustainable product through the use of pharmaceutical technologies aids in maintaining an efficient, cost effective, and consistent product. As consumers become more distant from food production practices alternative beef systems have become increasingly popular. Following suit with similar bans across the European Union, the Judicious Use Guidance will go into effect in early 2017 for the United States. Despite observing unintended negative results stemming from bans in Denmark, there is a belief that banning the use of feed grade antibiotics in U.S. livestock production will help alleviate increasing levels of microbial resistance. This protocol will require a veterinary directive to utilize antibiotics classified as medically important in human medicine; as well, the Judicious Use Guidance will remove any existing growth promotants claims and uses to current antibiotics.

Therefore, the objectives of this dissertation were to determine the economic effects of removal of specific technologies from U.S. beef cattle production. A whole systems structural econometric model was used to analyze the effects of a removal of feed-grade antibiotics as growth-promotant technologies. Additionally, the removal of all growth promoting technologies was investigated as the likely next policy facing beef cattle production. The proposed model assumes that feed-grade antibiotics impact productivity by adding additional pounds of carcass beef, therefore making production more efficient and aiding in maintaining a lower cost across all marketing levels. The removal of these products will have a pass-through effect throughout the industry, altering key model output variables: cattle price, cattle supply, total beef, and beef demand, which will iteratively alter production until a new equilibrium is established.

An equilibrium displacement model was also used to analyze the effects of a removal of feed-grade antibiotics used to control feedlot cattle liver abscesses. An exogenous shock to the fed cattle sector was implemented, causing a transmission effect between all levels of beef cattle production, as well as across market sectors pork and poultry. The model fed from the primary demand segment, “retail”, to the wholesale, slaughter, and feeder levels.

CHAPTER III

THE ECONOMIC IMPACT OF REMOVING SELECTED PHARMACEUTICALS ON BEEF CATTLE PRODUCTION

Introduction

The term sustainability in agricultural production often takes on different meanings depending on where individuals place value between social, environmental, and economic considerations (Cooprider et al., 2011). Livestock producers are continually tasked with producing more food with fewer resources. Improving overall animal efficiency decreases the inputs necessary per animal, thus aiding in maintaining a sustainable industry. Over the past 50 years, advances in pharmaceutical technologies have been catalysts to the dramatic increases in efficiency and overall sustainability across all segments of production (Elam and Preston, 2004; Avery and Avery, 2007; Hersom and Thrift, 2011). Producers and consumers differ widely on acceptance of growth-enhancing technologies, such as antibiotics, implants, and ionophores, but these pharmaceuticals can help merge economic and environmental goals while satisfying the social implications associated with animal health and wellbeing.

Antimicrobials used in agricultural production as growth-enhancing technologies have largely been blamed for increases in antimicrobial resistant bacteria strains in both humans and animals. Although the relationship is not largely understood, it is speculated that the use of antibiotics administered in feed or water leads to a selection pressure that fosters antibiotic resistant pathogens. Mounting public concerns over the use of growth enhancing technologies have lead to resolutions aimed at restricting the use of antibiotics in animal production (Matthews, 2001; Cox and Popken, 2007; Matthew et al., 2007; Capper, 2011). The Food and Drug Administration has released Guidance for Industry (GFI) 209 and 213 entitled “The Judicious Use of Medically Important Antimicrobial Drugs in Food-Producing Animals” and “New Animal Drugs and New Animal Drug Combination Products Administered in or on Medicated Feed or Drinking Water of Food-Producing Animals: Recommendations for Drug Sponsors for Voluntarily Aligning Product Use Conditions with GFI #209”, respectively (FDA, 2012c, 2013). These two documents implement a program aimed at promoting more appropriate uses of medically important human antibiotics in food animals, while phasing out the use of medically important antibiotics for growth promotion. The GFI #209 platform still allows the use of feed-grade antimicrobials, but under a prescription, or veterinary feed directive (VFD). Veterinary feed directives are issued specifically for the use of treating illness rather than increasing feed efficiency of livestock. A VFD can be obtained under one of many circumstances, including the prevention of illness for susceptible cattle, control of illness in groups of animals, and treatment of clinically sick animals. Guidance for Industry #213 allows companies with products on the medically important list to withdraw growth promotion claims and submit applications for relabeling products as therapeutic.

Many of the decisions regarding the use of antimicrobials in livestock production revolve around a cost-benefit relationship; therefore, the purpose of this study was to assess the production and economic impacts of the removal of feed-grade antibiotics and growth enhancing technologies from the U.S. beef cattle production system. The goal of this analysis was to determine the price and quantity effects of the removal of these technologies from the feedlot sector within U.S. the beef marketing chain.

Methods and model development

The specific purpose of this study was to evaluate the removal of feed grade antibiotics in accordance with GFI #209, with antibiotics no longer fed for growth promotion, and to also consider impacts on U.S. livestock production and consumers from a potential ban on all growth enhancing technologies. Using the model outlined in Maisashvili (2014) a partial equilibrium model of the U. S. livestock sector was used to evaluate the short and long-term effects of a removal of pharmaceuticals based on the Judicious Use Guidance #209.

Large-scale system models can be used to evaluate the effects of policy changes in both the short and long run (Mesarovic, 1979; Taylor et al., 1993). These models provide a quantitative estimation of key variables necessary for comparative analysis. The large-scale system model aims to estimate the equilibrium price and quantity under the current structure, exogenous shocks are then implemented as impacts of the proposed policy change, and the subsequent changes in production are then calculated year on year. The model in this study followed the basis that:

Beef Supply= f_1 *(Beginning Stocks, Beef Imports, Beef Production)*

where each independent variable is a system of fitted equations solved independently The previous equation can be further broken down as follows:

B*eef Imports =* f_2 *(beef imports* ${}_{t-1}$*, cow price, fed steer price, feeder steer price, feed cost, retail beef price)*

Beef Production = f_3 *(dairy slaughter, steer and heifer slaughter, beef cow slaughter, bull slaughter)*

Steer and heifer slaughter = f_4 *(cattle on feed, cattle in feedlots, cattle imports)*

Additionally, changes in macroeconomic variables of consumer price index, gross domestic product, and population growth were included to evaluate the overall impact on consumer driven behaviors.

The overarching objective of the model is to minimize the squared difference of the excess supply in all markets for a given year following the equation:

$$\min \Sigma\ (supply_i - demand_i)^2$$

where subscript i represents the market of interest. The model's solution is obtained when the squared difference between supply and demand in each market is minimized and all endogenous variables have been estimated for each equation.

The use of growth-enhancing technologies can be modeled as an exogenous production parameter affecting the endogenous variable of interest, which was beef carcass weight in this study. The model is dynamic and recursive; this model is solved sequentially one period at a time with each period calculated based off changes from the preceding period. Newly calculated changes are then inputted into the model for the next period to be solved. The changes stemming from a year one reduction will have a trickledown effect throughout the industry, altering key model output variables of cattle price, cattle supply, total beef, and beef demand, which will iteratively alter production, presumably until a new equilibrium is established.

Figure 3.1 depicts the expected short and long run impacts of an exogenous shock to beef cattle production. Initial price and quantity, P_0 and Q_0, respectively, represent the initial market equilibrium at the intersection of supply and demand curves, S_0 and D_0, respectively. A physical reduction in the amount of beef produced resulting from a removal of pharmaceutical technologies creates a short-term leftward shift of the supply curve. Lower quantities of beef produced drive prices up, incentivizing an increase in beef production across the long run horizon. Higher prices are met by an industry wide response to produce more cattle with less total production per animal. The increase in production causes a rightward shift in derived demand, establishing new demand curve, D_{Ban}. As the model calculates solutions year after year, it will continuously attempt to close in on new market equilibrium prices and quantities P_{Ban} and Q_{Ban}. Ultimately, establishing a new equilibrium with less production per animal, more overall animals, and higher prices across all market segments may not be possible, but the model will still continuously attempt to minimize the difference in supply and demand.

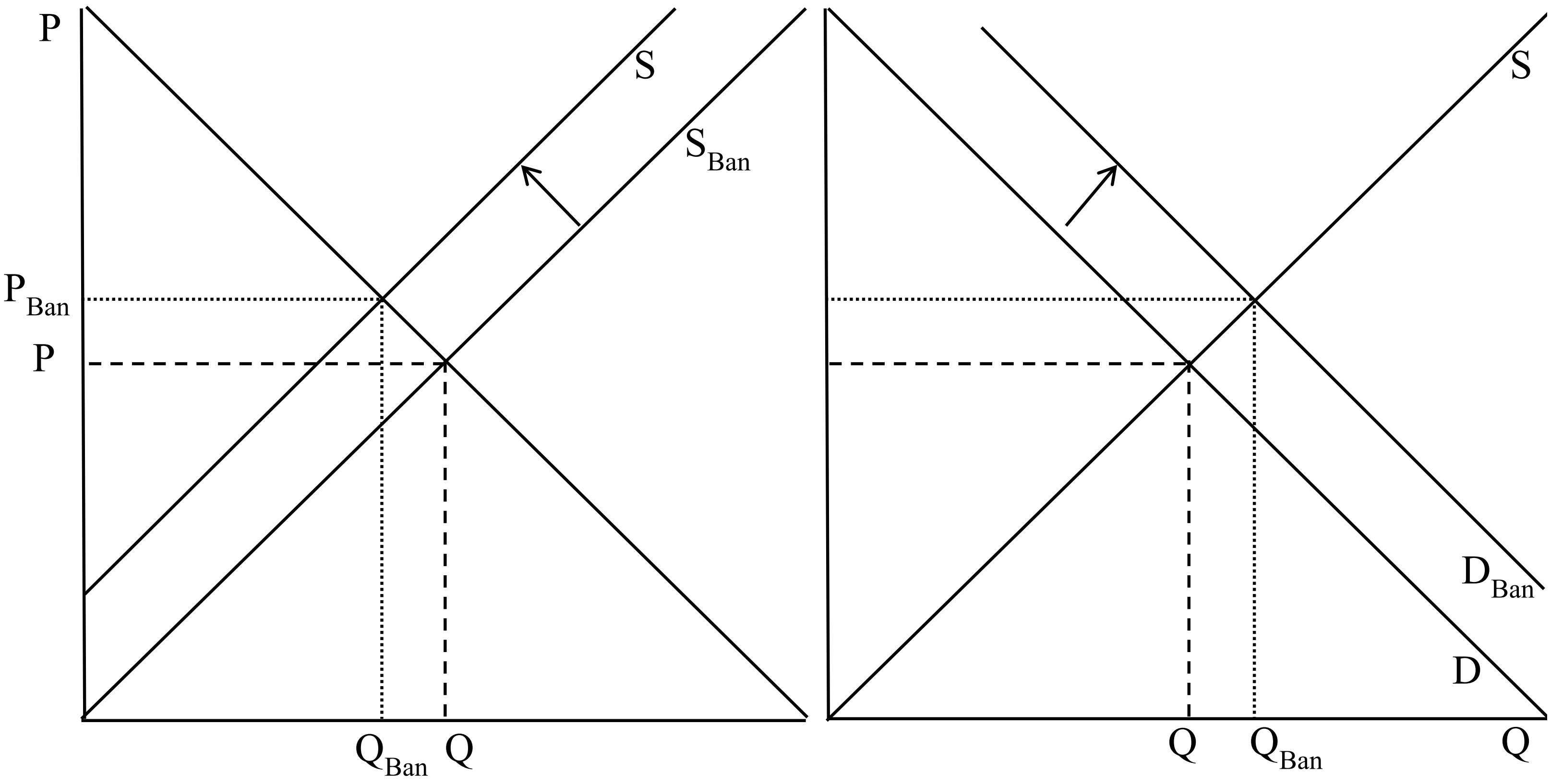

Figure 3.1. Short run (left) and long run (right) effects on supply and derived demand functions, respectively, resulting from a removal of selected pharmaceuticals at the feedlot level.

The removal of pharmaceutical technologies for growth promotion in accordance with GFI #209 and how this policy may affect the production landscape was evaluated by running three scenarios: (1) a baseline scenario, (2) removal of feed-grade antibiotics only, and (3) a removal of all growth enhancing technologies in U.S. beef cattle production. Similar to the model used by Lawrence and Ibarburu (2007), average daily gain and feed-to-gain ratios for feed-grade antibiotics, as well as all growth enhancing technologies (implants, ionophores, antibiotics, and beta-agonists) were used as the exogenous shocks to adjust the baseline scenario.

Lawrence and Ibarburu (2007) estimated that feed-grade antibiotics improved feedlot average daily gains by 3.37%, and the use of all growth enhancing technologies improved average daily gains by 37.31%. Additionally, antibiotics and all growth enhancing technologies decreased feed-to-gain by 2.69% and 24.16%, respectively. To determine the initial impact of GIF #209 a one-year deterministic industry outlook was created using 2014 NASS industry data. The deterministic model assumes growth-enhancing technologies improve average daily gains as well as feed-to-gain ratios, resulting in additional pounds of live animal, translating to heavier carcasses, therefore the removal of feed-grade antibiotics decreases total pounds produced per animal throughout the feeding period. This reduction in live weight for each alternative scenario was converted to a carcass weight equivalent, and the resulting difference was used as the year one exogenous shock in the large-scale system model.

Results and discussion

Table 3.1 and Table 3.2 present the deterministic model outputs using the stated reductions in average daily gains for feed-grade antibiotics and all growth-enhancing technologies, respectively. From these stand-alone models, the percent change in beef produced was converted to carcass weight then used as the initial shock to the large-scale systems model. The comparison is based on the 2014 baseline year representing a 0% change in technology use. For the purposes of the deterministic model, fed cattle inventories represent animal equivalents, calculated as a total reduction in beef produced, converted to an individual carcass equivalent, then converted back to live weight.

In the case of a removal of feed-grade antibiotics (Table 3.1), the changes in overall production appear relatively nominal; total fed cattle inventories are reduced by 270,000 animals, or 1.18% as compared to the baseline. The reduction in animals fed yields a 227.56 million pound loss in beef produced in the first year of the ban. In order to accommodate the loss in production, approximately 114,000 additional animal feeding days would have to be used to maintain baseline beef production.

Table 3.1. Deterministic model results comparing the baseline scenario with a 3.37% reduction in average daily gains resulting from the removal of feed-grade antibiotics at the feedlot level.

	Baseline[1]	Without antibiotics	Difference
Fed cattle inventory (million)	23.76	23.48	(0.27)
Steers (million)	15.38	15.21	(0.17)
Heifers (million)	8.38	8.28	(0.10)
Total beef (million lb)	19,964.32	19,736.76	(227.56)
Steers (million lb)	12,931.90	12,788.70	(143.20)
Heifers (million lb)	7,032.43	6,948.06	(84.36)
Total days on feed	4,354,122	4,468,010	113,889
Steers	2,645,050	2,714,236	69,185.
Heifers	1,709,071	1,753,775	44,703

[1] Baseline relative to 2014 NASS cattle industry numbers.

Table 3.2. Deterministic model results comparing the baseline scenario with a 37.31% reduction in average daily gains resulting from the removal of all growth enhancing technologies (GET) at the feedlot level.

	Baseline[1]	Without GET	Difference
Fed cattle inventory (million)	23.76	20.66	(3.09)
Steers (million)	15.38	13.45	(1.93)
Heifers (million)	8.38	7.22	(1.16)
Total pounds of beef (million)	19,964.32	17,803.85	(2,160.48)
Steers (million lb)	12,931.90	11,572.36	(1,359.54)
Heifers (million lb)	7,032.43	6,231.49	(800.94)
Total days on feed	4,354,122	6,020,754	1,666,632
Steers	2,645,050	3,657,499	1,012,449
Heifers	1,709,071	2,363,254	654,183

[1] Baseline relative to 2014 NASS cattle industry numbers.

The removal of all growth-enhancing technologies yields much greater changes in the one-year deterministic output (Table 3.2). With a reduction of 37.31% of average daily gains, fed cattle inventories are reduced by 3.09 million animals. The loss in fed cattle results in a reduction of 2.16 billion lb of beef produced, or a 10.82% total reduction. Overall, the reduction in beef produced necessitates almost 1.7 million additional feeding days to produce equivalent amounts of beef as compared to the baseline scenario.

Tables A1, A2, and A3 depict full model results for the baseline scenario, a removal of feed-grade antibiotics, and a removal of all growth-enhancing technologies, respectively. These appendix tables are the basis of the following tables included in this chapter. Tables 3.3 and 3.4 show the large-scale systems model outputs when the 1.18% and 10.82% reductions in total beef produced are incorporated as exogenous shocks from removals of feed-grade antibiotics and all growth-enhancing technologies, respectively. The baseline scenario and a removal of technologies scenario are compared at year 5-post ban, when it is assumed a majority of industry adjustments have already occurred. As well, the average change across years 6 through 10 is stated for comparison.

The results of removing feed-grade antibiotics (Table 3.3) project an industry wide attempt to close the production gap by increasing overall inventory numbers in response to higher cattle prices, similar to Figure 3.1. Beef cows, cattle and calves, and calf crop are all expected to increase by year 5, as well as continue to grow across years 6 through 10. This inventory growth is likely supported by increases in feeder steer prices. The number of cattle slaughtered is projected to increase as well, although at a slower rate than that of the other inventory related metrics. The increase by year 5 of approximately 100,000 animals continues to grow with years 6 through 10 averaging an additional 300,000 animals slaughtered annually. Despite harvesting slightly more cattle in year 5, total beef production is disproportionally lower, yielding 24.64 billion lb, a 2.7 million lb reduction. The decrease in total production is partially offset by increases in imported beef of approximately 20 million additional pounds. The lack of overall beef production causes an upward shift in the price of retail beef, effectively driving per capita consumption down by nearly a half pound per person, annually.

Table 3.3. Impact of withdrawing antibiotics from beef production 5 years post removal and average changes across years 6-10.

	Industry after 5 years			Average years 6-10		
	With antibiotics	Without antibiotics	Percent change	With antibiotics	Without antibiotics	Percent change
Inventory (million head)						
Beef cows	30.10	30.15	0.16%	30.56	30.63	0.24%
Cattle and calves	91.84	91.93	0.09%	92.82	92.97	0.16%
Calf crop	34.43	34.48	0.13%	34.55	34.61	0.19%
Cattle slaughter	30.17	30.18	0.03%	30.66	30.69	0.10%
Beef supply (billion lb)						
Production	24.91	24.64	-1.09%	25.81	25.55	-1.02%
Imports	2.93	2.95	0.84%	2.81	2.83	0.84%
Consumption (lb)	53.26	52.79	-0.89%	53.33	52.90	-0.80%
Price and returns						
Beef retail (¢/lb)	626.83	636.24	1.50%	632.07	639.21	1.13%
Fat steer ($/cwt)	145.61	147.84	1.53%	146.69	148.33	1.12%
Feeder steer ($/cwt)	188.08	190.63	1.36%	189.86	191.97	1.11%

Table 3.4. Impact of withdrawing all growth enhancing technologies (GET) from beef production 5 years post removal and average changes across years 6-10.

	Industry After 5 Years			Average Years 6-10		
	With GET	Without GET	Percent change	With GET	Without GET	Percent change
Inventory (million head)						
Beef cows	30.10	30.62	1.72%	30.56	31.39	2.71%
Cattle and calves	91.84	92.75	0.99%	92.82	94.52	1.84%
Calf crop	34.43	34.92	1.43%	34.55	35.26	2.06%
Cattle slaughter	30.17	30.22	0.13%	30.66	31.03	1.20%
Beef supply (billion lb)						
Production	24.91	22.30	-10.45%	25.81	23.36	-9.52%
Imports	2.93	3.19	9.14%	2.81	3.05	8.63%
Consumption (lb)	53.26	48.89	-8.21%	53.33	49.44	-7.28%
Price and returns						
Beef retail (¢/lb)	626.83	703.68	12.26%	632.07	699.68	10.70%
Fat steer ($/cwt)	145.61	162.49	11.59%	146.69	161.63	10.19%
Feeder steer ($/cwt)	188.08	211.71	12.56%	189.86	210.88	11.07%

The results of the model outlining the removal of all growth-enhancing technologies are shown in Table 3.4. Similar to estimates regarding the removal of feed-grade antibiotics, the industry responds by increasing inventories at the farm level in response to higher prices. Beef cows, cattle and calves, and calf crop increase into year 5 and continue to increase considerably across years 6 through 10. Additionally, the model estimates that an additional 50,000 animals by year 5, and an average of 370,000 in years 6 through 10 are slaughtered in an attempt to close the substantial losses in production. With production down 2.6 billion lb in year 5, imports begin to increase significantly. A lack of domestic production, even with greater imports, drives retail prices up considerably, reducing per capita consumption by 4.37 lb and 3.89 lb per person in year 5 and years 6 through 10, respectively.

Table 3.5 and Table 3.6 present the estimated percent changes from the baseline for each endogenous variable of interest for the removal of feed grade antibiotics and all growth enhancing technologies, respectively. In Table 3.5 it can be seen that the built in biological lag function of the model prevents the production metrics beef cows, cattle and calves, calf crop, and cattle slaughter from expanding in years one and two. To compensate for a lack of production of replacement cattle, year on year net exports decrease, as total production attempts to normalize and keep retail beef prices low, encouraging retail beef consumption. Just as exports decrease, beef imports increase, although the cumulative total of reduced exports and increased imports do not make up for the total lack of production. Increases in calf crop lead to more cattle slaughtered by year 10, but the losses in production from removing feed-grade antibiotics are not easily overcome and retail prices remain 6 cents, approximately 1% higher through the 10-year mark.

Table 3.5. Estimated percent changes from the baseline of endogenous variables of interest for a removal of feed-grade antibiotics at the feedlot level.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production	-1.09%	-1.15%	-1.16%	-1.11%	-1.09%	-1.09%	-1.04%	-1.01%	-1.00%	-0.97%
Imports	0.45%	0.73%	0.69%	0.73%	0.84%	0.82%	0.85%	0.87%	0.82%	0.82%
Exports	-0.36%	-0.69%	-0.71%	-0.81%	-1.01%	-1.14%	-1.24%	-1.33%	-1.35%	-1.37%
Domestic demand	-0.95%	-0.99%	-0.97%	-0.89%	-0.89%	-0.87%	-0.81%	-0.79%	-0.78%	-0.74%
Beef retail (¢/lb)	1.88%	1.77%	0.54%	0.95%	1.50%	1.23%	1.21%	1.24%	0.97%	0.99%
Fat steer ($/cwt)	1.34%	1.87%	0.42%	0.86%	1.53%	1.28%	1.19%	1.24%	0.95%	0.92%
Feeder steer ($/cwt)	1.62%	1.62%	0.82%	1.04%	1.36%	1.06%	1.21%	1.21%	0.99%	1.09%
Beef cows	0.00%	0.00%	0.04%	0.11%	0.16%	0.19%	0.22%	0.25%	0.27%	0.29%
Cattle and calves	0.00%	0.00%	0.02%	0.06%	0.09%	0.12%	0.15%	0.17%	0.18%	0.20%
Calf crop	0.00%	0.02%	0.06%	0.10%	0.13%	0.15%	0.17%	0.19%	0.20%	0.22%
Cattle slaughter	0.00%	-0.05%	-0.05%	-0.02%	0.03%	0.06%	0.09%	0.10%	0.12%	0.14%
Per capita consumption	-0.95%	-0.99%	-0.97%	-0.89%	-0.89%	-0.87%	-0.81%	-0.79%	-0.78%	-0.74%

Table 3.6. Estimated percent changes from the baseline of endogenous variables of interest for a removal of all growth-enhancing technologies at the feedlot level.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production	-10.43%	-10.90%	-11.05%	-10.83%	-10.45%	-10.05%	-9.70%	-9.45%	-9.27%	-9.15%
Imports	4.07%	6.97%	8.33%	8.92%	9.14%	9.04%	8.82%	8.60%	8.41%	8.24%
Exports	-2.79%	-5.40%	-7.43%	-9.06%	-10.31%	-11.25%	-11.94%	-12.46%	-12.85%	-13.15%
Domestic demand	-9.27%	-9.26%	-9.03%	-8.63%	-8.21%	-7.79%	-7.45%	-7.21%	-7.04%	-6.92%
Beef retail (¢/lb)	15.33%	15.10%	13.04%	12.50%	12.26%	11.54%	10.90%	10.49%	10.34%	10.23%
Fat steer ($/cwt)	12.10%	14.89%	12.81%	12.03%	11.59%	10.86%	10.30%	9.98%	9.91%	9.90%
Feeder steer ($/cwt)	16.16%	16.17%	13.97%	13.00%	12.56%	11.75%	11.23%	10.93%	10.80%	10.65%
Beef cows	0.00%	0.00%	0.39%	1.11%	1.72%	2.18%	2.53%	2.78%	2.97%	3.10%
Cattle and calves	0.00%	0.01%	0.20%	0.55%	0.99%	1.38%	1.68%	1.89%	2.05%	2.17%
Calf crop	0.00%	0.15%	0.57%	1.04%	1.43%	1.72%	1.94%	2.10%	2.22%	2.31%
Cattle slaughter	0.00%	-0.49%	-0.59%	-0.33%	0.13%	0.61%	1.00%	1.28%	1.48%	1.63%
Per capita consumption	-9.27%	-9.26%	-9.03%	-8.63%	-8.21%	-7.79%	-7.45%	-7.21%	-7.04%	-6.92%

The changes in production based on removing feed-grade antibiotics appear relatively nominal. Research suggests that small decreases in productivity associated with feeding antibiotics for growth promotion may be offset by production based adaptations such as increases in pen based hygiene, optimized nutritional plans, herd size limitations, or increases in biosecurity measures (Wierup, 2001; Barug et al., 2006; Lacminarayan et al., 2015). A majority of studies conducted regarding the removal of feed-grade antibiotics are centered on pork or poultry production. These studies fail to address the likely scenario that the removal of feed-grade antibiotics would result in a higher degree of liver condemnations, thus reducing saleable product. Additionally, increases in liver abscesses further reduce average daily gains; potentially further reducing beef production associated with a removal of feed-grade antibiotics.

Table 3.6 shows just how drastic the year on year changes are across the entire beef industry. The biological lag associated with increasing calves on the ground, then cattle ready for slaughter extremely disadvantages the industry’s ability to keep up with decreases in production. Just as in Table 3.5 imports rise and exports fall, but after losing 10.82% of total beef production in year one the initial losses continue to outweigh any additional pounds of beef. Slaughter cattle numbers fall slightly in years 2, 3, and 4, likely due to the model’s response to rebuild beef cows and cattle and calf numbers in response to higher prices brought on by decreases in demand. Total beef production still remains considerably depressed through year 10 as cattle slaughter moves back up in years 5 through 10.

The model estimates that by year 10 the likely result of a policy removing all growth-enhancing technologies would be a 1.83 million lb or 6.92% reduction, in domestic beef consumption, resulting from lower levels of total beef production and higher retail prices. As feedlot average daily gains are reduced by 37.31% the resulting industry impact would be highly detrimental at the retail level. With retail beef prices approximately 10% higher coupled with the removal of 2.6 billion lb of beef production, the cattle industry stands to see a more rapid decline in per capita beef consumption. Since 1976, per capita consumption has declined 40% (Elam and Preston, 2004) in the first year following the removal of all growth enhancing technologies, reducing per capita consumption by 5.1 may be difficult for the beef industry to overcome.

Within this model, retail prices are projected to increase to the point that consumers would likely seek other protein substitutes. As the price of food increases consumers are forced to spend larger percentages of their total income on food. Within higher income brackets the effects are less severe, but as total household income is lowered consumer are forced to make unfavorable sacrifices. Higher food expenditures reduce lower income households' available disposable income and access to savings, subjecting them to greater sensitivities to other price fluctuations within their normal purchasing patterns i.e. rent, clothes, transportation, etc. (Yousif and Al-Kahtani, 2014).

A trade-off must be made between purchasing higher nutritional value foods and purchasing lower quality substitute goods. As food prices increase, the percentage of food consumed away from home, consumptions of sugary drinks, and purchases of meals ready to eat increase, effectively deteriorating the long-term health of lower income consumers (Ni Mhurchu et al., 2013). Although the removal of growth-enhancing technologies may open up more export markets for U.S. beef, increases in export sales would likely not offset the total losses in domestic consumption. Moreover, increasing exports of U.S. beef would only drive domestic prices higher further establishing beef as a high priced luxury item.

Conclusion

By altering production parameters associated with beef cattle production, consumers are faced with higher retail prices while producers at the farm level are forced to expand their herds. Feedlots are purchasing higher priced cattle with increases in associated production costs. The term "sustainability" in agricultural production is often interpreted to mean natural or free of certain technologies. This study has shown that the removal of technological advances in beef cattle production decrease production efficiency as well as potentially increases beef production's negative environmental impacts while simultaneously decreasing both societal and animal welfare.

CHAPTER IV

THE ECONOMIC IMPACT OF REMOVING PREVENTATIVE LIVER ABSCESS CONTROLS

Introduction

Increasing public concerns over the use of antibiotics in animal agriculture have been the vehicle for increased regulations on use of pharmaceuticals in livestock production. Restaurant chains are publicly requiring their suppliers to produce goods that meet a limited to no antibiotic policy. Chains like Chipotle tout it as “food with integrity,” furthering the notion that the use of antibiotics is harmful (Chipotle, 2016). SUBWAY (2015) has vowed to remove all antibiotics in their animal proteins by 2025, starting with chicken by the end of 2016 and turkey following within 2-3 years. SUBWAY’s executive vice president of the company’s independent purchasing cooperative stated “today’s consumer is ever more mindful of what they are eating, and we’ve been making changes to address what they are looking for... we hope that this commitment will encourage other companies in our industry to follow our lead, and that, together, this will drive suppliers to move faster to make these important changes for consumers” (SUBWAY, 2015). This statement implies that the new policies implemented by SUBWAY are not rooted in foundational science, but instead in consumer perception.

A considerable amount of research has been conducted investigating the use of antibiotics in animal agriculture and its interactions in human health (Avery and Avery 2007; Cox and Popken, 2007; Mathew et al., 2007; Wileman et al., 2009; Johnson, 2011;

Capper and Hayes, 2012; Johnson et al., 2013). There is still a limited understanding of the overall relationships between antimicrobial resistance and pharmaceutical use in food animal production.   Interventions into animal production are seeking an end to the use of selected pharmaceuticals deemed medically important in human medicine. To date, the livestock industry has been relatively proactive in dealing with proposed regulations, but a majority of the literature regarding a removal of antibiotics revolves around the pork and poultry industries. Additionally, much of the current literature dealing with a removal of antibiotics in beef cattle production center on a removal of selected pharmaceuticals that have not been deemed medically important in human medicine (i.e. ionophores and beta agonists). Programs aimed at limiting antibiotics administered in feed or water are already being implemented through GIF #209 (FDA, 2012c). Among the affected pharmaceuticals, antibiotics used to suppress *Fusobacterium necrophorum* (the primary pathogen responsible for liver abscess formations) will now require a veterinary feed directive.

Liver abscesses are generally controlled through the use of feed-grade antibiotics in feedlot cattle. There are five antibiotics approved for prevention of liver abscesses in feedlot cattle: bacitracin, chlortetracycline (tetracycline), oxytetracycline (tetracycline), tylosin (macrolides), and virginiamycin (streptogramins) (Herrman and Stokka, 2002). Of the five approved preventative medications, bacitracin is the only one not listed as medically important in human medicine, but has been reported as of limited to no use for the prevention of liver abscesses in feedlot cattle (USDA, 2013). Tylosin is the most effective and the most commonly used feed additive for the control of liver abscesses, being fed to 70% of cattle in feedlots and reducing condemnation rates by 40 to 70% (Elanco, 2012; USDA, 2013). Oxytetracycline is the second most used feed additive (USDA, 2013).

Liver abscesses resulting from aggressive grain feeding programs represent a major economic liability to feedlot operators, packers, and consumers with condemnation rates averaging 12 to 32% in most feedlots (Brink et al., 1990; Nagaraja and Chengappa, 1998). Condemned livers are not suitable for human consumption and may either be severely discounted and sold for pet food or destroyed. Other economic considerations associated with the presence of liver abscesses include reductions in: feed intake, average daily gain, and feed efficiency.

The purpose of this of this study was to analyze the potential economic impacts of a removal of feed grade antibiotics used to treat liver abscesses in U.S. feedlot cattle. An equilibrium displacement model was constructed to investigate the effects of not only losses in animal efficiency, but also liver condemnation rates of affected cattle.

Methods and model development

Equilibrium displacement models have been demonstrated as a valuable tool in assessing the effects of exogenous shocks in “raw material-oriented industries”, where each material source can be treated as a separate industry within a vertically related marketing chain for a given commodity (Muth, 1964; Pendell et al., 2010). Equilibrium displacement models links beef, pork, and poultry demands horizontally across industries at the retail level, and vertically within each market for the feeder, slaughter, wholesale, and retail levels. The economic impact of technologies on the production system is a shift in the supply curve. Decreasing productivity causes a leftward shift in supply iteratively changing each vertical marketing segment through the use of transmission elasticities, and transferring between industries horizontally through cross-price elasticities.

Figure 4.1 depicts an exogenous shock to the beef industry as a result of removing feed grade antibiotics at the “slaughter” level. Each market level in Figure 4.1 depicts a whole marketing segment, where Feeder represents farm to feeder cattle, Slaughter is the feedlot level ending with fed (or slaughter) cattle, Wholesale spans from fed cattle through processing, and Retail is the consumer level. Under this model it is assumed that the primary demand function (D_r^0) is drawn at the retail level, while the primary supply function (S_f^0) is drawn at the feeder level. From here, the derived relationships are feeder cattle demand (D_f^0), slaughter cattle supply (S_s^0) and demand (D_s^0), wholesale supply (S_w^0) and demand (D_w^0), and retail supply (S_r^0). Therefore, the changes in prices and quantities within each market level can be calculated using elasticities of supply and demand for each level; intra-market segments are connected through transmission elasticities between each vertical level (Pendell et al., 2010; Schroeder and Tonsor, 2011). Initial equilibrium is denoted by superscript 0 where the initial market prices are (P_r^0, P_w^0, P_s^0, P_f^0,) corresponding to retail, wholesale, slaughter and feeder, respectively. Quantity (Q^0) represents the initial equilibrium quantity at the intersections of each supply and demand curve.

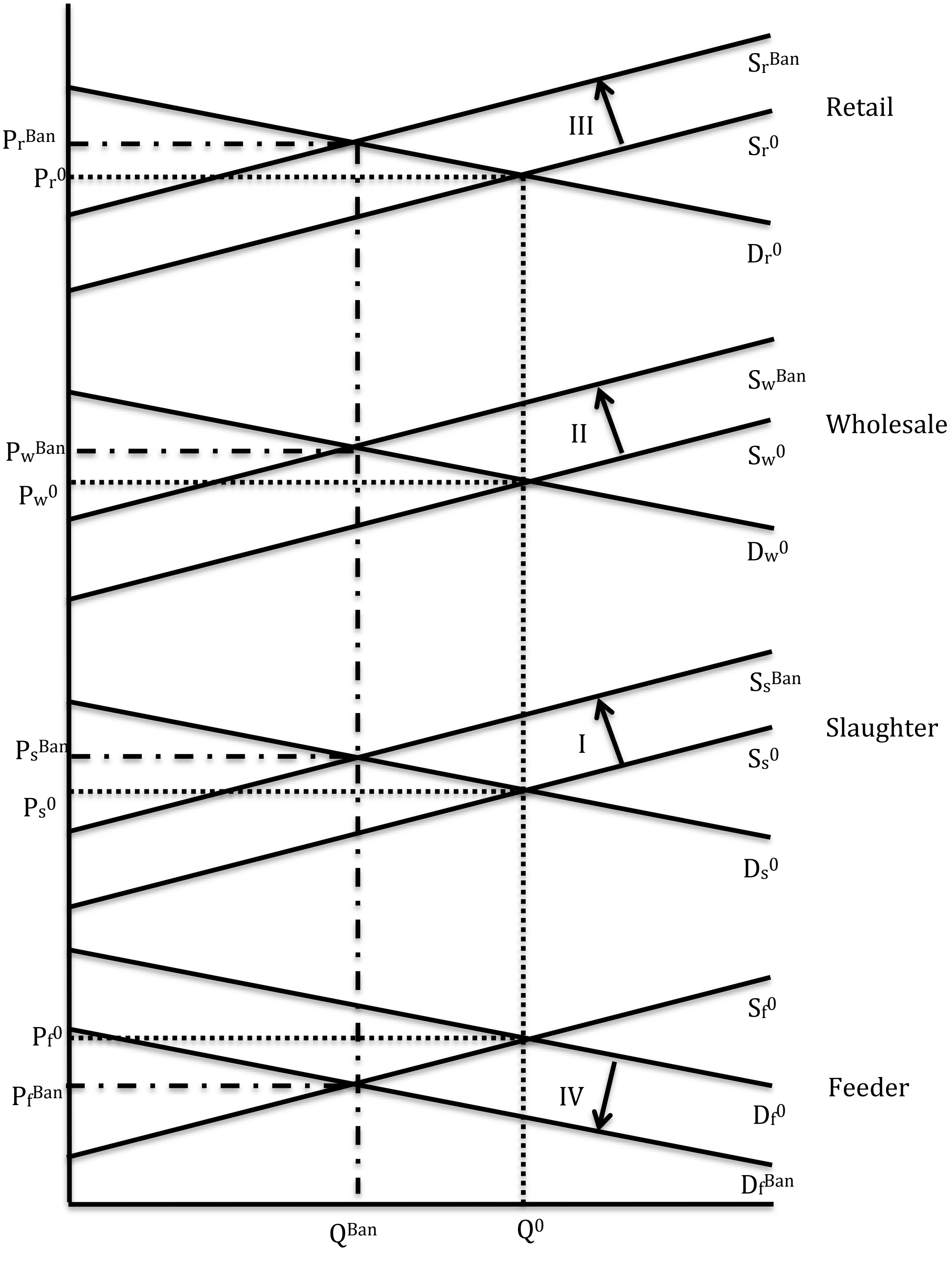

Figure 4.1. Effects of a removal of selected pharmaceuticals initiated at the slaughter level.

The removal of feed grade antibiotics is introduced into the model as an exogenous shock to the slaughter level and is denoted by shift I and results in new derived price S_s^{ban}. As previously mentioned, transmission elasticities are utilized to calculate changes as they occur intra-market. Wholesale supply (S_w^0) is calculated as a function of supply at the slaughter level (S_s^0). Additionally, retail supply (S_r^0) is calculated from wholesale supply (S_w^0). Therefore, shift I at the slaughter level results in a corresponding shift II at the wholesale level, translating to shift III at the retail level. Shift II results in wholesale supply curve S_w^{ban} and shift III at the retail level draws S_r^{ban} at the retail level. The overall result of a leftward shift in the supply curve is an increase in price resulting in a decrease in overall quantity demanded, as noted by the shift from Q^0 to Q^{ban}. With retail operating within the model as primary demand and the feeder sector responding as primary supply, the reduction in quantity demanded at the retail level results in the corresponding leftward, IV, and shifts derived demand at the feeder level (D_f^0) establishing D_f^{ban}.

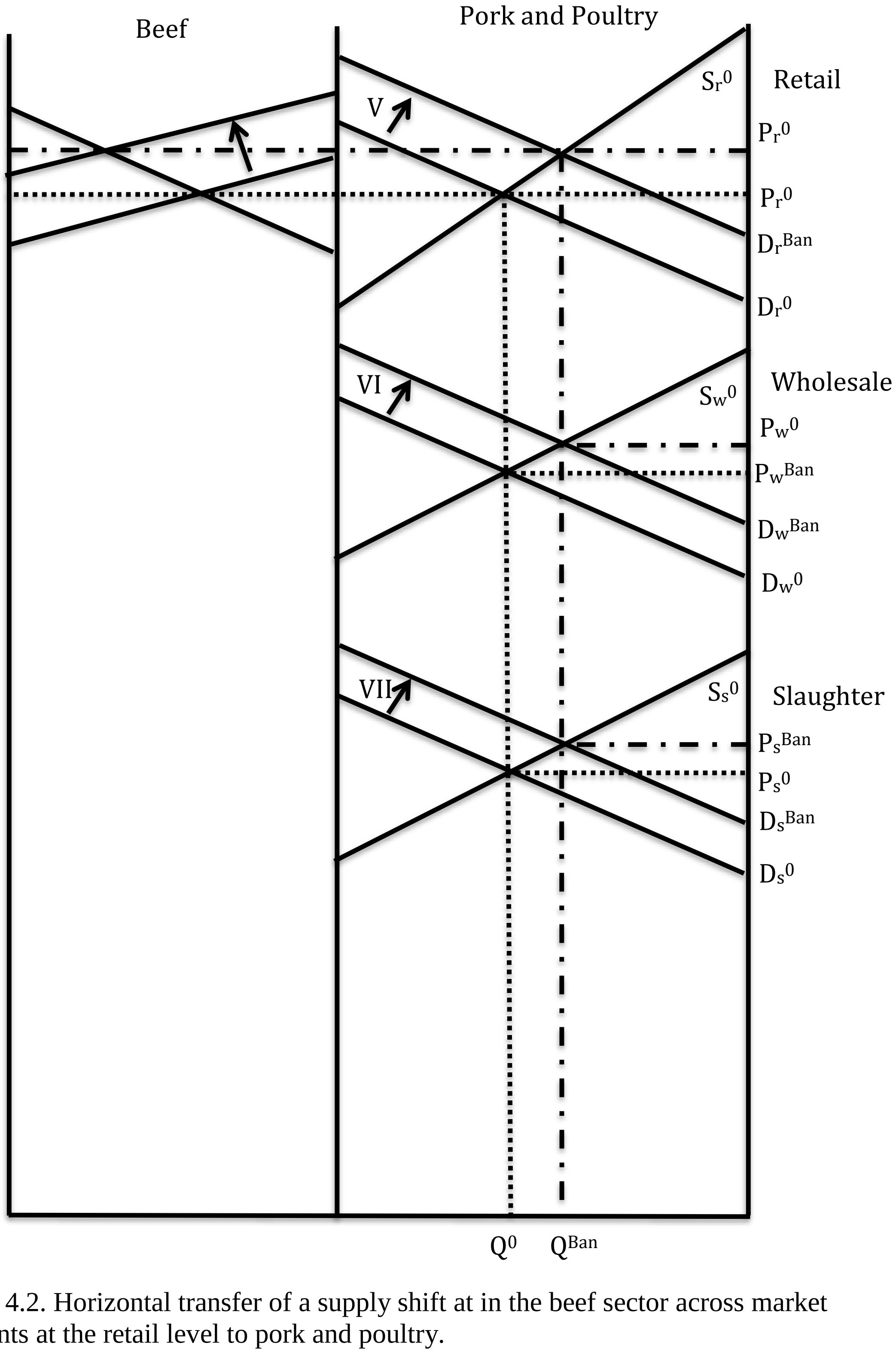

Figure 4.2. Horizontal transfer of a supply shift at in the beef sector across market segments at the retail level to pork and poultry.

Figure 4.2 depicts how the model moves horizontally between commodities utilizing inter-market cross-price elasticities to transfer between markets at the retail level allowing for a substitution effect for beef products. It should be noted that Figure 4.2 shows a reduced form model for the beef sector for ease of viewing. The leftward shift of the supply curve at the retail beef sector reduces the quantity of total meat supplied at the retail level, effectively creating a market void for total retail meat. The reduction in quantity of beef supplied is filled by a rightward shift in demand at both the pork and poultry markets. The rightward shift allows for an increase in prices across all market segments at a higher quantity demanded. Similar to the beef model in Figure 4.1 intra-market transmission elasticities are utilized to calculate supply shifts V and VI at the wholesale and slaughter levels, respectively. Unlike the beef sector model that utilizes a primary supply function stemming from the feeder sector, the pork and poultry models are predicated solely on retail beef demand as the primary demand shifter.

Equilibrium displacement model

An equilibrium displacement model is a linear approximation of unknown supply and demand functions. Each supply and demand function allows for variable input proportions that let the model adjust inputs and outputs based on changing production quantities across market segments (Muth et al., 2007; Pendell et al., 2010). The equilibrium displacement model is composed of three meat sectors beef, pork, and poultry with independently operated marketing segments within each meat sector. Beef is made up of feeder, slaughter, wholesale and retail, pork is comprised of slaughter, wholesale, and retail, and poultry only includes the wholesale and retail sectors. The model in this study is formatted similar to that of Schroeder and Tonsor (2011) in that the exogenous changes initiated within the beef-marketing channel have iterative effects across all market segments.

The typical market for a good is represented by a basic supply and demand function and a general market clearing condition as:

(1) $Q_d = f\,(P_d, Z)$ Demand

(2) $Q_s = f\,(P_s, W)$ Supply

(3) $Q_s = Q_d$ Equilibrium

For the demand function (1), Q_d is a function of the own price of good P_d and demand shifting variables Z. The supply function (2) has arguments P_s and W, which represent own price of Q_s and the supply shifting variables, respectively. The demand and supply shifters may be any variables thought to affect their respective curves, including but not limited to consumer taste and preference changes, interactions of substitutes and compliments, policy implementations, and technological advances. Equation 3 imposes the market clearing condition.

Next, equations 1-3 are expressed in total log differential form then converted into elasticity form.

(4) $EQ_d = \eta_d\,(EP_d + EZ)$ Demand

(5) $EQ_s = \varepsilon_s\,(EP_s + EW)$ Supply

(6) $EQ_s = EQ_d$ Equilibrium

For any variable *EX*, *E* represents the relative change in *X* and is represented as, $dX/X = d \ln X$. Parameters η_d and ε_s are the own-price elasticities of demand and supply, and *EZ* and *EW* are shifts in the demand and supply curves relative to initial price and quantity equilibrium, respectively.

Structural supply and demand model

The structural equations for both supply and demand are given in equations 7 through 30. Each endogenous price and quantity variable are represented as P and Q, respectively and are written in the form X_{kl}^{ij} where *i* represents the market level (r = retail, w = wholesale, s = slaughter, and f = feeder). Superscript *j* represents either the supply (s) or demand (d) function. Subscript *k* denotes the specific market of interest (B = beef, K = pork, and Y = poultry). Finally, subscript *l* represents the wholesale segment import (i) or export (e), when applicable. Within this model, market levels are linked downstream by quantity variables utilizing demand equations and upstream quantity variables utilizing supply equations (Wohlgenant, 1993).

BEEF SECTOR

<u>*Beef Retail Level*</u>

Retail beef primary demand

(7) $Q_B^{rd} = f_1\,(P_B^{rd}, P_K^{rd},\ P_Y^{rd},\ Z_B^{rd})$

Retail beef derived supply

(8) $Q_B^{rs} = f_2\,(P_B^{rs}, Q_B^{ws},\ W_B^{rs})$

Beef Wholesale Level

Wholesale beef derived demand

(9) $Q_B^{wd} = f_3\,(P_B^{wd}, Q_B^{rd},\ Z_B^{wd})$

Wholesale beef derived supply

(10) $Q_B^{ws} = f_4\,(P_B^{ws}, Q_B^{ss}, Q_{Bi}^{ws}, Q_{Be}^{wd},\ W_B^{ws})$

Imported beef derived demand

(11) $Q_{Bi}^{wd} = f_5\,(P_{Bi}^{wd}, Q_B^{wd},\ Z_{Bi}^{wd})$

Imported beef derived supply

(12) $Q_{Bi}^{ws} = f_6\,(P_{Bi}^{ws},\ W_{Bi}^{ws})$

Exported beef derived demand

(13) $Q_{Be}^{wd} = f_7\,(P_B^{wd},\ Z_{Be}^{wd})$

Beef Slaughter Level

Slaughter cattle derived demand

(14) $Q_B^{sd} = f_8\,(P_B^{sd}, Q_B^{sd},\ Z_B^{sd})$

Slaughter cattle derived supply

(15) $Q_B^{ss} = f_9\,(P_B^{ss}, Q_B^{fs},\ W_B^{ss})$

Beef Feeder Level

Feeder cattle derived demand

(16) $Q_B^{fd} = f_{10}\,(P_B^{fd}, Q_B^{sd},\ Z_B^{fd})$

Feeder cattle primary supply

(17) $Q_B^{fs} = f_{11}\,(P_B^{fs}, W_B^{fs})$

PORK SECTOR

Pork Retail Level

Retail pork derived demand

(18) $Q_K^{rd} = f_{12}\,(P_K^{rd}, P_B^{rd},\ P_Y^{rd},\ Z_K^{rd})$

Retail pork derived supply

(19) $Q_K^{rs} = f_{13}\,(P_K^{rs}, Q_K^{ws},\ W_K^{rs})$

Pork Wholesale Level

Wholesale pork derived demand

(20) $Q_K^{wd} = f_{14}\,(P_K^{wd}, Q_K^{rd},\ Z_K^{wd})$

Wholesale pork derived supply

(21) $Q_K^{ws} = f_{15}\,(P_K^{ws}, Q_K^{ss}, Q_{Ki}^{ws}, Q_{Ke}^{wd},\ W_K^{ws})$

Imported pork derived demand

(22) $Q_{Ki}^{wd} = f_{16}\,(P_{Ki}^{wd}, Q_K^{wd},\ Z_{Ki}^{wd})$

Imported pork derived supply

(23) $Q_{Ki}^{ws} = f_{17}\,(P_{Ki}^{ws},\ W_{Ki}^{ws})$

Exported pork derived demand

(24) $Q_{Ke}^{wd} = f_{18}\,(P_K^{wd},\ Z_{Ke}^{wd})$

Slaughter Hog Level

Slaughter hog derived demand

(25) $Q_K^{sd} = f_{19}\,(P_K^{sd}, Q_K^{wd}, Z_K^{sd})$

Slaughter hog derived supply

(26) $Q_K^{ss} = f_{20}\,(P_K^{ss}, W_K^{ss})$

POULTRY SECTOR

Poultry Retail Level

Retail poultry derived demand

(27) $Q_Y^{rd} = f_{21}\,(P_Y^{rd}, P_B^{rd}, P_K^{rd}, Z_Y^{rd})$

Retail poultry derived supply

(28) $Q_Y^{rs} = f_{22}\,(P_Y^{rs}, Q_Y^{ws}, W_Y^{rs})$

Poultry Wholesale Level

Wholesale poultry derived demand

(29) $Q_Y^{wd} = f_{23}\,(P_Y^{wd}, Q_Y^{rd}, Z_Y^{wd})$

Wholesale poultry derived supply

(30) $Q_Y^{ws} = f_{24}\,(P_Y^{ws}, W_Y^{ws})$

Table 4.1 outlines the variable definitions from equations 7 through 30 as well as gives the estimates used throughout the equilibrium displacement model.

Table 4.1 Variable definitions and endogenous estimates for the structural equilibrium displacement model, 2014.

Symbol	Definition	Mean [a]
Q_B^r	Quantity of retail beef, billions pounds	17.95
P_B^r	Price of Choice retail beef, cents per pound	528.93
P_K^r	Price of retail pork, cents per pound	364.39
P_Y^r	Price of retail poultry, cents per pound	196.50
Q_B^w	Quantity of wholesale beef, billions pounds	25.26
P_B^w	Price of wholesale Choice beef, cents per pound	298.48
Q_B^s	Quantity of slaughter cattle beef, billion pounds (live weight)	25.72
Q_{Bi}^w	Quantity of beef imports, billion pounds (carcass weight)	2.25
Q_{Be}^w	Quantity of beef exports, billion pounds (carcass weight)	2.583
P_{Bi}^w	Price of beef imports, cents per pound	298.48
P_B^s	Price of slaughter cattle, dollars per hundred weight (live weight)	125.88
Q_B^f	Quantity of beef obtained from feeder cattle, billion pounds (live weight)	28.82
P_B^f	Price of feeder cattle, dollars per hundred weight	150.54
Q_K^r	Quantity of retail pork, billions pounds	13.46
Q_K^w	Quantity of wholesale pork, billions pounds	23.21
P_K^w	Price of wholesale pork, cents per pound	92.55
Q_K^s	Quantity of pork obtained from slaughter hogs, billions pounds (live weight)	23.19
Q_{Ki}^w	Quantity of pork imports, billion pounds (carcass weight)	0.88
Q_{Ke}^w	Quantity of pork exports, billion pounds (carcass weight)	4.99

Table 4.1 (continued)

Symbol	Definition	Mean [a]
P_{Ki}^{w}	Price of pork imports, cents per pound	152.00
P_{K}^{s}	Price of slaughter hogs, \$/cwt (live weight)	87.16
Q_{Y}^{r}	Quantity of retail poultry, billions pounds	31.51
Q_{Y}^{w}	Quantity of wholesale poultry, billions pounds	37.43
P_{Y}^{w}	Price of wholesale poultry, cents per pound	99.70
Z_{kl}^{i}	Demand shifters at the *i*th market level for the *k*th commodity and *l*th market (domestic/import)	--[b]
W_{kl}^{i}	Supply shifters at the *i*th market level for the *k*th commodity and *l*th market (domestic/import)	--[b]

[a] All prices and quantities reflect 2014 annual averages as reported by the Livestock Marketing Information Center.
[b] Variables without means are model inputs without reported means.

Linear elasticity model

As noted earlier, totally differentiating equations 7 through 30 of the structural model and converting these equations to elasticity form yields the linear elasticity model outlined in equations 31 through 54. Through the linear elasticity model, exogenous shocks Z and W can be measured as percent changes from initial equilibrium. Introduced in this model segment are variables g and t which represent supply and demand quantity transmission elasticities. The transmission elasticities quantify the percent change in a desired market level given a 1% change in another specified market level and are measured as $X_{K}^{ii'}$ where *i* represents the affected market level (r = retail, w =

wholesale, s = slaughter, and f = feeder), and *i'* represents the secondary market level (r = retail, w = wholesale, s = slaughter, and f = feeder) affecting *i*. Subscript *k* denotes the specific market of interest (B = beef, K = pork, and Y = poultry).

BEEF SECTOR

(31) $EQ_B^r = h_B^r EP_B^r + h_{BK}^r EP_K^r + h_{BY}^r EP_Y^r + Ez_B^r$

(32) $EQ_B^r = e_B^r EP_B^r + g_B^{wr} EQ_B^w + Ew_B^r$

(33) $EQ_B^w = h_B^w EP_B^w + t_B^{rw} EQ_B^r + Ez_B^w$

(34) $EQ_B^w = e_B^w EP_B^w + g_B^{sw}(Q_B^s / Q_B^w)EQ_B^s + (Q_{Bi}^w / Q_B^w)EQ_{Bi}^w - (Q_{Be}^w / Q_B^w)EQ_{Be}^w + Ew_B^r$

(35) $EQ_{Bi}^w = h_{Bi}^w EP_B^w + t_B^{rw} EQ_B^w + (Q_{Bi}^w / Q_B^w)Ez_{Be}^w + Ez_B^r$

(36) $EQ_{Bi}^w = e_{Bi}^w EP_{Bi}^w + Ew_{Bi}^w$

(37) $EQ_{Be}^w = h_{Be}^w EP_B^w + Ez_{Be}^r$

(38) $EQ_B^s = h_B^s EP_B^s + t_B^{ws} EQ_B^w + (Q_{Be}^w / Q_B^w)Ez_{Be}^w + Ez_B^s$

(39) $EQ_B^s = e_B^s EP_B^s + g_B^{fs} EQ_B^f + Ew_B^s$

(40) $EQ_B^f = h_B^f EP_B^f + t_B^{sf} EQ_B^s + Ez_B^f$

(41) $EQ_B^f = e_B^f EP_B^f + Ew_B^f$

PORK SECTOR

(42) $EQ_K^r = h_K^r EP_K^r + h_{KB}^r EP_B^r + h_{YK}^r EP_Y^r + Ez_K^r$

(43) $EQ_K^r = e_K^r EP_K^r + g_K^{wr} EQ_K^w + Ew_K^r$

(44) $EQ_K^w = h_K^w EP_K^w + t_K^{rw} EQ_K^r + Ez_K^w$

(45) $EQ_K^w = e_K^w EP_K^w + g_K^{sw}(Q_K^s / Q_K^w) EQ_K^s + (Q_{Ki}^w / Q_K^w) EQ_{Ki}^w - (Q_{Ke}^w / Q_K^w) EQ_{Ke}^w + Ew_K^r$

(46) $EQ_{Ki}^w = h_{Ki}^w EP_K^w + t_K^{rw} EQ_K^w + (Q_{Ki}^w / Q_K^w) Ez_{Ke}^w + Ez_K^r$

(47) $EQ_{Ki}^w = e_{Ki}^w EP_{Ki}^w + Ew_{Ki}^w$

(48) $EQ_{Ke}^w = h_{Ke}^w EP_K^w + Ez_{Ke}^r$

(49) $EQ_K^s = h_K^s EP_K^s + t_K^{ws} EQ_K^w + (Q_{Ke}^w / Q_K^w) Ez_{Ke}^w + Ez_K^s$

(50) $EQ_K^s = e_K^s EP_K^s + Ew_K^s$

POULTRY SECTOR

(51) $EQ_Y^r = h_Y^r EP_Y^r + h_{YB}^r EP_B^r + h_{YK}^r EP_K^r + Ez_Y^r$

(52) $EQ_Y^r = e_Y^r EP_Y^r + g_Y^{wr} EQ_Y^w + Ew_Y^r$

(53) $EQ_Y^w = h_Y^w EP_Y^w + t_Y^{rw} EQ_Y^r + Ez_Y^w$

(54) $EQ_Y^w = e_Y^w EP_Y^w + Ew_Y^r$

Again, *EX* represents the relative change operator of *X* and is represented as, $dX/X = d \ln X$. Additionally, z_k^i and w_k^i represent the single elements that are influenced by the removal of pharmaceuticals at the slaughter level of the supply and demand shifters Z_k^i and W_k^i, respectively. All other elements of Z_k^i and W_k^i are assumed to be unaffected within the model. Table A.4 and Table A.5 define the elasticity estimates and quantity transmission elasticities used in the linear elasticity model.

Exogenous shock to the beef sector

The exogenous shock to the equilibrium displacement model is applied at the beef slaughter sector through equation 39, value Ew_B^s, where w_B^s represents a single element of the total demand shifter W_B^s. For this analysis, w_B^s represents the percent change in production associated with the removal of feed-grade antibiotics administered for the treatment of liver abscess control, in accordance with GFI #209.

The exogenous shock was calculated assuming 31% of total feedlots fed liver abscess controls to 71.2% of all cattle fed in the United States (USDA, 2013). By removing liver abscess controls, cattle average daily gains have been estimated to be reduced by 2.3% up to 5.7%, and even as high as 11% in some cases (Rust et al., 1980; Brown and Lawrence, 2010; Elanco, 2014). Reductions in average daily gains associated with incidents of liver abscess are assumed to be additive to reductions resulting from a removal of antibiotics of 3.37% as stated by Lawrence and Ibarburu (2007). Therefore, a 9% reduction in total average daily gain was used to model the preliminary shock. Assuming all animals were fed for the same duration and on the same nutritional plane, total weight gain in the feedlot was estimated to be 63 lb less, or -4.96%, for cattle not fed antibiotics. The resulting economic impact combining the market penetration of liver abscess controls coupled with a reduction in total fed weights results in a leftward shift of the slaughter level supply curve of 7.81%.

Results and discussion

Appendix tables A6, A7, and A8 include the full equilibrium displacement model results for all market levels of the beef, pork, and poultry sectors, respectively. The remaining tables herein are derived from those results.

Table 4.2 presents the estimated changes in prices and quantities for all meat markets and intra-market segments resulting from a removal of antibiotics administered in feed or water, relative to a 0% change in the use of antibiotics. The results are shown with year 1 representing the first full year of removing feed grade antibiotics, where year 0 would refer to values outlined in Table 4.1. The results outlined in Table 4.2 align appropriately with the theoretical expectations depicted in Figure 4.1 and Figure 4.2. The results of the equilibrium displacement model show that over 10 years, all prices and quantities reach a zero, or near zero percent change for year 10. The establishment of a relatively nominal percent change suggests the market has equilibrated at a new market structure. With higher prices and less quantity in the beef sector, and higher prices and more quantity supplied for both pork and poultry markets.

Overall, the model estimates that the beef industry will observe a roughly 3 to 4% reduction in quantities produced across all beef market segments in just the first year. With retail beef prices projected to increase by 2.89% in year one, consumers will likely seek to substitute beef with a cheaper good, creating a market void for meat. While notably smaller than the decreases in beef quantities, the pork and poultry sectors expect to see an increase in quantities produced across all levels attempting to fill an established demand for protein products. The only exception is the quantity of exported wholesale pork, which decreases by 1.26% in the first year. The decrease in pork exports is likely due to higher domestic pork prices for producers encouraging more domestic sales of pork coupled with significantly higher beef prices at the retail level.

Within the beef sector, all quantities are reduced as prices increase, except for the price of feeder cattle, which increases approximately 14 cents per pound. With the feeder sector representing the primary supply function within this model, lower quantities demanded at each segment paired with higher prices throughout the beef marketing chain result in an inability for producers at the slaughter level to bid as aggressively for feeder cattle. A 4.26% lower cattle placement coupled with the losses in production associated with removing feed grade antibiotics drastically reduce the margins by which the slaughter level producers get paid. The end result is fewer feeder cattle supplied at a reduced price until the market establishes a new equilibrium.

The following tables (Table 4.3, Table 4.4, and Table 4.5) show the calculated net change (cumulative change) at interval years 1, 3, 5, 7, and 10. These tables show that, for all markets, approximately 50% of the 10-year net change occurs in year 1. The largest first year change, as expected, is within the slaughter cattle sector with a 4.45% reduction in quantities supplied and an 11.13% increase in slaughter cattle price.

Table 4.2. Estimated percent changes of endogenous variables from the removal of feed grade liver abscess control

Endogenous variable	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Retail beef quantity	-3.12%	-1.76%	-0.81%	-0.39%	-0.19%	-0.09%	-0.05%	-0.02%	-0.01%	-0.01%
Wholesale beef quantity	-4.05%	-2.29%	-1.05%	-0.50%	-0.25%	-0.12%	-0.06%	-0.03%	-0.01%	-0.01%
Imported beef quantity	-3.10%	-1.75%	-0.81%	-0.39%	-0.19%	-0.09%	-0.05%	-0.02%	-0.01%	-0.01%
Exported beef quantity	-4.25%	-2.40%	-1.10%	-0.53%	-0.26%	-0.13%	-0.06%	-0.03%	-0.02%	-0.01%
Slaughter cattle quantity	-4.45%	-2.51%	-1.15%	-0.55%	-0.27%	-0.13%	-0.07%	-0.03%	-0.02%	-0.01%
Feeder cattle quantity	-4.26%	-2.41%	-1.10%	-0.53%	-0.26%	-0.13%	-0.06%	-0.03%	-0.02%	-0.01%
Retail pork quantity	0.65%	0.37%	0.17%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
Wholesale pork quantity	0.64%	0.36%	0.17%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
Imported pork quantity	0.59%	0.34%	0.15%	0.07%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
Exported pork quantity	-1.26%	-0.71%	-0.33%	-0.16%	-0.08%	-0.04%	-0.02%	-0.01%	0.00%	0.00%
Slaughter hog quantity	0.62%	0.35%	0.16%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
Retail poultry quantity	0.65%	0.37%	0.17%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
Wholesale poultry quantity	0.68%	0.38%	0.18%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
Retail beef price	2.89%	1.63%	0.80%	0.39%	0.19%	0.09%	0.05%	0.02%	0.01%	0.01%
Wholesale beef price	6.59%	3.94%	1.81%	0.87%	0.42%	0.21%	0.10%	0.05%	0.03%	0.01%
Imported beef price	5.48%	3.10%	1.42%	0.68%	0.33%	0.16%	0.08%	0.04%	0.02%	0.01%
Slaughter cattle price	11.13%	6.29%	2.89%	1.39%	0.68%	0.33%	0.16%	0.08%	0.04%	0.02%
Feeder cattle price	-5.82%	-4.07%	-1.51%	-0.65%	-0.30%	-0.14%	-0.07%	-0.03%	-0.02%	-0.01%
Retail pork price	0.17%	0.10%	0.05%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
Wholesale pork price	1.46%	0.82%	0.38%	0.18%	0.09%	0.04%	0.02%	0.01%	0.01%	0.00%
Imported pork price	0.42%	0.24%	0.11%	0.05%	0.03%	0.01%	0.01%	0.00%	0.00%	0.00%
Slaughter hog price	1.50%	0.85%	0.39%	0.19%	0.09%	0.04%	0.02%	0.01%	0.01%	0.00%
Retail poultry price	1.96%	1.11%	0.51%	0.24%	0.12%	0.06%	0.03%	0.01%	0.01%	0.00%
Wholesale poultry price	4.83%	2.73%	1.25%	0.60%	0.29%	0.14%	0.07%	0.04%	0.02%	0.01%

The 10-year net change for retail beef is estimated to be a 6.31% reduction in total quantity, which corresponds to a 1.13 billion lb loss in total beef supplied at the retail level. The associated 10-year net change for pork and poultry at the retail levels are both an increase in total quantity supplied of 1.36%. This increase in retail pork and retail poultry quantities is 310 and 430 million lb, respectively. This means that despite modest increases in both pork and poultry quantities, at the end of a 10-year period the combined beef, pork, and poultry markets have lost a total protein market share of 396 million pounds of product at the retail level.

Table 4.3. Calculated net changes from year zero as a result of a removal of feed grade antibiotics in the beef cattle sector for all beef marketing segments.

	1 Year	3 Year	5 Year	7 Year	10 Year
Retail beef					
% Change in quantity	-3.12%	-5.60%	-6.14%	-6.27%	-6.31%
% Change in price	2.89%	5.41%	6.02%	6.16%	6.21%
Wholesale beef					
% Change in quantity	-4.05%	-7.22%	-7.92%	-8.08%	-8.13%
% Change in price	6.59%	12.80%	14.26%	14.62%	14.72%
Beef imports					
% Change in quantity	-3.10%	-5.57%	-6.11%	-6.24%	-6.28%
% Change in price	5.48%	10.29%	11.41%	11.69%	11.77%
Beef exports					
% Change in quantity	-4.25%	-7.58%	-8.30%	-8.48%	-8.53%
Slaughter cattle					
% Change in quantity	-4.45%	-7.93%	-8.69%	-8.87%	-8.92%
% Change in price	11.13%	21.52%	24.04%	24.66%	24.83%
Feeder cattle					
% Change in quantity	-4.26%	-7.60%	-8.32%	-8.50%	-8.55%
% Change in price	-5.82%	-11.02%	-11.87%	-12.05%	-12.10%

Table 4.4. Calculated net changes from year zero as a result of a removal of feed grade antibiotics in the beef cattle sector for all pork marketing segments.

	1 Year	3 Year	5 Year	7 Year	10 Year
Retail pork					
% Change in quantity	0.65%	1.20%	1.32%	1.35%	1.36%
% Change in price	0.17%	0.32%	0.35%	0.36%	0.36%
Wholesale pork					
% Change in quantity	0.64%	1.17%	1.30%	1.32%	1.33%
% Change in price	1.46%	2.68%	2.96%	3.03%	3.05%
Pork imports					
% Change in quantity	0.59%	1.09%	1.20%	1.23%	1.23%
% Change in price	0.42%	0.77%	0.85%	0.87%	0.87%
Pork exports					
% Change in quantity	-1.26%	-2.28%	-2.51%	-2.57%	-2.58%
Pork slaughter					
% Change in quantity	0.62%	1.13%	1.24%	1.27%	1.28%
% Change in price	1.50%	2.77%	3.05%	3.12%	3.14%

Table 4.5. Calculated net changes from year zero as a result of a removal of feed grade antibiotics in the beef cattle sector for all poultry marketing segments.

	1 Year	3 Year	5 Year	7 Year	10 Year
Retail poultry					
% Change in quantity	0.65%	1.20%	1.32%	1.35%	1.36%
% Change in price	1.96%	3.62%	4.00%	4.09%	4.11%
Wholesale poultry					
% Change in quantity	0.68%	1.24%	1.36%	1.39%	1.40%
% Change in price	4.83%	9.03%	10.01%	10.25%	10.32%

Tables 4.6, 4.7, and 4.8 show the calculated year on year differences for each marketing segment beef, pork, and poultry, respectively. Each value is calculated by subtracting the current interval's net change value from the previous interval's net change (i.e. the year 10 value for retail beef is calculated as: the net change in year 10, -6.31, less the net change from year 7, -6.27, yielding a two-year interval difference of -

.04). Across all market segments, greater than 95% of changes occur within the first 5 years of production. These results are consistent with those of Schroeder and Tonsor (2011) who assessed that following the loss of zilpaterol hydrochloride, in years 1 through 4 supplies at the slaughter level are more inelastic resulting in larger production impacts. As supplies become more elastic in years 5 through 10 the markets are able to adjust at a greater rate, resulting considerably smaller industry impacts. The results showed 6.21% higher retail prices for beef, and 1.36% higher retail prices for pork, and poultry after 10 years, negatively affecting consumers. Higher retail prices coupled with decreased quantities of beef supplied across all market segments adversely affecting producers leaves the entire meat protein market disadvantaged (Schroeder and Tonsor, 2011).

Some studies suggest that decreases in productivity associated with antibiotics administered in feed or water may be offset by industry wide changes in general production practices. Greater attention to pen based hygiene may reduce sickness; optimized nutritional plans can potentially lower acidosis incidents or liver abscesses. Herd size limitations or increases in biosecurity measures may as well reduce incidents of sick animals (Wierup, 2001; Barug et al., 2006; Lacminarayan et al., 2015). These studies failed to address the effect feed-grade antibiotics have on animal health and wellbeing.

Table 4.6. Percent differences across 2-year intervals resulting from the removal of feed grade antibiotics in beef cattle production for the beef marketing segments.

	1 Year	3 Year	5 Year	7 Year	10 Year
Retail beef					
% Change in quantity	-3.12%	-2.48%	-0.54%	-0.13%	-0.04%
% Change in price	2.89%	2.52%	0.61%	0.15%	0.04%
Wholesale beef					
% Change in quantity	-4.05%	-3.18%	-0.69%	-0.17%	-0.05%
% Change in price	6.59%	6.21%	1.46%	0.36%	0.10%
Wholesale beef imports					
% Change in quantity	-3.10%	-2.47%	-0.54%	-0.13%	-0.04%
% Change in price	5.48%	4.81%	1.12%	0.27%	0.08%
Wholesale beef exports					
% Change in quantity	-4.25%	-3.33%	-0.73%	-0.17%	-0.05%
Slaughter cattle					
% Change in quantity	-4.45%	-3.48%	-0.76%	-0.18%	-0.05%
% Change in price	11.13%	10.40%	2.52%	0.62%	0.18%
Feeder cattle					
% Change in quantity	-4.26%	-3.34%	-0.73%	-0.17%	-0.05%
% Change in price	-5.82%	-5.20%	-0.84%	-0.19%	-0.05%

Table 4.7. Percent differences across 2-year intervals resulting from the removal of feed grade antibiotics in beef cattle production for the pork marketing segments.

	1 Year	3 Year	5 Year	7 Year	10 Year
Retail pork					
% Change in quantity	0.65%	0.54%	0.12%	0.03%	0.01%
% Change in price	0.17%	0.14%	0.03%	0.01%	0.00%
Wholesale pork					
% Change in quantity	0.64%	0.53%	0.12%	0.03%	0.01%
% Change in price	1.46%	1.22%	0.28%	0.07%	0.02%
Wholesale pork imports					
% Change in quantity	0.59%	0.49%	0.11%	0.03%	0.01%
% Change in price	0.42%	0.35%	0.08%	0.02%	0.01%
Wholesale pork exports					
% Change in quantity	-1.26%	-1.02%	-0.23%	-0.05%	-0.02%
Pork slaughter					
% Change in quantity	0.62%	0.51%	0.12%	0.03%	0.01%
% Change in price	1.50%	1.26%	0.29%	0.07%	0.02%

Table 4.8. Percent differences across 2-year intervals resulting from the removal of feed grade antibiotics in beef cattle production for the poultry marketing segments.

	1 Year	3 Year	5 Year	7 Year	10 Year
Retail poultry					
% Change in quantity	0.65%	0.54%	0.12%	0.03%	0.01%
% Change in price	1.96%	1.66%	0.38%	0.09%	0.03%
Wholesale poultry					
% Change in quantity	0.68%	0.56%	0.13%	0.03%	0.01%
% Change in price	4.83%	4.21%	0.98%	0.24%	0.07%

Beef variety meats play a vital roll in U.S. beef export markets, accounting for 28.4% of total beef export value or $701.3 million (USMEF, 2013). Specifically, livers accounted for 31% of all offal exports in 2010 (USDA ERS, 2011). A majority of all livers are exported to Egypt, and Russia when the Russian market is open to U.S. exports. In 2014, with Russian markets closed, Egypt accounted for 78.4% of total exports, as compared to 2010 when Egypt made up 53.6% and Russia comprised 20.3% (USDA ERS, 2011; USMEF, 2013). When Russia stopped accepting U.S. exports, the price of liver went from 64 cents per pound to 39 cents, costing the beef cattle industry an estimated $30 million (USMEF, 2013). When access to Egyptian markets was threatened based on civil unrest in the region, prices were estimated to drop as low as 7 cents per pound. With liver condemnation rates increasing post ban, the total value of U.S. exports would decrease dramatically. Hicks (2011) estimated that under the current structure liver condemnations represent losses of approximately $15.9 million in unrealized liver values. The losses associated with a removal of liver abscess controls would likely be substantially greater as significantly more cattle would be affected and exports would be decreased to a greater degree.

Conclusion

The use of antibiotics in beef cattle production continues to be a major point of contention for groups seeking an end to the use of selected pharmaceuticals deemed medically important in human medicine. The livestock industry must remain proactive in its approach to analyzing policies aimed and removing technologies in production that aid in operational efficiency. This study established that the removal of antibiotics used to control liver abscesses pose a significant economic concern to beef producers and consumers alike. Additionally, the analysis quantified an often overlooked subclinical effect that results in more efficient animals and adheres to a more appropriate definition of sustainability, improving productivity to meet global food demands through environmental and economic efficiencies while reducing the resources necessary to produce one unit of protein.

CHAPTER V

OVERALL SUMMARY AND CONCLUSIONS

Antimicrobials used in livestock production are increasingly perceived to be associated with antimicrobial resistant bacterial strains in both humans and animals. As progressive consumers are continually influenced by social media campaigns and targeted advertising, alternative beef and other meat production systems have become more popular. The term "sustainability" in agricultural production is often interpreted to mean natural or free of certain technologies. This study has shown that the removal of technological advances in beef cattle production decrease production efficiency as well as potentially increases beef production's negative environmental impacts, simultaneously decreasing both societal and animal welfare.

The two methods used in this dissertation, though different, yielded relatively similar overall results of lower total production leading to an increased reliance on imports, reducing exports, resulting in higher prices at the retail level, ultimately depressing per capita consumption. Figure 5.1 compares the production parameters, beef production and wholesale beef quantity, for both the structural econometric model (SEM) and the equilibrium displacement model (EDM), respectively. When comparing the two models for a removal of feed-grade antibiotics, the effects of liver abscess controls become more apparent. The divergence in the results can be directly attributed to the additional losses in production associated with liver abscess controls. By year 10 the loss of liver abscess controls is estimated to reduce total production by an additional

6.99% as compared to just feed-grade antibiotics not associated with liver abscess control.

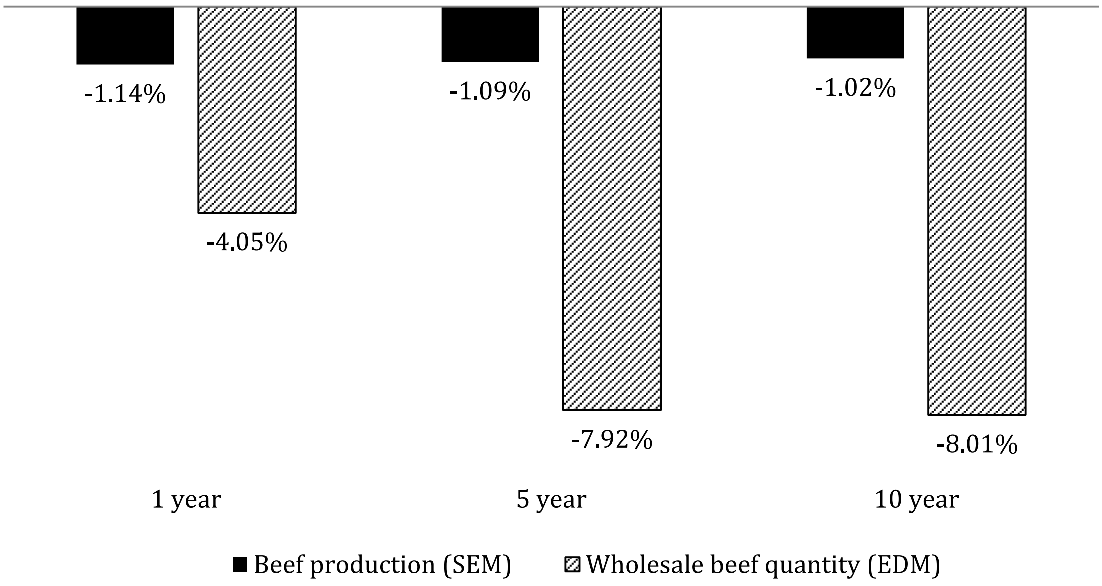

Figure 5.1. Comparison of production parameters beef production (SEM[1]) and wholesale beef quantity (EDM[2]) in years 1, 5, and 10 post feed grade antibiotic ban.

[1] Structural econometric model
[2] Equilibrium displacement model

Figure 5.2 compares retail beef price and retail consumption for the two models, resulting from a ban on feed grade antibiotics. With retail demand operating as the primary demand function in both models, decreased retail demand severely disadvantages the overall beef industry for both models. The structural model operates on the basis that a decrease in total production would be met with a rightward shift in demand, adding approximately 45,500 additional slaughter animals into the production system by year 10. The additional animals are the model's attempt to overcome losses associated with potential bans. Conversely, the equilibrium displacement model did not attempt to replace the losses in production, instead shifted the supply curve leftward and adjusted the industry to a new production norm without technologies.

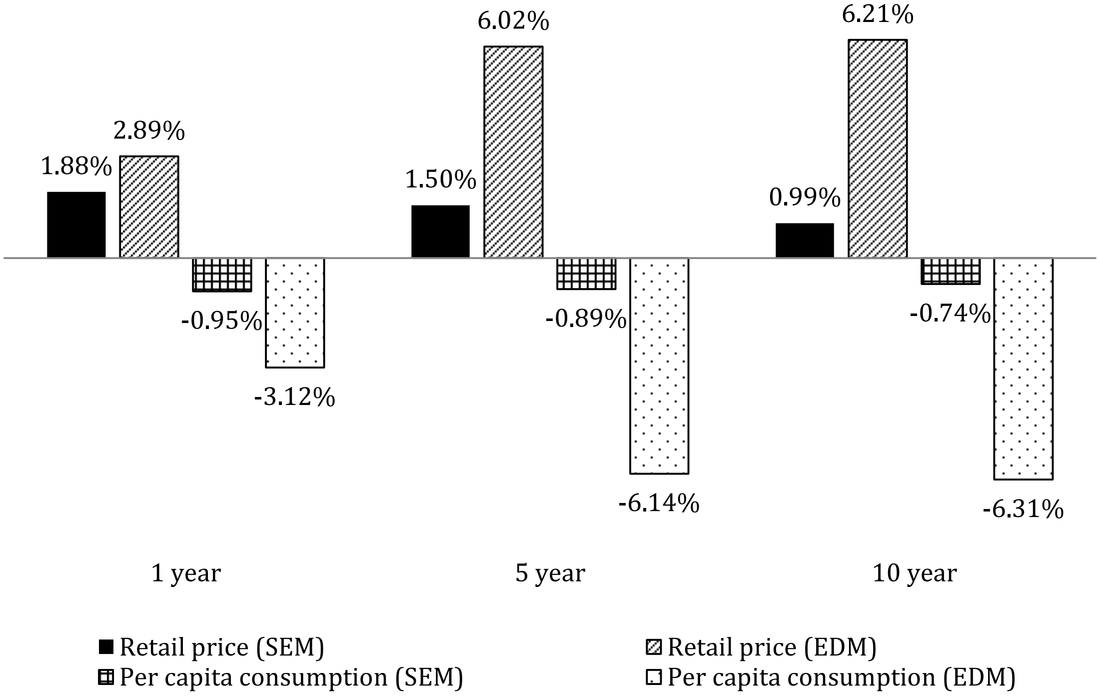

Figure 5.2. Comparison of retail beef price and per capita consumption for both the SEM[1] and EDM[2] in years 1, 5, and 10 post feed grade antibiotic ban.

[1] Structural econometric model
[2] Equilibrium displacement model

From these model differences a divergence is seen in the year one results of 1.01% and 2.17% for retail price and per capita consumption, respectively, and then grow to 5.22% and 5.57%, respectively, in year 10. These results show that increasing available inventories post ban may help the beef production industry mitigate the damage associated with losses in production.

Figure 5.3 shows the effects of a removal of all growth-enhancing technologies from feedlot production on output variables retail price, per capita consumption, and total beef production. A removal of all growth-enhancing technologies is a likely next target for opponents of pharmaceuticals in animal agriculture. In year one, an initial decrease in beef production of 10.43%, or approximately 2.5 billion pounds, causes an increase in beef retail price of approximately 15%, driving per capita consumption down 9.27%. As beef production increases into year 4, driven largely by a reliance on greater imports and more cattle slaughtered, prices begin to fall at the retail level. Even as retail beef prices fall, per capita consumption remains stifled by the initial shock, recovering only approximately 2% over ten years. A shock of this magnitude would likely cause the beef industry to struggle to maintain its current retail market share, more rapidly eroding an already downward trend in beef consumption. The beef cattle industry may find it extremely difficult to fill the production void with enough additional animals, as well as alter production enough to accommodate losses to animal daily gains of 37.31%.

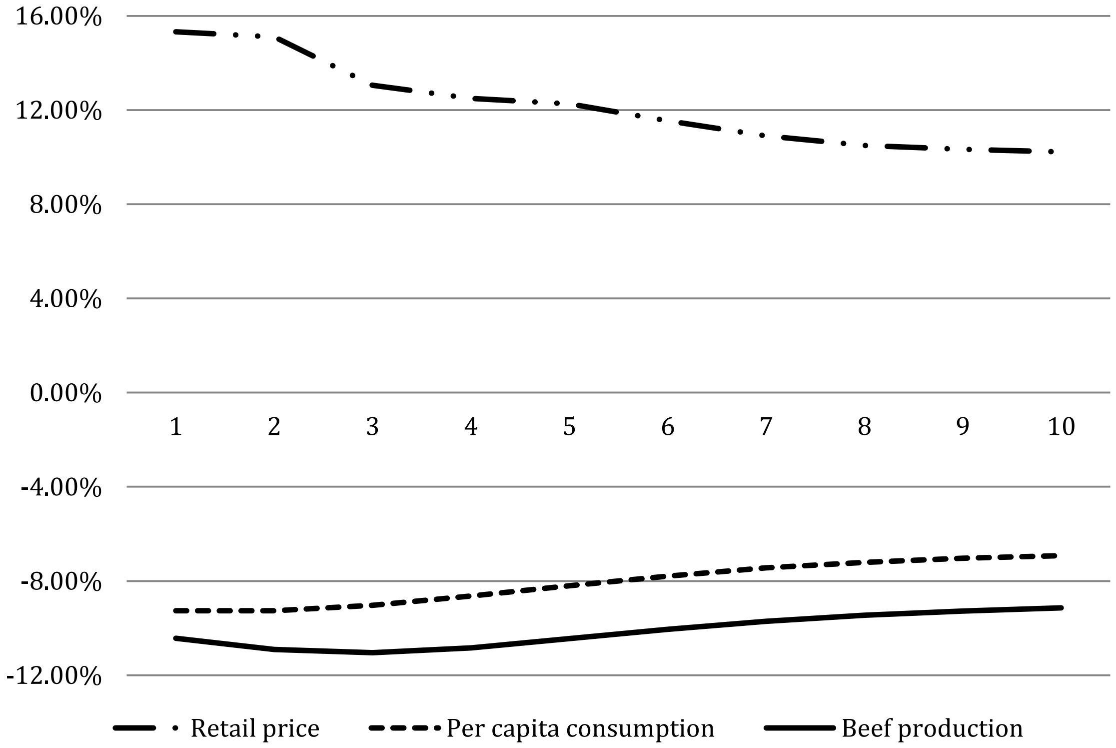

Figure 5.3. Retail price, per capita consumption, and beef production percent changes, as compared to a zero base, resulting from the removal of all growth enhancing technologies in U.S. beef feedlots.

Despite observing unintended negative effects stemming from similar bans in Denmark, there is still a belief that banning the use of feed grade antibiotics in livestock production may help alleviate increasing levels of microbial resistance. Proponents of the ban argue that preventing "subtherapeutic" uses of antibiotics forces producers to improve management practices and even opens the door for new, innovative products and protocols. The loss of feed grade antibiotics appears to be manageable, increasing retail price over baseline projections an average of 1.1% across all 10 years. When the removal of liver abscess controls is factored in, the effects become somewhat more severe. Retail price increases 6.21%, decreasing wholesale beef production 8.13% by year 10. Lower production and higher overall prices would severely disadvantage the industry, but as a whole consumer preferences would shift and beef production would likely make adjustments to establish a new beef market structure, though on a smaller scale. The removal of all growth-enhancing technologies would likely cause a shift in retail beef consumption large enough to spur consumers to seek substitute goods, disadvantaging lower income consumers.

By reducing certain parameters associated with efficiency in beef cattle production consumers are faced with higher retail prices, while beef cattle production loses operational efficiency as well as potentially increasing beef production’s negative environmental effects. The term “sustainability” in agricultural production is often interpreted to mean natural or free of certain technologies. The livestock industry has a duty to remain vigilant in their efforts to keep the public informed of both the scientific and societal implications of restrictions to agricultural production based on consumerism instead of foundational science. This study has shown that the removal of technological advances poses a significant economic concern to beef producers and consumers alike, moving against the foundation of sustainable production.

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APPENDIX

The following appendix contains all numerical results for the structural econometric model presented in Chapter III. Additionally, it contains all elasticity estimates used in Chapter IV, as well as the quantity transmission elasticities used in the linear elasticity model. Finally, this appendix lists all numerical results for the equilibrium displacement model for the beef, pork, and poultry sectors.

Table A1. Baseline scenario estimates from the large-scale systems model.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production (million lb)	24,541.27	24,770.77	24,485.74	24,575.62	24,908.31	25,263.93	25,570.16	25,843.99	26,082.11	26,302.70
Imports (million lb)	3,237.52	3,105.63	3,041.34	2,989.84	2,925.73	2,874.37	2,832.92	2,802.23	2,774.66	2,751.06
Exports (million lb)	2,404.14	2,431.74	2,445.35	2,463.70	2,496.10	2,530.95	2,568.54	2,607.26	2,649.17	2,692.64
Domestic demand (million lb)	25,334.39	25,437.06	25,081.35	25,093.24	25,336.69	25,605.89	25,832.92	26,037.65	26,207.46	26,360.35
Beef retail (¢/lb)	616.17	609.59	623.92	633.53	626.83	628.47	629.62	633.18	633.37	635.71
Fat steer ($/cwt)	149.18	142.18	147.96	148.35	145.61	146.08	146.33	146.98	146.87	147.17
Feeder steer ($/cwt)	185.66	185.49	192.41	192.69	188.08	188.15	188.60	190.11	190.70	191.74
Beef cows (thousand hd)	29,693.00	29,282.94	29,579.14	29,845.00	30,103.64	30,328.90	30,487.56	30,590.40	30,663.95	30,720.43
Cattle and calves (thousand hd)	92,259.66	91,719.65	90,826.02	91,230.36	91,842.78	92,319.35	92,664.99	92,904.91	93,049.83	93,143.18
Calf crop (thousand hd)	34,001.84	33,979.87	34,149.42	34,301.55	34,431.28	34,519.70	34,558.68	34,565.44	34,554.80	34,530.32
Cattle Slaughter (thousand hd)	30,469.31	30,553.65	30,012.55	29,939.82	30,174.99	30,407.04	30,576.61	30,700.54	30,780.94	30,839.44
Per capita consumption (lb)	55.07	54.79	53.69	53.23	53.26	53.35	53.34	53.29	53.33	53.33

Table A2. Scenario estimates for the removal of 1.18% of beef production, corresponding to a removal of feed-grade antibiotics from the large-scale systems model.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production (million lb)	24,273.00	24,485.06	24,200.84	24,302.12	24,636.21	24,989.68	25,305.19	25,581.73	25,820.48	26,047.79
Imports (million lb)	3,252.13	3,128.22	3,062.38	3,011.67	2,950.24	2,898.06	2,857.13	2,826.71	2,797.55	2,773.63
Exports (million lb)	2,395.46	2,415.03	2,428.04	2,443.76	2,470.85	2,502.02	2,536.75	2,572.66	2,613.35	2,655.88
Domestic demand (million lb)	25,094.39	25,184.96	24,838.85	24,870.22	25,110.90	25,383.86	25,624.88	25,832.63	26,003.22	26,164.48
Beef retail (¢/lb)	627.74	620.35	627.30	639.52	636.24	636.19	637.26	641.06	639.54	642.00
Fat steer ($/cwt)	151.18	144.85	148.58	149.64	147.84	147.96	148.07	148.81	148.27	148.53
Feeder steer ($/cwt)	188.66	188.50	193.99	194.70	190.63	190.14	190.87	192.40	192.59	193.82
Beef cows (thousand hd)	29,693.00	29,282.94	29,591.71	29,879.04	30,151.50	30,385.79	30,554.83	30,666.35	30,746.62	30,809.56
Cattle and calves (thousand hd)	92,259.66	91,718.10	90,845.39	91,281.75	91,928.01	92,433.39	92,801.93	93,059.19	93,221.14	93,329.22
Calf crop (thousand hd)	34,001.84	33,984.98	34,170.02	34,335.31	34,475.10	34,571.95	34,617.55	34,630.07	34,625.31	34,604.93
Cattle Slaughter (thousand hd)	30,469.36	30,537.29	29,996.05	29,935.23	30,182.99	30,423.91	30,602.78	30,732.65	30,818.96	30,884.03
Per capita consumption (lb)	54.55	54.24	53.17	52.76	52.79	52.88	52.91	52.87	52.91	52.93

Table A3. Scenario estimates for the removal of 10.82% of beef production, corresponding to a removal of all growth-enhancing technologies from the large-scale systems model.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Production (million lb)	21,980.62	22,069.54	21,780.91	21,912.88	22,304.85	22,725.96	23,088.68	23,400.81	23,663.00	23,897.31
Imports (million lb)	3,369.30	3,322.00	3,294.69	3,256.53	3,193.01	3,134.15	3,082.88	3,043.15	3,008.00	2,977.86
Exports (million lb)	2,336.96	2,300.47	2,263.71	2,240.46	2,238.69	2,246.22	2,261.93	2,282.52	2,308.79	2,338.52
Domestic demand (million lb)	22,986.23	23,081.82	22,815.77	22,927.09	23,257.59	23,611.28	23,909.08	24,159.69	24,362.76	24,535.64
Beef retail (¢/lb)	710.60	701.65	705.31	712.71	703.68	700.97	698.26	699.62	698.83	700.74
Fat steer ($/cwt)	167.24	163.36	166.91	166.19	162.49	161.94	161.40	161.64	161.43	161.73
Feeder steer ($/cwt)	215.66	215.49	219.30	217.75	211.71	210.25	209.79	210.89	211.29	212.16
Beef cows (thousand hd)	29,693.00	29,282.94	29,695.66	30,176.15	30,621.80	30,989.99	31,257.52	31,441.26	31,573.46	31,673.37
Cattle and calves (thousand hd)	92,259.66	91,707.02	91,011.91	91,730.96	92,752.02	93,595.82	94,219.59	94,663.35	94,959.19	95,163.84
Calf crop (thousand hd)	34,001.84	34,031.55	34,345.05	34,659.79	34,923.78	35,113.69	35,228.71	35,291.33	35,322.06	35,328.91
Cattle Slaughter (thousand hd)	30,469.75	30,402.66	29,835.97	29,841.96	30,215.59	30,593.69	30,882.17	31,093.49	31,237.97	31,343.47
Per capita consumption (lb)	49.97	49.71	48.84	48.63	48.89	49.19	49.37	49.45	49.58	49.64

Table A4. Elasticity definitions and estimates used in the linear elasticity model[1].

Symbol	Definition	Estimate	
		Short Run	Long Run
h^r_B	Own- price elasticity of demand for retail beef	-0.86	-1.17
h^r_{BK}	Cross- price elasticity of demand for retail beef with respect to the price of retail pork	0.10	
h^r_{BY}	Cross- price elasticity of demand for retail beef with respect to the price of retail poultry	0.05	
e^r_B	Own- price elasticity of supply for retail beef	0.36	4.62
h^w_B	Own- price elasticity of demand for wholesale beef	-0.58	-0.94
e^w_B	Own- price elasticity of supply for wholesale beef	0.28	3.43
h^w_{Bi}	Own- price elasticity of demand for beef imports	-0.58	-0.94
e^w_{Bi}	Own- price elasticity of supply for beef imports	1.83	10.00
h^w_{Be}	Own- price elasticity of demand for beef exports	-0.42	-3.00
h^s_B	Own- price elasticity of demand for slaughter cattle	-0.40	-0.53
e^s_B	Own- price elasticity of supply for slaughter cattle	0.26	3.24
h^f_B	Own- price elasticity of demand for feeder cattle	-0.14	-0.75
e^f_B	Own- price elasticity of supply for feeder cattle	0.22	2.82
h^r_K	Own- price elasticity of demand for retail pork	-0.69	-1.00
h^r_{KB}	Cross- price elasticity of demand for retail pork with respect to the price of retail beef	0.18	
h^r_{KY}	Cross- price elasticity of demand for retail pork with respect to the price of retail poultry	0.02	
e^r_K	Own- price elasticity of supply for retail pork	0.73	3.87
h^w_K	Own- price elasticity of demand for wholesale pork	-0.71	-1.00
e^w_K	Own- price elasticity of supply for wholesale pork	0.44	1.94
h^w_{Ki}	Own- price elasticity of demand for pork imports	-0.71	-1.00
e^w_{Ki}	Own- price elasticity of supply for pork imports	1.41	10.00
h^w_{Ke}	Own- price elasticity of demand for pork exports	-0.89	-1.00
h^s_K	Own- price elasticity of demand for slaughter hogs	-0.51	-1.00
e^s_K	Own- price elasticity of supply for slaughter hogs	0.41	1.80
h^r_Y	Own- price elasticity of demand for retail poultry	-0.29	-1.00
h^r_{YB}	Cross- price elasticity of demand for retail poultry with respect to the price of retail beef	0.18	
h^r_{YK}	Cross- price elasticity of demand for retail poultry with respect to the price of retail pork	0.04	

Table A4. (continued)

Symbol	Definition	Estimate	
e_Y^r	Own- price elasticity of supply for retail poultry	0.18	13.10
h_{Ye}^w	Own- price elasticity of demand for wholesale poultry exports	-0.31	-1.00
h_Y^w	Own- price elasticity of demand for wholesale poultry	-0.22	-1.00
e_Y^w	Own- price elasticity of supply for wholesale poultry	0.14	14.00

[1] All supply and demand elasticity estimates correspond to those published by Pendell et al. (2010).

Table A5. Quantity transmission elasticity definitions and estimates used in the linear elasticity model[1].

Symbol	Definition	Estimate	Standard Deviation
γ_B^{wr}	Percentage change in retail beef supply given a 1% change in wholesale beef supply	0.771	0.072
τ_B^{rw}	Percentage change in wholesale beef demand given a 1% change in retail beef demand	0.995	0.095
γ_B^{sw}	Percentage change in wholesale beef supply given a 1% change in slaughter cattle supply	0.909	0.024
τ_B^{ws}	Percentage change in slaughter cattle demand given a 1% change in wholesale beef demand	1.09	0.024
γ_B^{fs}	Percentage change in slaughter cattle supply given a 1% change in feeder cattle supply	1.07	0.351
τ_B^{sf}	Percentage change in feeder cattle demand given a 1% change in slaughter cattle demand	0.957	0.036
γ_K^{wr}	Percentage change in retail pork supply given a 1% change in wholesale pork supply	0.962	0.038
τ_K^{rw}	Percentage change in wholesale pork demand given a 1% change in retail pork demand	0.983	0.037
γ_K^{sw}	Percentage change in wholesale pork supply given a 1% change in slaughter hog supply	0.963	0.039
τ_K^{ws}	Percentage change in slaughter hog demand given a 1% change in wholesale pork demand	0.961	0.037
γ_Y^{wr}	Percentage change in retail poultry supply given a 1% change in wholesale poultry supply	0.806	0.022
τ_Y^{rw}	Percentage change in wholesale poultry demand given a 1% change in retail poultry demand	1.035	0.103

[1] All quantity transmission elasticity estimates correspond to those published by Pendell et al. (2010).

Table A6. Beef sector equilibrium displacement model whole industry results, retail, wholesale, slaughter, and feeder market levels.

	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Retail beef											
Quantity (bil lbs.)	17.950	17.390	17.084	16.945	16.880	16.848	16.832	16.824	16.820	16.818	16.817
Price (cents/lb)	528.93	544.21	553.09	557.55	559.70	560.75	561.27	561.53	561.66	561.72	561.75
% Change in quantity		-3.12%	-1.76%	-0.81%	-0.39%	-0.19%	-0.09%	-0.05%	-0.02%	-0.01%	-0.01%
% Change in price		2.89%	1.63%	0.80%	0.39%	0.19%	0.09%	0.05%	0.02%	0.01%	0.01%
Wholesale beef											
Quantity (bil lbs.)	25.26	24.24	23.68	23.44	23.32	23.26	23.23	23.22	23.21	23.21	23.21
Price (cents/lb)	298.48	318.16	330.70	336.68	339.61	341.05	341.76	342.11	342.29	342.37	342.42
% Change in quantity		-4.05%	-2.29%	-1.05%	-0.50%	-0.25%	-0.12%	-0.06%	-0.03%	-0.01%	-0.01%
% Change in price		6.59%	3.94%	1.81%	0.87%	0.42%	0.21%	0.10%	0.05%	0.03%	0.01%
Beef imports											
Quantity (bil lbs.)	2.25	2.180	2.142	2.125	2.116	2.112	2.111	2.110	2.109	2.109	2.109
Price (cents/lb)	298.48	314.84	324.59	329.20	331.45	332.55	333.10	333.36	333.50	333.57	333.60
% Change in quantity		-3.10%	-1.75%	-0.81%	-0.39%	-0.19%	-0.09%	-0.05%	-0.02%	-0.01%	-0.01%
% Change in price		5.48%	3.10%	1.42%	0.68%	0.33%	0.16%	0.08%	0.04%	0.02%	0.01%
Beef exports											
Quantity (bil lbs.)	2.58	2.47	2.41	2.39	2.37	2.37	2.37	2.36	2.36	2.36	2.36
Price (cents/lb)	271.0	298.41	315.46	323.74	327.82	329.83	330.83	331.32	331.57	331.69	331.75
% Change in quantity		-4.25%	-2.40%	-1.10%	-0.53%	-0.26%	-0.13%	-0.06%	-0.03%	-0.02%	-0.01%

Slaughter cattle											
Quantity (bil lbs.)	25.72	24.58	23.96	23.68	23.55	23.49	23.45	23.44	23.43	23.43	23.43
Quantity (1,000 head)	19,294.8	18,436.0	17,972.4	17,764.9	17,666.4	17,618.6	17,595.2	17,583.6	17,577.9	17,575	17,573.6
Price (cents/lb)	125.88	139.89	148.68	152.97	155.09	156.14	156.66	156.92	157.05	157.11	157.14
% Change in quantity		-4.45%	-2.51%	-1.15%	-0.55%	-0.27%	-0.13%	-0.07%	-0.03%	-0.02%	-0.01%
% Change in price		11.13%	6.29%	2.89%	1.39%	0.68%	0.33%	0.16%	0.08%	0.04%	0.02%
Feeder cattle											
Quantity (bil lbs.)	28.82	27.59	26.93	26.63	26.49	26.42	26.39	26.37	26.36	26.36	26.36
Quantity (1,000 head)	38,426.67	36,789.9	35,904.5	35,507.7	35,319.4	35,228.0	35,183.1	35,161.0	35,150.0	35,144.6	35,141.9
Price (cents/lb)	150.54	141.77	136.00	133.94	133.07	132.68	132.49	132.40	132.35	132.33	132.32
% Change in quantity		-4.26%	-2.41%	-1.10%	-0.53%	-0.26%	-0.13%	-0.06%	-0.03%	-0.02%	-0.01%
% Change in price		-5.82%	-4.07%	-1.51%	-0.65%	-0.30%	-0.14%	-0.07%	-0.03%	-0.02%	-0.01%

Table A7. Pork sector equilibrium displacement model whole industry results, retail, wholesale, and slaughter market levels.

	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Retail pork											
Quantity (bil lbs.)	13.46	13.55	13.60	13.62	13.63	13.64	13.64	13.64	13.64	13.64	13.64
Price (cents/lb)	364.39	365.03	365.39	365.55	365.63	365.67	365.69	365.70	365.71	365.71	365.71
% Change in quantity		0.65%	0.37%	0.17%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
% Change in price		0.17%	0.10%	0.05%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
Wholesale pork											
Quantity (bil lbs.)	23.21	23.36	23.44	23.48	23.50	23.51	23.51	23.51	23.51	23.52	23.52
Price (cents/lb)	92.55	93.90	94.67	95.03	95.20	95.29	95.33	95.35	95.36	95.37	95.37
% Change in quantity		0.64%	0.36%	0.17%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
% Change in price		1.46%	0.82%	0.38%	0.18%	0.09%	0.04%	0.02%	0.01%	0.01%	0.00%
Pork imports											
Quantity (bil lbs.)	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
Price (cents/lb)	152.00	152.64	153.00	152.67	152.51	152.43	152.40	152.38	152.37	152.36	152.36
% Change in quantity		0.59%	0.34%	0.15%	0.07%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
% Change in price		0.42%	0.24%	-0.22%	-0.10%	-0.05%	-0.03%	-0.01%	-0.01%	0.00%	0.00%

Pork exports											
Quantity (bil lbs.)	4.99	4.93	4.89	4.88	4.87	4.86	4.86	4.86	4.86	4.86	4.86
Price (cents/lb)	134.00	135.94	137.05	137.57	137.82	137.94	138.00	138.03	138.04	138.05	138.05
% Change in quantity		-1.26%	-0.71%	-0.33%	-0.16%	-0.08%	-0.04%	-0.02%	-0.01%	0.00%	0.00%
Pork slaughter											
Quantity (bil lbs.)	23.19	23.33	23.41	23.45	23.47	23.48	23.48	23.48	23.48	23.48	23.48
Price (cents/lb)	87.16	88.47	89.22	89.57	89.74	89.82	89.86	89.88	89.89	89.90	89.90
% Change in quantity		0.62%	0.35%	0.16%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
% Change in price		1.50%	0.85%	0.39%	0.19%	0.09%	0.04%	0.02%	0.01%	0.01%	0.00%

Table A8. Poultry sector equilibrium displacement model whole industry results, retail and wholesale market levels.

	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Retail poultry											
Quantity (bil lbs.)	31.51	31.72	31.83	31.89	31.91	31.93	31.93	31.93	31.94	31.94	31.94
Price (cents/lb)	196.50	200.36	202.58	203.61	204.11	204.35	204.47	204.53	204.56	204.58	204.59
% Change in quantity		0.65%	0.37%	0.17%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
% Change in price		1.96%	1.11%	0.51%	0.24%	0.12%	0.06%	0.03%	0.01%	0.01%	0.00%