DISSERTATION

ESSAYS IN THE ECONOMIC IMPLICATIONS OF SELECT ANIMAL HEALTH AND CROP PRODUCTION ISSUES

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ABSTRACT

ESSAYS IN THE ECONOMIC IMPLICATIONS OF SELECT ANIMAL HEALTH AND CROP PRODUCTION ISSUES

Production agriculture is faced with many risks which may be difficult to manage and can result in significant negative economic impacts. For the individual farmer, this can be problematic and potentially poses a challenge to remain viable and profitable when faced with uncertain circumstances. Economic matters evaluated in this dissertation include the topics of animal health and crop production efficiency both focusing on improving production agriculture.

This dissertation is comprised of three separate essays or three individual chapters. The first chapter contains an essay on a growing global threat to human health and safety and the biosecurity of livestock production in the United States in the form of antimicrobial resistant pathogens. An equilibrium displacement model (EDM) of the U.S. meat industry (i.e., beef, pork, lamb and poultry) is used to analyze welfare implications occurring from the potential restriction on the use of antimicrobial technologies or the implementation of biosecurity measures at the slaughter (i.e., feedlot) level of beef cattle production. Producer and consumer surplus measures showed that the beef industry losses the most from a reduction on the use of antimicrobial technology in beef cattle production in both the short- and long-run. An 11.95% industry adoption of a wildlife population management (WPM) program on livestock facilities cause a gain in producer surplus of \$1.15 billion in the short-run with long-run gains of \$18.33 million for the meat industry.

The second essay assesses the impact of various biosecurity strategies to prevent the incursion of bovine viral diarrhea virus (BVDV) in a cow-calf herd and minimize the uncertain financial impacts. The specific objectives of this study are to estimate the impact of BVDV introduction to representative U.S. cow-calf operations using an epidemiological disease spread model and to estimate annual costs of BVDV in cow-calf herds. Epidemiological results will be used to evaluate the expected returns and risk for various BVDV biosecurity measures in U.S. cow-calf herds by using a linear programming model which incorporates risk. Results from the study show that, in the context of whole farm planning, vaccination, testing or a combination of both can be effective biosecurity measures to control BVDV.

In all five regions, biosecurity strategy M (no biosecurity control measures) generate the highest expected returns which could be a result of no biosecurity costs. Expected returns by each biosecurity strategy shows that N (vaccination of breeding stock) generates the highest expected return for the Southern Plains (SP), North Central (NC), and West (W) regions. Biosecurity strategy T (testing for BVDV) had the highest expected returns for the Northern Plains (NP) and Southeast (SE) regions. The information from this essay is useful to the cow-calf industry as impacts and costs from various biosecurity measures are provided.

The third essay estimates and analyzes efficiency measures of conventional and organic crop producers. The estimation of efficiency measures was conducted by using a non-parametric approach commonly referred to as data envelopment analysis (DEA). Estimated efficiency results were evaluated using Tobit analysis to identify those farm and producer factors that influence the efficiency of U.S. crop producers. Results indicate that on average organic producers have a higher variable returns to scale technical efficiency (0.5656) than conventional producers (0.4741) and are better at producing their maximum output level given the inputs used compared to conventional producers.

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I would like to thank my committee members for their guidance, insight and all the time they have invested to help me accomplish this endeavor. Thank you to my family for all of their love, support and encouragement that they have provided over the years. I am sincerely grateful to the USDA National Wildlife Research Center and Colorado State University for funding this research. Any errors or mistakes in this dissertation are my own.

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CHAPTER 1

Introduction

Production agriculture is faced with many challenges ranging from price and yield risk to weather and disease impacts. This presents challenges for the individual farmer to stay viable and profitable in the face of uncertain circumstances. Current issues of interest and evaluated in this dissertation are the topics of animal health and crop production efficiency with both geared towards improving production agriculture. This dissertation is comprised of five chapters including this introduction chapter.

Chapter 2 presents a growing global threat to human health and safety and the biosecurity of livestock production in the United States in the form of antimicrobial resistant pathogens. The epidemiology of antimicrobial resistance is a complex ecosystem-level issue, and there are a number of vectors by which antimicrobial resistance (AMR) bacteria can affect human populations, including through direct human antimicrobial (AM) uses, as well as via veterinary, agricultural, and wildlife channels. This analysis uses an equilibrium displacement model (EDM) of the U.S. meat industry (i.e., beef, pork, lamb and poultry) to analyze welfare implications in the event that the uses of antimicrobial technologies are restricted or increased biosecurity measures are implemented at the slaughter (i.e., feedlot) level of beef cattle production.

Chapter 3 presents the relative contribution of bovine viral diarrhea virus (BVDV) prevention strategies that minimize risk related to farm income and the uncertain financial impacts of a BVDV outbreak. The specific objectives of this study is to estimate the impact of BVDV introduction to representative U.S. cow-calf operations using an epidemiological disease spread model and to estimate annual costs of BVDV in cow-calf herds. Epidemiological results will be used to evaluate the expected returns and risk for various BVDV biosecurity measures in U.S. cow-calf herds by using a linear programming model which incorporates risk. This study expands on the work by Smith et al. (2014) by regionalizing their BVDV epidemiological model by major cow-calf producing regions. The output from the BVDV model are then incorporated into a LP framework which optimizes the allocation of scarce resources between competing activities to maximize expected returns. The information from this study is useful to the cow-calf industry as impacts and costs from various biosecurity measures are provided. Further, this study provides U.S. cow-calf producers the necessary information to see the tradeoffs between returns and risk of the alternates control strategies at the whole farm level.

Chapter 4 presents an evaluation of efficiency measures for both conventional and organic crop producers. The estimation of efficiency measures will be conducted by using a non-parametric approach commonly referred to as data envelopment analysis (DEA). The efficiency measures will be estimated at the farm level for conventional and organic U.S. crop producers surveyed in the 2009 USDA ARMS Wheat survey. The estimated efficiency results will be evaluated using Tobit analysis to identify those farm and producer factors that influence the efficiency of U.S. crop producers. Study findings will provide information to producers and industry stakeholders on productive efficiency and the economic forces influencing efficiency to improve the viability of conventional and organic crop producers.

Each chapter contains a motivation, literature review relevant to the topic of interest, along with a methods section describing the analysis procedure for the essay, as well as the results from the analysis conducted. The dissertation as a whole is to be an assessment of the economic impacts of select animal health topics and crop production efficiency with a strong emphasis on production agriculture at the farm level.

CHAPTER 2

Examining the Potential Economic Implications of Wildlife Vectored Antimicrobial Resistance on the Livestock Supply Chain System

INTRODUCTION

The development and spread of antimicrobial resistant (AMR) pathogens is a growing global threat to human health and safety. The potential for this threat was recognized alongside the discovery of antibiotics; Sir Alexander Fleming suggested in his 1945 Nobel lecture that increased bacterial exposure to antibiotics could result in bacterial resistance to the administered drugs (Sir Alexander Fleming, 1945). The epidemiology of antimicrobial resistance is a complex ecosystem-level issue, and there are a number of vectors by which AMR bacteria can affect human populations, including through direct human antimicrobial (AM) uses, as well as via veterinary, agricultural, and wildlife channels (WHO 2014; Radhouani et. al., 2014). AMR presents a serious problem, because as diseases and other microorganisms cease to respond to antimicrobial compounds that once offered treatment, it becomes substantially more costly and more difficult to address an array of common infections and injuries in both humans and animals (Singer et al., 2003; CDC 2013).

In addition to the human health and safety issues raised by AMR, there is mounting concern with respect to the biosecurity of the farm-to-fork supply chain in the presence of AMR bacteria. The potential for disease transmission between humans and animals has been acknowledged for centuries, and there are a number of studies linking human illness to increased animal densities (e.g., Frank et al. 2008; Vidovic and Korber, 2006; Friesema et al., 2011; Haus-Cheymol et al., 2006). It is generally accepted that foodborne pathogens enter the farm-to-fork supply chain at the livestock production level, and although the various routes of AMR transmission are not completely understood, the potential for pathogen transmission within and between wildlife, livestock, and humans is plausible (see Figure 2.1). There are increasing questions regarding the growth and transfer of AMR bacteria in various animal populations, and how human-animal interactions, whether involving livestock or wildlife, may pose a threat of human exposures to AMR pathogens (e.g., Singer et al., 2003; Silbergeld et. al., 2008; CDC 2013; WHO 2014).

Given the severity of the AMR problem, there is considerable societal interest in finding strategies which may help address the growing prevalence of AMR bacteria within the ecosystem. We recognize that livestock operations are an important control point for AMR transmission between populations, and as such, livestock producers play an important role in maintaining the biosecurity of the food chain: prevention of AMR pathogens from entering livestock populations represents a potentially critical opportunity to stem the incursion of these pathogens into the wider food supply chain. For producers to undertake the appropriate efforts necessary to address their contribution to the larger AMR problem requires evaluation of the costs associated with possible control strategies, in order to better inform their feedlot management decisions.

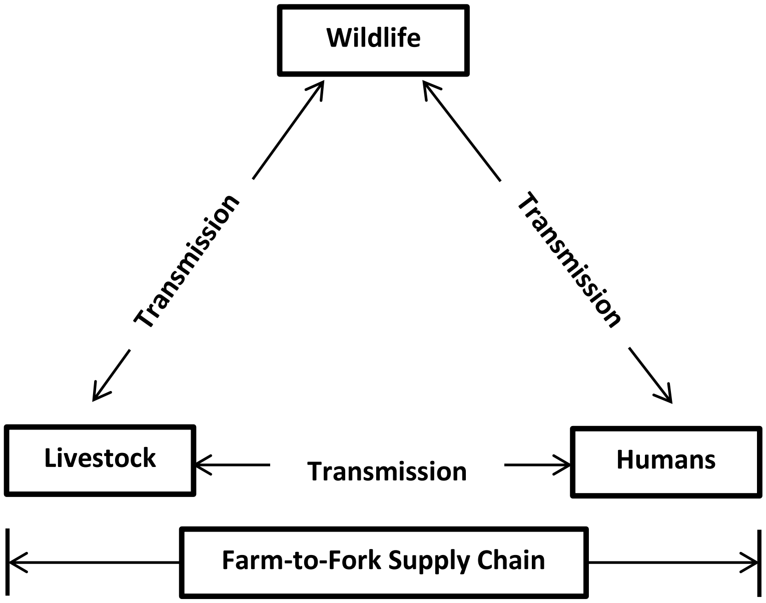

Figure 2.1: Routes of Potential Transmission for AMR Pathogens

With the growing industrialization of the agricultural food production sector, and rising consumer concerns and awareness surrounding the use of antimicrobials in livestock production for a variety of therapeutic and non-therapeutic purposes, there is considerable research attention devoted to AMR transmissions between humans and livestock animals in industrial agricultural production processes (e.g., Callaway et al., 2003; Van Baale et al., 2004; Mathew et al., 2005; McAllister et al., 2006; Silbergeld et al., 2008; Paddock et al., 2011). The use of antibiotics in livestock production has become increasingly implicated in human AMR infections, and as a result, the reduction or removal of particular antimicrobial technologies in livestock production has been suggested as a possible risk management tool to reduce and/or eliminate the selection and transmission of AMR pathogens at livestock facilities.

In addition, wildlife populations have been known to act as vectors for potentially resistant pathogens, including Escherichia coli O157:H7 and Salmonella spp. (Grieg, et al. 2014). A number of studies have suggested that while livestock are major reservoirs for some pathogens, wildlife may have originally transmitted the pathogens to livestock (Bono et al., 2012; Jay et al., 2007; Ferens and Hovde, 2011; Renter et al., 2001; Rice et al., 2003; Garcia-Sanchez et al., 2007). There are clearly links between wildlife and livestock populations, with a growing body of research on the specific contributions of wildlife to the prevalence of AMR on livestock facilities, and the role wildlife plays in the contamination of the farm-to-fork food supply chain (Grieg et. al., 2014; Radhouani et. al., 2014; Langholz and Jay-Russel, 2013; Gaukler et. al., 2008). Epidemiologically, linking the transmission of pathogens from wildlife populations to livestock on different farms can illustrate the risk wildlife populations pose to the biosecurity of livestock facilities (Pedersen and Clark, 2007). Wildlife populations can contribute to the prevalence and spread of pathogens, and their reduction may be an important disease prevention strategy (LeJeune et al., 2008; Williams, Pearl and LeJeune, 2011; Pedersen et al., 2006). The management of wildlife populations may serve as a risk mitigation tool to reduce wildlife-vectored AMR pathogens to livestock facilities, potentially leading to reduced human illnesses.

The overarching purpose of this study is to explore the potential economic impacts of feedlot level management strategies designed to reduce the prevalence of AMR pathogens on livestock facilities. This analysis uses an equilibrium displacement model (EDM) of the U.S. meat industry (i.e., beef, pork, lamb and poultry) to explore the economic implications of implementing two particular feedlot management strategies for AMR reduction within livestock operations. More specifically, we wish to examine: 1) voluntary reductions in antimicrobial usage for growth promotion in livestock operations and 2) wildlife population management strategies (WPM).

This paper will proceed by establishing some background information regarding these particular strategies, to introduce additional context and provide justification for the evaluation of these particular strategies as relevant to the larger AMR problem. We then introduce the economic model, and analyze each strategy individually, identifying the theoretical economic impacts on the industry, and describing the potential changes in welfare accruing to the U.S. meat industry. Assessing the costs and benefits of such strategies will play a key role in determining the most effective course of action for dealing with this threat; identifying the welfare impacts of possible AMR reduction strategies improves the information available to all involved parties, improving society's ability to deal with the complexities of the AMR problem.

METHODS

The potential role of wildlife populations transmitting AMR pathogens to livestock and humans creates an increased risk along the farm-to-fork supply chain. This analysis looks specifically at the shifting in supply curves resulting from restrictions on the use of antimicrobial technologies and mitigation strategies to minimize wildlife-livestock interactions to reduce morbidity and/or mortality production losses in livestock. Potential antimicrobial technologies in the livestock industry that could be restricted are the use of, ionophores, antibiotics, and anthelmintics (i.e., de-wormers) where each technology contributes to the control of morbidity and/or mortality in livestock leading to a safe, uniform and consistent end product (Lawrence and Ibarburu, 2007; Elam, 2004). Wildlife-livestock interaction at livestock facilities poses a plausible route of transmitting AMR pathogens generating a significant threat to the safety of the farm-to-fork food supply chain. The restricting of antimicrobial technologies and wildlife-livestock interactions could lead to significant challenges for producers as additional costs may be incurred ranging from increased feeding costs resulting from a loss of feed efficiency in the animal to increased biosecurity measures (i.e., implementation of WPM) all in an effort to ensure food safety.

This analysis generates an economic framework to analyze the welfare implications to the beef industry and livestock producers in the event that the uses of antimicrobial technologies are restricted or increased biosecurity measures are implementation at the feedlot level of beef cattle production. If livestock producers see a rise in AMR pathogens on their facilities, this could potentially lead to a loss in animal productivity which translates into a leftward shift of the derived supply curve (Figure 2.2). Subsequently this will cause an upward shift of the supply curve at derived marketing levels (i.e., wholesale and retail). Assuming a competitive market, the changes in prices and quantities at all marketing levels due to the increased presence of AMR pathogens can be determined by the elasticities of demand and supply at each marketing level (Brester et al., 2004; Pendell et al., 2010; Schroeder and Tonsor, 2011).

Figure 2.2 gives a simple case of an exogenous supply shock to the beef industry of restricting the use of antimicrobials in beef cattle production at the slaughter level and the resulting impacts along the marketing supply chain. Assuming fixed input proportions at each marketing level, the "primary" relations would be the retail (consumer) demand (D_r^0) and farm (feeder) supply (S_f^0), while the "derived" relations would be the feeder cattle demand (D_f^0), both supply and demand at the slaughter and wholesale levels and the retail beef supply (S_r^0). The market clearing prices (P_r^0, P_w^0, P_s^0, and P_f^0) and quantity (Q_0) for the beef marketing supply chain is at the intersection of the supply and demand curves at each marketing level. The farm-retail price spread, or marketing margin, can be found by taking the difference between the equilibrium price at the retail and farm levels ($P_r - P_f$) (Tomek and Robinson, 2003).

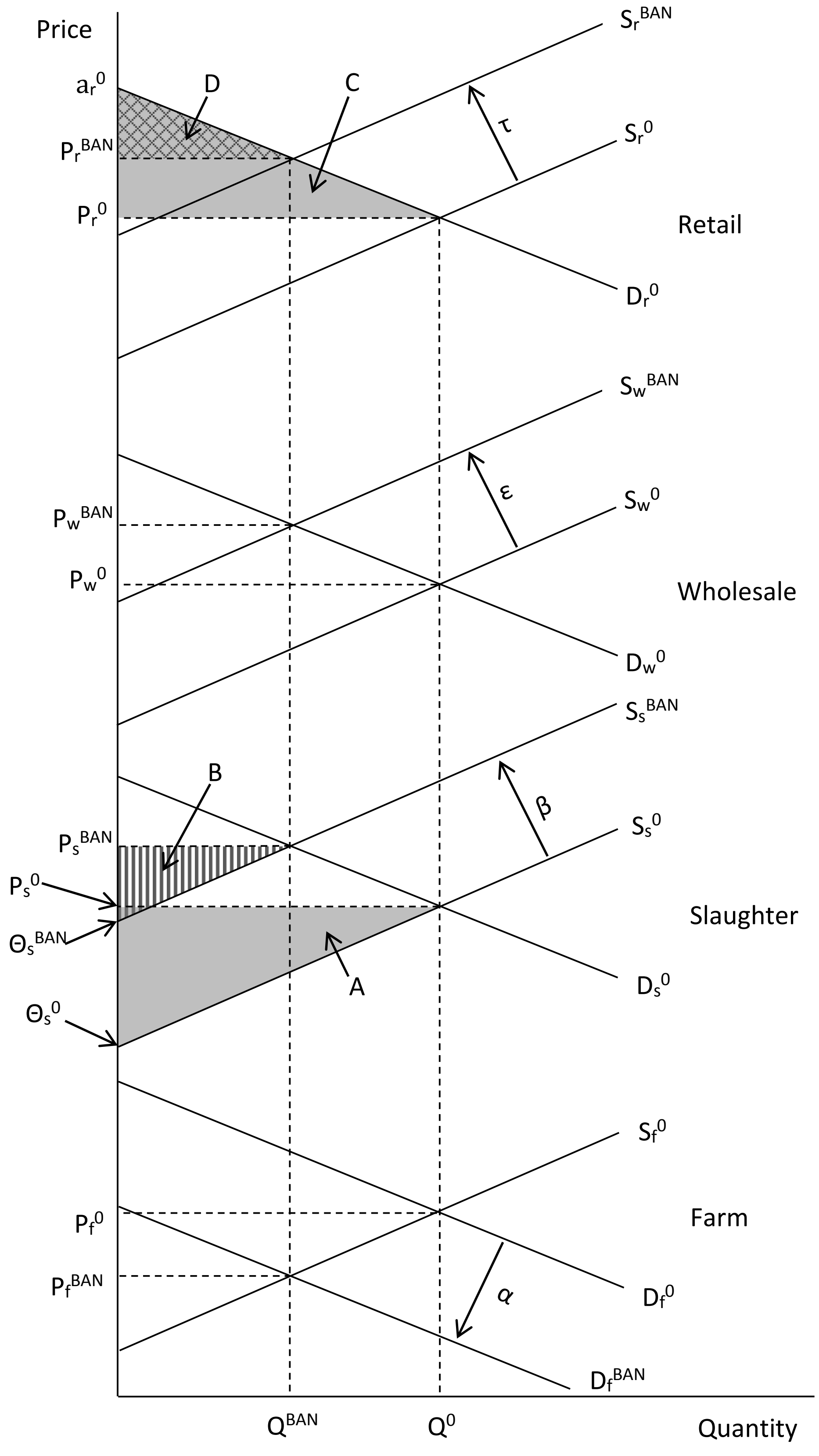

Figure 2.2: Effects on the Beef Sector of Restricting Antimicrobial Use.

Restricting the use of antimicrobial technologies in livestock production could be considered a worst case scenario to control and reduce the prevalence of AMR pathogens on livestock facilities. Reducing antimicrobial technology use would result in a shift of the derived slaughter supply curve (S_s^0) up and to the left by the amount of β to S_s^{BAN} measured by a change in net revenue on a per head basis. With the wholesale supply curve (S_w^0) being derived from the slaughter supply curve and the retail supply curve (S_r^0) being derived from the wholesale supply curve, a leftward shift of the slaughter supply curve will cause a leftward shift of the wholesale supply curve by ε to S_w^{BAN} and the retail supply curve by τ to S_r^{BAN}. The leftward shift of these supply curves causes prices to increase resulting in the quantity demanded of beef cattle and beef products to decrease from Q^0 to Q^{BAN}. Less quantity demanded at the retail level (primary demand) causes derived demand at the wholesale, slaughter and farm levels to decrease as well eventually causing the farm level derived demand curve (D_f^0) to shift leftward by the amount α to D_f^{BAN}.

The effects from an exogenous shift of the supply curve at the slaughter level from the restriction of antimicrobial technologies results in a new equilibrium price (P_s^{BAN}) and quantity (Q_s^{BAN}). To determine the economic implications to the slaughter level the change in producer surplus can be measured to determine welfare effects. Producer surplus is the total benefit or revenue that producers receive beyond production costs which is the price of a good (i.e., cattle) minus the marginal cost of producing that same good. In figure 2.2, shaded area A represents producer surplus at the slaughter level at the original equilibrium price (P_s^0) and quantity (Q_s^0). Shaded area B represents producer surplus at the slaughter level when the use of antimicrobial technologies in livestock production are restricted. Assuming linear supply and demand curves and that consumer demand does not change (the D_r^0 curve does not shift) then the change in producer surplus for the shaded areas A and B can be calculated as:

$$\Delta PS = B - A = \left[\frac{1}{2}(P_s^{BAN} - \theta_s^{BAN})Q^{BAN}\right] - \left[\frac{1}{2}(P_s^0 - \theta_s^0)Q^0\right] \tag{2.1}$$

The derived retail supply curve (S_r^0) will shift to (S_r^{BAN}) giving the new equilibrium price (P_r^{BAN}) and quantity (Q_r^{BAN}) conditions from which the change in consumer surplus, the difference between shaded areas C and D, at the retail level can be calculated as follows:

$$\Delta CS = D - C = \left[\frac{1}{2}(a_r^0 - P_r^{BAN})Q^{BAN}\right] - \left[\frac{1}{2}(a_r^0 - P_r^0)Q^0\right] \tag{2.2}$$

The resulting change in both consumer and producer surplus will evaluate the welfare effects from restricting the use of antimicrobial technologies in beef cattle production at the slaughter level.

The implementation of a wildlife population management (WPM) program at the slaughter level will be evaluated as an alternative mitigation strategy for producers to reduce the exogenous shock to the slaughter level supply curve from the presence of AMR pathogens. Studies have shown that the increased presence of wildlife populations (i.e., European starlings) increases both the prevalence of and the probability for the transmission of AMR pathogens to livestock (Carlson et al., 2011; Gaukler, 2009). It is the ability of wildlife populations to act as both a transmission and maintenance vector of AMR pathogens to livestock presents a formidable problem for livestock producers. The management of wildlife populations can serve to be a viable risk mitigation strategy. Figure 2.3 shows a similar supply chain marketing structure as that previously described for a potential ban on antimicrobial technologies; although the implementation of a WPM program will have differing impacts at the slaughter level and on the beef marketing supply chain. The use of WPM will, in theory, cause a rightward shift of the slaughter level supply curve by λ due in large part to the decreased cost of production from feed depredation (Depenbusch, 2011). The resulting new slaughter level supply curve (S_s^{WPM}) would then yield new equilibrium prices of P_s^{WPM} at the slaughter level, P_w^{WPM} at the wholesale level and P_r^{WPM} at the retail level and a new quantity of Q^{WPM}. As a result of the increase in quantity at the retail level, the derived demand for beef cattle at the farm level will cause a rightward shift of that demand curve by δ from D_f^0 to D_f^{WPM} . To determine the welfare effects of implementing WPM at the slaughter level, the resulting change in producer surplus will be evaluated to measure the welfare effects of applying such a program.

In figure 2.3, shaded area E represents the initial slaughter level producer surplus and shaded area F represents producer surplus at the slaughter level when WPM is implemented to reduce wildlife-livestock interaction and the spread of AMR pathogens. Again, assuming linear supply and demand curves and no variation in consumer demand the change in producer surplus for the shaded areas E and F can be calculated as

$$\Delta PS = F - E = \left[\frac{1}{2}(P_s^{WPM} - \theta_s^{WPM})Q_s^{WPM}\right] - \left[\frac{1}{2}(P_s^0 - \theta^0)Q^0\right] \tag{2.3}$$

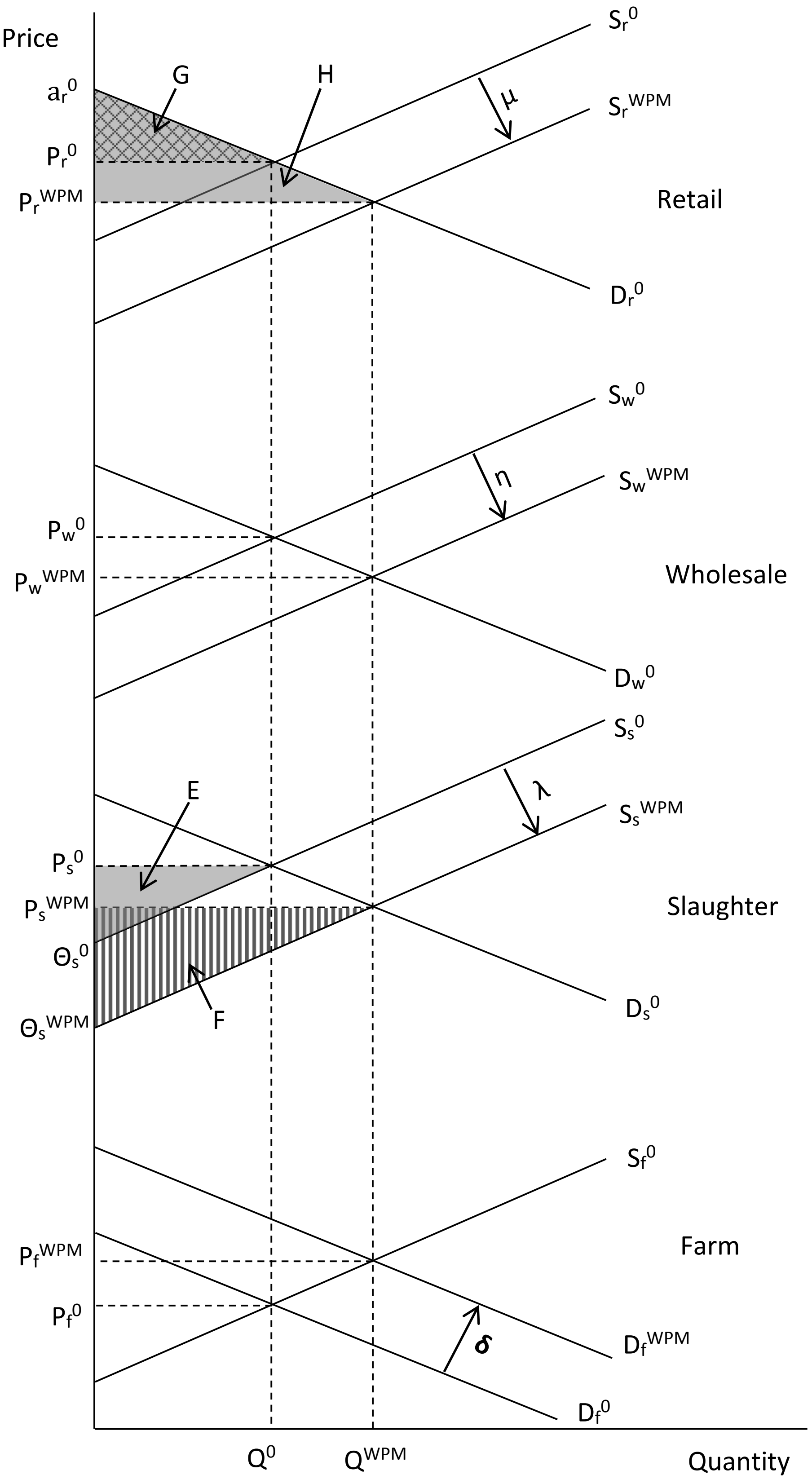

Figure 2.3: Effects on the Beef Sector from the Implementation of a WPM Program.

The change between shaded areas E and F represents the increase in livestock productivity and the benefit a producer recognizes from implementing a WPM program on their livestock facility. The evaluation of producer surplus under each shifting supply curve case can be used in determining welfare effects and to compare the efficacy of employing a WPM program at the slaughter level. The derived retail supply curve (S_r^0) will shift to (S_r^{WPM}) giving the new equilibrium price (P_r^{WPM}) and quantity (Q_r^{WPM}) conditions from which the change in consumer surplus, the difference between shaded areas G and H, at the retail level can be calculated as follows:

$$\Delta CS = H - G = \left[\frac{1}{2}(a_r^0 - P_r^{WPM})Q^{WPM}\right] - \left[\frac{1}{2}(a_r^0 - P_r^0)Q^0\right] \tag{2.4}$$

Calculating the change in both consumer and producer surplus can be evaluated to determine welfare effects from the implementation of a WPM program in beef cattle production at the slaughter level.

Equilibrium Displacement Model

An equilibrium displacement model (EDM) is a linear approximation of unknown supply and demand functions which can be used to model exogenous shocks to both supply and demand (primary and derived) within the farm-to-fork marketing supply chain. Quantity transmission elasticities between supply and demand sectors allow the model to incorporate variable input proportions among live animals and marketing service inputs. Variable input proportions allow the EDM to adjust for varying production quantities across market levels allowing for input substitution in response to changing output and input prices (Muth et al., 2007; Pendell et al., 2010). The analysis will look at the shift in supply curves resulting from additional costs incurred on producers and suppliers along the farm-to-fork marketing supply chain. Potential costs incurred to be evaluated will range from bans on antimicrobial use to increased biosecurity measures in an effort to ensure a safe reliable food source.

Muth (1964) developed the EDM where he focused on housing and urban land economics. Later refinements to the model included estimation of the change in retail-farm price ratio when there are shifts in the supply curve, demand curve or both due to changes in product marketing (Gardner, 1975). Mullen et al. (1988) expanded the use of EDMs by applying the model to the distribution of surplus gains that occur between farm and non-farm inputs. Lemieux and Wohlgenant (1989) used an EDM to estimate the potential effects growth hormones could have on the U.S. pork industry. Kinnucan and Belleza (1995) combined an EDM with an econometric model to estimate the relationship between changes in farm level prices and how quickly the retail prices of milk respond.

In this study, an EDM will be developed representing the U.S. meat industry. This EDM will consist of four meat sectors beef, pork, lamb and poultry. It will then be modified to account for an exogenous supply shock caused by a ban on the use of antimicrobial technologies in feedlot cattle production and the implementation of wildlife population management to increase biosecurity on livestock facilities. Following Tomek and Robinson (2003), Schroeder and Tonsor (2011) and Pendell et al. (2010) the EDM in this study analyzes the effects from changing livestock production practices and the changes to the model's exogenous factors. Key assumptions of an EDM are that the market is competitive, market clearing is imposed, and it is written in true parameters or estimates (Alston et al., 1995, Tomek and Robinson, 2003). A basic EDM theoretical structural function for the beef cattle market is as follows:

$Q_{\mathrm{d}} = f(P_{\mathrm{d}}, Z)$ Demand (2.5)

$Q_{\mathrm{s}} = f(P_{\mathrm{s}}, W)$ Supply (2.6)

$$Q_{\mathrm{s}} = Q_{\mathrm{d}}. \qquad \text{Market Clearing} \qquad (2.7)$$

The demand function (eq. 2.5) where Q_{d} is represented by the consumer demand for cattle as a function of the price of cattle and other factors such as consumer taste and income. The quantity of cattle demanded, P_{d} is the price for cattle, and Z represents a demand shifting variable. The supply function (eq. 2.6) where Q_{s} is the quantity of cattle supplied, P_s is the price for cattle, and W represents the supply shifting variable. Equation 2.7 represents the market clearing condition.

An EDM is a linear approximation therefore the structural equations (eqns. 2.5-2.7) are converted to log-linear functions by taking the total derivative of each function and then converting each function into elasticity form. The exogenous shocks can then be measured in percent changes that will occur from an increase (or decrease) in the affected variable (Z, W). The following equations (eqns. 2.8-2.12) are the converted theoretical structural functions.

Total Differentiation

$$EQ_{\mathrm{d}} = \frac{\mathrm{d}Q_{\mathrm{d}}}{Q_{\mathrm{d}}} = dlnQ_{\mathrm{d}} \qquad \text{Demand} \qquad (2.8)$$

$$EQ_{\mathrm{s}} = \frac{\mathrm{d}Q_{\mathrm{s}}}{Q_{\mathrm{s}}} = dlnQ_{\mathrm{s}} \qquad \text{Supply} \qquad (2.9)$$

Elasticity Form

$$E(Q_{\mathrm{d}}) = \eta_j\left[E(P) + EZ_j\right] \qquad \text{Demand} \qquad (2.10)$$

$$E(Q_s) = \varepsilon_i[E(P) - EW_i] \qquad \text{Supply} \qquad (2.11)$$

$$E(Q_s) = E(Q_{\mathrm{d}}) \qquad \text{Market Clearing} \qquad (2.12)$$

The variable E represents the relative change, η is the elasticity of demand, and EZ_j is the shift in the demand function relative to the equilibrium price and quantity. In the supply function, ε is the elasticity of supply, and EW_i is the shift in the supply function relative to the equilibrium price and quantity. In the equations above, α and β are the exogenous variables shifting the demand and supply functions. This study specifically examined the exogenous supply shifting variable β caused by the restricting of antimicrobial use and the implementation of wildlife population management, as the equilibrium displacement measurements within the model framework.

Structural Supply and Demand Model

To model the economic implications of banning the use of antimicrobials and the implementation of WPM on livestock facilities an equilibrium displacement model (EDM) is developed. An EDM is a commonly used economic framework in which to analyze the impacts of technology change and policy implications (e.g., Balagtas and Kim, 2007; Pendell et al., 2010; Brester, Marsh, and Atwood, 2004; Lusk and Norwood, 2005). An EDM is useful in that it allows for the analysis of both producer and consumer surplus to determine welfare effects from a technology and policy change.

The EDM has four market levels for the beef industry: 1) retail (consumer), 2) wholesale (processor), 3) slaughter (feedlot cattle), and 4) farm (feeder cattle). The model also incorporates markets for pork, lamb and poultry at the retail level to allow for the possibility of substitution for beef products. The pork sector has three market levels (retail, wholesale, and slaughter), the lamb sector has four market levels (retail, wholesale, slaughter, and feeder) where the poultry sector has two sectors (retail and wholesale). The EDM does incorporate international trade into the model at the wholesale levels for all four species modeled denoted by subscript i (import) or e (export) which is consistent with Pendell et al. (2010). The structural equations for both demand and supply for the EDM are developed in equations 2.13 through 2.47 where quantity and price are represented by Q and P, demand and supply shifters are denoted by Z and W, respectively. Superscripts denote market levels where f represents feeder-level, s represents slaughter-level, *w* represents wholesale-level, and *r* represents retail-level. The subscripts *B, K, L,* and *P* represent beef, pork, lamb, and poultry respectively. Variable definitions and estimates for the structural model are found in Table 2.1.

BEEF SECTOR:

Beef Retail Level

Retail Beef Primary Demand

$$Q_B^{rd} = f_1\left(P_B^{rd}, P_K^{rd}, P_{Ld}^{rd}, P_{Li}^{rd}, P_Y^{rd}, \boldsymbol{Z}_B^{rd}\right) \tag{2.13}$$

Retail Beef Derived Supply

$$Q_B^{rs} = f_2(P_B^{rs},\ Q_B^{ws},\ \boldsymbol{W}_B^{rs}) \tag{2.14}$$

Beef Wholesale Level

Wholesale Beef Derived Demand

$$Q_B^{wd} = f_3\left(P_B^{wd},\ Q_B^{rd}, \boldsymbol{Z}_B^{wd}\right) \tag{2.15}$$

Wholesale Beef Derived Supply

$$Q_B^{ws} = f_4\left(P_B^{ws},\ Q_B^{ss}, Q_{Bi}^{ws}, Q_{Be}^{wd}, \boldsymbol{W}_B^{ws}\right) \tag{2.16}$$

Imported Wholesale Beef Derived Demand

$$Q_{Bi}^{wd} = f_5\left(P_{Bi}^{wd}, Q_B^{wd}, \boldsymbol{Z}_{Bi}^{wd}\right) \tag{2.17}$$

Imported Wholesale Beef Derived Supply

$$Q_{Bi}^{ws} = f_6(P_{Bi}^{ws}, \boldsymbol{W}_{Bi}^{ws}) \tag{2.18}$$

Exported Wholesale Beef Derived Demand

$$Q_{Be}^{wd} = f_7\left(P_B^{wd}, \boldsymbol{Z}_{Be}^{wd}\right) \tag{2.19}$$

Beef Slaughter Level

Slaughter Cattle Derived Demand

$$Q_B^{sd} = f_8\left(P_B^{sd}, Q_B^{wd}, \boldsymbol{Z}_B^{sd}\right) \tag{2.20}$$

Slaughter Cattle Derived Supply

$$Q_B^{ss} = f_9\left(P_B^{ss}, Q_B^{fs}, \boldsymbol{W}_B^{ss}\right) \tag{2.21}$$

Beef Farm Level

Feeder Cattle Derived Demand

$$Q_B^{fd} = f_{10}\left(P_B^{fd}, Q_B^{sd}, \boldsymbol{Z}_B^{fd}\right) \tag{2.22}$$

Feeder Cattle Primary Supply

$$Q_B^{fs} = f_{11}\left(P_B^{fs}, \boldsymbol{W}_B^{fs}\right) \tag{2.23}$$

PORK SECTOR:

Pork Retail Level

Retail Pork Primary Demand

$$Q_K^{rd} = f_{12}\left(P_K^{rd}, P_B^{rd}, P_{Ld}^{rd}, P_{Li}^{rd}, P_Y^{rd}, \boldsymbol{Z}_K^{rd}\right) \tag{2.24}$$

Retail Pork Derived Supply

$$Q_K^{rs} = f_{13}(P_K^{rs},\ Q_K^{ws},\ \boldsymbol{W}_K^{rs}) \tag{2.25}$$

Pork Wholesale Level

Wholesale Pork Derived Demand

$$Q_B^{wd} = f_{14}\left(P_B^{wd},\ Q_B^{rd}, \boldsymbol{Z}_B^{wd}\right) \tag{2.26}$$

Wholesale Pork Derived Supply

$$Q_K^{ws} = f_{15}\left(P_K^{ws},\ Q_K^{ss}, Q_{Ki}^{ws}, Q_{Ke}^{wd}, \boldsymbol{W}_K^{ws}\right) \tag{2.27}$$

Imported Wholesale Pork Derived Demand

$$Q_{Ki}^{wd} = f_{16}\left(P_{Ki}^{wd}, Q_K^{wd}, \boldsymbol{Z}_{Ki}^{wd}\right) \tag{2.28}$$

Imported Wholesale Pork Derived Supply

$$Q_{Ki}^{ws} = f_{17}(P_{Ki}^{ws}, \boldsymbol{W}_{Ki}^{ws}) \tag{2.29}$$

Exported Wholesale Pork Derived Demand

$$Q_{Ke}^{wd} = f_{18}\left(P_K^{wd}, \boldsymbol{Z}_{Ke}^{wd}\right) \tag{2.30}$$

Pork Slaughter Level

Slaughter Cattle Derived Demand

$$Q_K^{sd} = f_{19}\left(P_K^{sd}, Q_K^{wd}, \boldsymbol{Z}_K^{sd}\right) \tag{2.31}$$

Slaughter Cattle Derived Supply

$$Q_K^{ss} = f_{20}(P_K^{ss},\ \boldsymbol{W}_K^{ss}) \tag{2.32}$$

LAMB SECTOR:

Lamb Retail Level

Domestic Retail Lamb Primary Demand

$$Q_{Ld}^{rd} = f_{21}\left(P_{Ld}^{rd}, P_{Li}^{rd}, P_B^{rd}, P_K^{rd}, P_Y^{rd}, \boldsymbol{Z}_{Ld}^{rd}\right) \tag{2.33}$$

Domestic Retail Lamb Derived Supply

$$Q_{Ld}^{rs} = f_{22}(P_{Ld}^{rs},\ Q_L^{ws},\ \boldsymbol{W}_{Ld}^{rs}) \tag{2.34}$$

Imported Retail Lamb Primary Demand

$$Q_{Li}^{rd} = f_{23}\left(P_{Li}^{rd}, P_{Ld}^{rd}, P_B^{rd}, P_K^{rd}, P_Y^{rd}, \boldsymbol{Z}_{Li}^{rd}\right) \tag{2.35}$$

Imported Retail Lamb Derived Supply

$$Q_{Li}^{rs} = f_{24}(P_{Li}^{rs},\ \boldsymbol{W}_{Li}^{rs}) \tag{2.36}$$

Lamb Wholesale Level

Wholesale Lamb Derived Demand

$$Q_L^{wd} = f_{25}\left(P_L^{wd},\ Q_{Ld}^{rd}, \boldsymbol{Z}_{\boldsymbol{L}}^{wd}\right) \tag{2.37}$$

Wholesale Lamb Derived Supply

$$Q_L^{ws} = f_{26}(P_L^{ws},\ Q_L^{ss},\ \boldsymbol{W}_L^{ws}) \tag{2.38}$$

Lamb Slaughter Level

Domestic Slaughter Lamb Derived Demand

$$Q_L^{sd} = f_{27}\left(P_L^{sd}, Q_L^{wd}, \boldsymbol{Z}_L^{sd}\right) \tag{2.39}$$

Domestic Slaughter Lamb Derived Supply

$$Q_L^{ss} = f_{28}\left(P_L^{ss}, Q_L^{fs}, \boldsymbol{W}_L^{ss}\right) \tag{2.40}$$

Lamb Farm Level

Domestic Feeder Lamb Derived Demand

$$Q_L^{fd} = f_{29}\left(P_L^{fd}, Q_L^{sd}, \boldsymbol{Z}_L^{fd}\right) \tag{2.41}$$

Domestic Feeder Lamb Primary Supply

$$Q_L^{fs} = f_{30}\left(P_L^{fs}, \boldsymbol{W}_L^{fs}\right) \tag{2.42}$$

POULTRY SECTOR:

Poultry Retail Level

Retail Poultry Primary Demand

$$Q_Y^{rd} = f_{31}\left(P_Y^{rd}, P_B^{rd}, P_K^{rd}, P_{Ld}^{rd}, P_{Li}^{rd}, \boldsymbol{Z}_Y^{rd}\right) \tag{2.43}$$

Retail Poultry Derived Supply

$$Q_Y^{rs} = f_{32}\left(P_Y^{rs},\ Q_Y^{ws}, Q_{Ye}^{rd},\ \boldsymbol{W}_Y^{rs}\right) \tag{2.44}$$

Exported Retail Poultry Primary Demand

$$Q_{Ye}^{rd} = f_{33}\left(P_Y^{rd}, \boldsymbol{Z}_{Ye}^{rd}\right) \tag{2.45}$$

Poultry Wholesale Level

Wholesale Poultry Derived Demand

$$Q_Y^{wd} = f_{34}\left(P_Y^{wd},\ Q_Y^{rd}, \boldsymbol{Z}_Y^{wd}\right) \tag{2.46}$$

Wholesale Poultry Derived Supply

$$Q_Y^{ws} = f_{35}(P_Y^{ws},\ \boldsymbol{W}_Y^{ws}) \tag{2.47}$$

Table 2.1: Variable Definitions and Estimates for the Structural and Equilibrium Displacement Model, 2013.

Symbol	Definition	Mean[a]
Q_B^r	Quantity (consumption) of retail beef, billions pounds (retail weight)	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_{Ld}^r	Price of retail domestic lamb, cents per pound	529.37
P_{Li}^r	Price of retail imported lamb, cents per pound	657.67
P_Y^r	Price of retail poultry, cents per pound	149.62
Q_B^w	Quantity of wholesale beef, billions pounds (carcass weight)	25.26
P_B^w	Price of wholesale Choice beef, cents per pound	298.48
Q_B^s	Quantity of beef obtained from slaughter cattle, billions pounds (live weight)	28.81
Q_{Bi}^w	Quantity of wholesale beef imports, billions pounds (carcass weight)	2.25
Q_{Be}^w	Quantity of wholesale beef exports, billions pounds (carcass weight)	2.583
P_{Bi}^w	Price of wholesale beef imports, cents per pound	298.48
P_B^s	Price of slaughter cattle, \$/cwt (live weight)	126.10
Q_B^f	Quantity of beef obtained from feeder cattle, billions pounds (live weight)	28.82
P_B^f	Price of feeder cattle, \$/cwt	150.54
Q_K^r	Quantity (consumption) of retail pork, billions pounds (retail weight)	13.46
Q_K^w	Quantity of wholesale pork, billions pounds (carcass weight)	22.94
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)	26.94
Q_{Ki}^w	Quantity of wholesale pork imports, billions pounds (carcass weight)	0.88

Q_{Ke}^{w}	Quantity of wholesale pork exports, billions pounds (carcass weight)	4.99
P_{Ki}^{w}	Price of wholesale pork imports, cents per pound	58.97
P_{K}^{s}	Price of slaughter hogs, $/cwt (live weight)	87.16
Q_{Ld}^{r}	Quantity (consumption) of retail domestic lamb, billions pounds (retail weight)	0.15
Q_{L}^{w}	Quantity of wholesale lamb, billions pounds (carcass weight)	0.14
Q_{Li}^{r}	Quantity (consumption) of retail imported lamb, billions pounds (retail weight)	0.15
P_{L}^{w}	Price of wholesale lamb, cents per pound	285.23
Q_{L}^{s}	Quantity of lamb obtained from slaughter lamb, billions pounds (live weight)	0.30
P_{L}^{s}	Price of slaughter lamb, $/cwt (live weight)	115.02
Q_{L}^{f}	Quantity of lamb obtained from feeder lamb, billions pounds (live weight)	0.28
P_{L}^{f}	Price of feeder lamb, $/cwt	135.98
Q_{Y}^{r}	Quantity (consumption) of retail poultry, billions pounds (retail weight)	25.90
Q_{Y}^{w}	Quantity of wholesale poultry, billions pounds (RTC)	58.60
Q_{Ye}^{w}	Quantity of retail poultry exports, billions pounds (retail weight)	7.36
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)	model input
W_{kl}^{i}	Supply shifters at the *i*th market level for the *k*th commodity and *l*th market (domestic/import)	model input

Notes: All price and quantity values reflect 2013 annual averages as obtained from the Livestock Marketing Information Center.

Structural Models Converted to Elasticity Form

Following the process outlined above in the theoretical models the beef structural models (eqns. 2.13-2.47) were converted to elasticity form by logarithmic differentiation. The exogenous shocks (*Z* and *W*) can then be measured in percent changes that will occur from a one unit increase/decrease in the variable. *E* represents a relative change operator (i.e., $EQ = d \ln Q = dQ/Q$) so that each relation can be expressed in terms of elasticities. In the demand equations, η is the own-price elasticity of demand, and τ is the percent change in a market level given a 1% change in another market level (i.e., percentage change in retail beef supply given a 1% change in wholesale beef supply). In the supply equation ε is the own-price supply elasticity and γ is the percent change in a market level given a 1% change in another market level (i.e., percentage change in wholesale beef demand given a 1% change in retail beef demand). Variable definitions are presented in Table A.1 and Table A.2 presents elasticity estimates and definitions used in the log differential models. Quantity transmission elasticities (i.e., τ and γ) are presented in Table A.3 (See Appendix Tables A.1-A.3). The following are equations 2.13-2.47 converted to elasticity form.

<u>Elasticity Form</u>

Beef Sector

$$EQ_B^r = \eta_B^r EP_B^r + \eta_{BK}^r EP_K^r + \eta_{BLd}^r EP_{Ld}^r + \eta_{BLi}^r EP_{Li}^r + \eta_{BY}^r EP_Y^r + Ez_B^r \tag{2.48}$$

$$EQ_B^r = \varepsilon_B^r EP_B^r + \gamma_B^{wr} EQ_B^w + Ew_B^r \tag{2.49}$$

$$EQ_B^w = \eta_B^w EP_B^w + \tau_B^{rw} EQ_B^r + Ez_B^w \tag{2.50}$$

$$EQ_B^w = \varepsilon_B^w EP_B^w + \gamma_B^{sw} (Q_B^s/Q_B^w) EQ_B^s + (Q_{Bi}^w/Q_B^w) EQ_{Bi}^w - (Q_{Be}^w/Q_B^w) EQ_{Be}^w + Ew_B^w \tag{2.51}$$

$$EQ_{Bi}^w = \eta_{Bi}^w EP_{Bi}^w + \tau_B^{rw} EQ_B^w + (Q_{Bi}^w/Q_B^w) Ez_{Be}^w + Ez_{Bi}^w \tag{2.52}$$

$$EQ_{Bi}^w = \varepsilon_{Bi}^w EP_{Bi}^w + Ew_{Bi}^w \tag{2.53}$$

$$EQ_{Be}^{w} = \eta_{Be}^{w} EP_{B}^{w} + Ez_{Be}^{w} \tag{2.54}$$

$$EQ_{B}^{s} = \eta_{B}^{s} EP_{B}^{s} + \tau_{B}^{ws} EQ_{B}^{w} + (Q_{Be}^{w}/Q_{B}^{w}) Ez_{Be}^{w} + Ez_{B}^{s} \tag{2.55}$$

$$EQ_{B}^{s} = \varepsilon_{B}^{s} EP_{B}^{s} + \gamma_{B}^{fs} EQ_{B}^{f} + Ew_{B}^{s} \tag{2.56}$$

$$EQ_{B}^{f} = \eta_{B}^{f} EP_{B}^{f} + \tau_{B}^{sf} EQ_{B}^{s} + Ez_{B}^{f} \tag{2.57}$$

$$EQ_{B}^{f} = \varepsilon_{B}^{f} EP_{B}^{f} + Ew_{B}^{f} \tag{2.58}$$

Pork Sector

$$EQ_{K}^{r} = \eta_{K}^{r} EP_{K}^{r} + \eta_{KB}^{r} EP_{B}^{r} + \eta_{KLd}^{r} EP_{Ld}^{r} + \eta_{KLi}^{r} EP_{Li}^{r} + \eta_{KY}^{r} EP_{Y}^{r} + Ez_{K}^{r} \tag{2.59}$$

$$EQ_{K}^{r} = \varepsilon_{K}^{r} EP_{K}^{r} + \gamma_{K}^{wr} EQ_{K}^{w} + Ew_{K}^{r} \tag{2.60}$$

$$EQ_{K}^{w} = \eta_{K}^{w} EP_{K}^{w} + \tau_{K}^{rw} EQ_{K}^{r} + Ez_{K}^{w} \tag{2.61}$$

$$EQ_{K}^{w} = \varepsilon_{K}^{w} EP_{K}^{w} + \gamma_{K}^{sw} (Q_{K}^{s}/Q_{K}^{w}) EQ_{K}^{s} + (Q_{Ki}^{w}/Q_{K}^{w}) EQ_{Ki}^{w} - (Q_{Ke}^{w}/Q_{K}^{w}) EQ_{Ke}^{w} + Ew_{K}^{w} \tag{2.62}$$

$$EQ_{Ki}^{w} = \eta_{Ki}^{w} EP_{Ki}^{w} + \tau_{K}^{rw} EQ_{K}^{w} + (Q_{Ki}^{w}/Q_{K}^{w}) Ez_{Ke}^{w} + Ez_{Ki}^{w} \tag{2.63}$$

$$EQ_{Ki}^{w} = \varepsilon_{Ki}^{w} EP_{Ki}^{w} + Ew_{Ki}^{w} \tag{2.64}$$

$$EQ_{Ke}^{w} = \eta_{Ke}^{w} EP_{K}^{w} + Ez_{Ke}^{w} \tag{2.65}$$

$$EQ_{K}^{s} = \eta_{K}^{s} EP_{K}^{s} + \tau_{K}^{ws} EQ_{K}^{w} + (Q_{Ke}^{w}/Q_{K}^{w}) Ez_{Ke}^{w} + Ez_{K}^{s} \tag{2.66}$$

$$EQ_{K}^{s} = \varepsilon_{K}^{s} EP_{K}^{s} + Ew_{K}^{s} \tag{2.67}$$

Lamb Sector

$$EQ_{Ld}^{r} = \eta_{Ld}^{r} EP_{Ld}^{r} + \eta_{LdLi}^{r} EP_{Li}^{r} + \eta_{LdB}^{r} EP_{B}^{r} + \eta_{LdK}^{r} EP_{K}^{r} + \eta_{LdY}^{r} EP_{Y}^{r} + Ez_{Ld}^{r} \tag{2.68}$$

$$EQ_{Ld}^{r} = \varepsilon_{Ld}^{r} EP_{Ld}^{r} + \gamma_{L}^{wr} EQ_{L}^{w} + Ew_{Ld}^{r} \tag{2.69}$$

$$EQ_{Li}^{r} = \eta_{Li}^{r} EP_{Li}^{r} + \eta_{LiLd}^{r} EP_{Ld}^{r} + \eta_{LiB}^{r} EP_{B}^{r} + \eta_{LiK}^{r} EP_{K}^{r} + \eta_{LiY}^{r} EP_{Y}^{r} + Ez_{Li}^{r} \tag{2.70}$$

$$EQ_{Li}^{r} = \varepsilon_{Li}^{r} EP_{Li}^{r} + Ew_{Li}^{r} \tag{2.71}$$

$$EQ_{L}^{w} = \eta_{L}^{w} EP_{L}^{w} + \tau_{L}^{rw} EQ_{Ld}^{r} + Ez_{L}^{w} \tag{2.72}$$

$$EQ_{L}^{w} = \varepsilon_{L}^{w} EP_{L}^{w} + \gamma_{L}^{sw} EQ_{L}^{s} + Ew_{L}^{w} \tag{2.73}$$

$$EQ_{L}^{s} = \eta_{L}^{s} EP_{L}^{s} + \tau_{L}^{ws} EQ_{L}^{w} + Ez_{L}^{s} \tag{2.74}$$

$$EQ_L^s = \varepsilon_L^s EP_L^s + \gamma_L^{fs} EQ_L^f + Ew_L^s \tag{2.75}$$

$$EQ_L^f = \eta_L^f EP_L^f + \tau_L^{sf} EQ_L^s + Ez_L^f \tag{2.76}$$

$$EQ_L^f = \varepsilon_L^f EP_L^f + Ew_L^f \tag{2.77}$$

Poultry Sector

$$EQ_Y^r = \eta_Y^r EP_Y^r + \eta_{YB}^r EP_B^r + \eta_{YK}^r EP_K^r + \eta_{YLd}^r EP_{Ld}^r + \eta_{YLi}^r EP_{Li}^r + Ez_y^r \tag{2.78}$$

$$EQ_Y^r = \varepsilon_Y^r EP_Y^r + \gamma_Y^{wr} EQ_Y^w + (Q_{Ye}^r / Q_Y^r) EQ_{Ye}^r + Ew_Y^r \tag{2.79}$$

$$EQ_{Ye}^r = \eta_Y^r EP_Y^r + Ez_{Ye}^r \tag{2.80}$$

$$EQ_Y^w = \eta_Y^w EP_Y^w + \tau_Y^{rw} EQ_Y^r + (Q_{Ye}^r / Q_Y^r) Ez_{Ye}^r + Ew_Y^w \tag{2.81}$$

$$EQ_Y^w = \varepsilon_Y^w EP_Y^w + Ew_Y^w \tag{2.82}$$

Endogenous Variables on the Left-Hand Side

To implement the EDM all of the endogenous variables in equations 2.48 through 2.82 were placed on the left-hand side of each equation. This allows for the isolation of exogenous effects (i.e., demand and supply shifters *W* and *Z*) to be on the right-hand side of each equation.

Beef Sector

$$EQ_B^r - \eta_B^r EP_B^r - \eta_{BK}^r EP_K^r - \eta_{BLd}^r EP_{Ld}^r - \eta_{BLi}^r EP_{Li}^r - \eta_{BY}^r EP_Y^r = Ez_B^r \tag{2.83}$$

$$EQ_B^r - \varepsilon_B^r EP_B^r - \gamma_B^{wr} EQ_B^w = Ew_B^r \tag{2.84}$$

$$EQ_B^w - \eta_B^w EP_B^w - \tau_B^{rw} EQ_B^r = Ez_B^w \tag{2.85}$$

$$EQ_B^w - \varepsilon_B^w EP_B^w - \gamma_B^{sw} (Q_B^s / Q_B^w) EQ_B^s - (Q_{Bi}^w / Q_B^w) EQ_{Bi}^w + (Q_{Be}^w / Q_B^w) EQ_{Be}^w = Ew_B^w \tag{2.86}$$

$$EQ_{Bi}^w - \eta_{Bi}^w EP_{Bi}^w - \tau_B^{rw} EQ_B^w - (Q_{Bi}^w / Q_B^w) Ez_{Be}^w = Ez_{Bi}^w \tag{2.87}$$

$$EQ_{Bi}^w - \varepsilon_{Bi}^w EP_{Bi}^w = Ew_{Bi}^w \tag{2.88}$$

$$EQ_{Be}^w - \eta_{Be}^w EP_B^w = Ez_{Be}^w \tag{2.89}$$

$$EQ_B^s - \eta_B^s EP_B^s - \tau_B^{ws} EQ_B^w - (Q_{Be}^w / Q_B^w) Ez_{Be}^w = Ez_B^s \tag{2.90}$$

$$EQ_B^s - \varepsilon_B^s EP_B^s - \gamma_B^{fs} EQ_B^f = Ew_B^s \tag{2.91}$$

$$EQ_B^f - \eta_B^f EP_B^f - \tau_B^{sf} EQ_B^s = Ez_B^f \tag{2.92}$$

$$EQ_B^f - \varepsilon_B^f EP_B^f = Ew_B^f \tag{2.93}$$

Pork Sector

$$EQ_K^r - \eta_K^r EP_K^r - \eta_{KB}^r EP_B^r - \eta_{KLd}^r EP_{Ld}^r - \eta_{KLi}^r EP_{Li}^r - \eta_{KY}^r EP_Y^r = Ez_K^r \tag{2.94}$$

$$EQ_K^r - \varepsilon_K^r EP_K^r - \gamma_K^{wr} EQ_K^w = Ew_K^r \tag{2.95}$$

$$EQ_K^w - \eta_K^w EP_K^w - \tau_K^{rw} EQ_K^r = Ez_K^w \tag{2.96}$$

$$EQ_K^w - \varepsilon_K^w EP_K^w - \gamma_K^{sw} (Q_K^s/Q_K^w) EQ_K^s - (Q_{Ki}^w/Q_K^w) EQ_{Ki}^w + (Q_{Ke}^w/Q_K^w) EQ_{Ke}^w = Ew_K^w \tag{2.97}$$

$$EQ_{Ki}^w - \eta_{Ki}^w EP_{Ki}^w - \tau_K^{rw} EQ_K^w - (Q_{Ki}^w/Q_K^w) Ez_{Ke}^w = Ez_{Ki}^w \tag{2.98}$$

$$EQ_{Ki}^w - \varepsilon_{Ki}^w EP_{Ki}^w = Ew_{Ki}^w \tag{2.99}$$

$$EQ_{Ke}^w - \eta_{Ke}^w EP_K^w = Ez_{Ke}^w \tag{2.100}$$

$$EQ_K^s - \eta_K^s EP_K^s - \tau_K^{ws} EQ_K^w - (Q_{Ke}^w/Q_K^w) Ez_{Ke}^w = Ez_K^s \tag{2.101}$$

$$EQ_K^s - \varepsilon_K^s EP_K^s = Ew_K^s \tag{2.102}$$

Lamb Sector

$$EQ_{Ld}^r - \eta_{Ld}^r EP_{Ld}^r - \eta_{LdLi}^r EP_{Li}^r - \eta_{LdB}^r EP_B^r - \eta_{LdK}^r EP_K^r - \eta_{LdY}^r EP_Y^r = Ez_{Ld}^r \tag{2.103}$$

$$EQ_{Ld}^r - \varepsilon_{Ld}^r EP_{Ld}^r - \gamma_L^{wr} EQ_L^w = Ew_{Ld}^r \tag{2.104}$$

$$EQ_{Li}^r - \eta_{Li}^r EP_{Li}^r - \eta_{LiLd}^r EP_{Ld}^r - \eta_{LiB}^r EP_B^r - \eta_{LiK}^r EP_K^r - \eta_{LiY}^r EP_Y^r = Ez_{Li}^r \tag{2.105}$$

$$EQ_{Li}^r - \varepsilon_{Li}^r EP_{Li}^r = Ew_{Li}^r \tag{2.106}$$

$$EQ_L^w - \eta_L^w EP_L^w - \tau_L^{rw} EQ_{Ld}^r = Ez_L^w \tag{2.107}$$

$$EQ_L^w - \varepsilon_L^w EP_L^w - \gamma_L^{sw} EQ_L^s = Ew_L^w \tag{2.108}$$

$$EQ_L^s - \eta_L^s EP_L^s - \tau_L^{ws} EQ_L^w = Ez_L^s \tag{2.109}$$

$$EQ_L^s - \varepsilon_L^s EP_L^s - \gamma_L^{fs} EQ_L^f = Ew_L^s \tag{2.110}$$

$$EQ_L^f - \eta_L^f EP_L^f - \tau_L^{sf} EQ_L^s = Ez_L^f \tag{2.111}$$

$$EQ_L^f - \varepsilon_L^f EP_L^f = Ew_L^f \tag{2.112}$$

Poultry Sector

$$EQ_Y^r - \eta_Y^r EP_Y^r - \eta_{YB}^r EP_B^r - \eta_{YK}^r EP_K^r - \eta_{YLd}^r EP_{Ld}^r - \eta_{YLi}^r EP_{Li}^r = Ez_y^r \tag{2.113}$$

$$EQ_Y^r - \varepsilon_Y^r EP_Y^r - \gamma_Y^{wr} EQ_Y^w - (Q_{Ye}^r / Q_Y^r) EQ_{Ye}^r = Ew_Y^r \tag{2.114}$$

$$EQ_{Ye}^r - \eta_Y^r EP_Y^r = Ez_{Ye}^r \tag{2.115}$$

$$EQ_Y^w - \eta_Y^w EP_Y^w - \tau_Y^{rw} EQ_Y^r - (Q_{Ye}^r / Q_Y^r) Ez_{Ye}^r = Ew_Y^w \tag{2.116}$$

$$EQ_Y^w - \varepsilon_Y^w EP_Y^w = Ew_Y^w \tag{2.117}$$

The model can then be expressed in matrix form where:

$$\mathbf{A} \text{ x } \mathbf{Y} = \mathbf{B} \text{ x } \mathbf{X} \tag{2.118}$$

The **A** matrix is a 35x35 nonsingular matrix of elasticities; **Y** is a 35x1 vector of changes in endogenous prices and quantities relative to an initial equilibrium; **B** is a 35x35 matrix of parameters associated with the exogenous variables; and **X** is a 35x1 vector of percentage changes in the exogenous supply and demand variables associated with the banning of antimicrobial use and the implementation of WPM on livestock facilities. The model is then solved for the **Y** matrix to find the relative changes to the endogenous variables in the model.

$$\mathbf{Y} = \mathbf{A}^{-1} \text{ x } \mathbf{B} \text{ x } \mathbf{X} \tag{2.119}$$

To quantify the net economic impact of banning antimicrobial use and the implementation of WPM on livestock facilities consumer and producer surplus are calculated as shown in equations 2.1 and 2.2, respectively.

Elasticities

Elasticity parameters are required for the **B** matrix in the EDM. A couple of approaches can be utilized to obtain the elasticities. Econometric estimation of elasticity values can be employed, but econometric estimation can be difficult due to the large number of equations along with identification problems Pendell et al. (2010). If the shifts of the supply and/or demand curves are relatively small (proportionally) then the EDM procedure of utilizing published elasticity values can be used. This analysis used the approach of utilizing published elasticity values as reported by Pendell et al. (2010) to parameterize the **B** matrix (Table A.2 and A.3). Following that of Schroeder and Tonsor (2011), it was assumed that industry adoption of the change in beef cattle production technology at the slaughter level would take ten years for full adjustment. To reflect the change in livestock and meat markets elasticity values are linearly adjusted from short-run elasticity values to long-run elasticity values in the EDM. Base prices and quantities for the model are needed for the calculation of both consumer and producer surplus. Average prices and quantities for 2013 were used as reported by the Livestock Marketing Information Center (LMIC) (see Table 2.1).

Supply Curve Shifts

The determination of exogenous shifts of supply curve at the slaughter (i.e. feedlot) level of cattle production from a hypothetical reduction on the use of antimicrobial technologies and the implementation of wildlife population management (WPM) at livestock facilities was conducted using a livestock budgeting analysis (see Table 2.2). A baseline livestock budget for finishing beef cattle at the slaughter level was constructed assuming 63% are steers and 37% are heifers as reported by LMIC. The returns per head are based on the initial in weight of each animal which are assumed to be 750 pounds for steers and 650 pounds for heifers and an out weight of 1300 pounds for steers and 1250 pounds for heifers. Purchase price and sale price are based on 2013 average values as reported by LMIC. The factors used to determine the costs associated with finishing beef cattle were that steers would be in the feedlot for 142 days while heifers would be fed for 170 days with an assumed average daily gain of 3.87 and 3.53 for steers and heifers, respectively. Feed conversion for steers was assumed to be 6.32 pounds as fed and 6.68 pounds as fed for heifers. This allowed for the calculation of feed costs along with other variable costs associated with finishing beef cattle.

Table 2.2: Beef Feedlot Cattle Enterprise Budget for Base, Antimicrobial Ban and Wildlife Population Management Scenarios.

BEEF FEEDLOT CATTLE	Base Scenario		Antimicrobial Ban		Wildlife Management	
	Steers	Heifers	Steers	Heifers	Steers	Heifers
RETURNS PER HEAD						
Market animal	$1,639.33	$1,576.28	$1,639.33	$1,576.28	$1,639.33	$1,576.28
Less cost of animal	1129.05	978.51	1129.05	978.51	1129.05	978.51
Less death loss (3.2 percent of line 1)	26.23	25.22	52.46	50.44	26.23	25.22
GROSS RETURNS PER HEAD	$484.05	$572.55	$457.82	$547.33	$484.05	$572.55
COSTS PER HEAD						
Harvested forage	38.83	44.77	42.77	49.31	38.83	44.77
Grain	319.84	368.79	352.30	406.22	319.84	368.79
Supplement	17.95	20.70	19.78	22.80	17.95	20.70
Decreased Cost of Technology Use			-4.96	-4.96		
Lost Feed Depredation Cost					-43.00	-43.00
Wildlife Population Management					3.21	3.21
Labor	9.45	11.32	9.45	11.32	9.45	11.32
Veterinary, drugs, and supplies	12.00	12.00	12.00	12.00	12.00	12.00
Marketing costs	6.00	6.00	6.00	6.00	6.00	6.00
Utilities, fuel, and oil	7.87	7.87	7.87	7.87	7.87	7.87
Facility and equipment repairs	9.00	9.00	9.00	9.00	9.00	9.00
Professional fees (legal, accounting, etc.)	1.75	1.75	1.75	1.75	1.75	1.75
Miscellaneous	7.00	7.00	7.00	7.00	7.00	7.00
Depreciation on facilities and equipment	12.00	12.00	12.00	12.00	12.00	12.00
Interest on facilities and equipment	6.45	6.45	6.45	6.45	6.45	6.45
Insurance and taxes on fac. and equip.	1.74	1.74	1.74	1.74	1.74	1.74
SUB TOTAL	449.88	509.38	483.27	548.63	410.08	469.59
Interest on feeder and 1/2 operating costs	33.93	36.96	34.35	37.56	33.43	36.36
TOTAL COSTS	483.81	546.34	517.62	586.19	443.50	505.95
RETURNS OVER TOTAL COSTS	**$0.25**	**$26.21**	**-$59.80**	**-$38.86**	**$40.55**	**$66.60**

Note: Enterprise budget information was developed from Dhuyvetter, K., M. Langemeier, and S. Johnson. 2011. FM - Guides -- Beef.xls http://www.agmanager.info/livestock/budgets/projected/. Accessed March 29, 2014.

Ban Calculation

For the calculation of a hypothetical reduction on the use of antimicrobials, it is assumed that all gross returns and costs remained the same except for the modification of a few select parameters in order to determine the shift of the supply curve. The budget is modified to first reflect the decrease in cost of purchasing sub-therapeutic antimicrobials to be fed which is determined to be approximately $4.96 per head as shown in Table 2.2. To develop the per head cost of each antimicrobial, the dosage amount is taken from the antimicrobial label and the Merck Veterinary Manual (Kahn, 2010) along with the cost for each antimicrobial are from the livestock concepts website as reported on July 15, 2014. The calculated costs per head for the use of ionophores (Bovatec 91), de-wormers (Safeguard Beef 1.96% Pellets), and an antimicrobial (Aureomycin 50 Granular) are $0.64, $1.16, and $3.16 per head, respectively (Table 2.3). The National Animal Health Monitoring System (NAHMS) reported that 90.6% of feedlots use ionophores, the most common antimicrobial fed, at a sub-therapeutic level in feed and/or water as a health or production management tool (USDA, 2011). Additionally, USDA (2011) reported an industry average death loss of 1.6%, it was conservatively assumed that in the absence of antimicrobial technology use death loss would increase to 3.2%. In a study by Lawrence and Ibarburu (2007) they report that removing antimicrobials such as; ionophores, antibiotics and de-wormers from feed rations would result in a 3.55%, 2.69% and 3.91% effect on feed to gain, respectively, with a cumulative effect of a 10.15% (assuming an additive effect of the antimicrobials) increase in feed to gain efficiency resulting in higher feed costs for the producer.

Table 2.3: Per Head Cost of Antimicrobial Technology.

	Cost/lb	Dosage	Cost per Head
Ionophore[1]	\$10.30	200 mg/hd/day	\$0.64
De-Wormer[2]	\$14.28	1/4 lb per 1000 lbs of body weight	\$1.16
Antibiotic[3]	\$1.82	1 pound per ton of feed	\$3.16
Total Cost Per Head			**\$4.96**

[1] \$514.90 per 50 lb bag, Bovatec 91, assuming 142 days on feed

[2] \$356.95 per 25 lb bag, Safeguard Beef 1.96% Pellets, assuming an out weight of 1300 pounds

[3] \$90.80 per 50 lb bag, Chlortetracycline Aureomycin 50 Granular, assuming an average total tons of feed per head of 1.74

Ban Shift

The analysis of different technologies in the beef feedlot industry is analyzed as a supply shock at the beef slaughter marketing level. The first change in technology is the elimination of antimicrobials in beef cattle production at the slaughter level. Reducing antimicrobial use causes a decrease in production efficiency primarily in the form of increased morbidity and mortality. The resulting economic impact is a leftward shift of the slaughter level supply curve by 3.46% as in Table 2.5. The effects of banning antimicrobial technologies is introduced into the EDM by shocking EW_B^S in equation 2.91. A leftward shift of this supply curve causes prices to increase resulting in less quantity demanded of the product. Derived supply curves at the wholesale and retail levels also have a leftward shift of ε and τ, respectively, from the reduced supply at the slaughter level. With higher prices and less quantity demanded at the retail level (primary demand), the derived demand curve for feeder cattle will at the farm level will have a leftward shift of α as depicted in Figure 2.2.

WPM Calculation

The use of wildlife population management (WPM) has been shown to reduce the number of starlings on feedlot sites and also the prevalence of AMR pathogens. Although the link of wildlife's contribution to both the prevalence and maintenance is unknown there is a growing need for research to determine this link and its impact to livestock production primarily in avian populations (Grieg, 2014). Despite the inherent knowledge gap an analysis on the implementation of WPM is still appropriate and relevant. In a study by Depenbusch et al. (2011), they found a 33% increase in meal-type feed delivered to the bunk where starling populations are present. The primary feed type consumed by starlings was steam-flaked corn with the starlings consuming 179kg of feed per pen during the 47 days of the study translating into a $43 increase in costs per heifer. The cost of starling control is determined to be approximately $3.21 per head where it is assumed that the feedlot had a capacity of 28,000 head with approximately 358,963 starlings on site and the cost of WPM was $0.25 per bird as determined by expert opinion (Carlson, forthcoming).

WPM Shift

The implementation of a WPM program on a beef cattle facility is analyzed by evaluating the associated costs. As previously discussed, the reduction of starling populations on these facilities has been shown to reduce feed costs by $43 per head and a cost of $3.21 per head for WPM as shown in Table 2.2. To analyze the economic impacts of WPM, two scenarios are developed based on the total number of cattle impacted by the use of WPM programs already in place in Colorado, Iowa, Kansas, Missouri and Texas. To determine the adoption rate of WPM the total number of cattle on feed in 1000+ feedlot capacity in 2013 for each state is found as reported by NASS (NASS, 2014). From there, the USDA APHIS Wildlife Services (WS) reported the total number of cattle impacted by the use of WPM in each state. It is found that across Colorado, Iowa, Kansas, Missouri and Texas WS impacts cattle on feed from 5.82% on the low side and 11.95% on the high side (see Table 2.4 and 2.5). The use of a low and high estimate for WPM adoption was due to the assumption that the implementation of WPM on livestock facilities will vary from year to year. Therefore, two scenarios are analyzed to evaluate the economic implications of WPM for a 5.82% and 11.95% adoption rate in the slaughter level of beef cattle production.

Table 2.4: Calculation of 11.95% Industry Adoption of WPM.

State	Number of Sites	Herd Size	Estimated Bird Population
CO	8	553,000	112,692
IA	8	23,800	28,910
KS	8	280,500	615,370
MO	3	3,885	8,489
TX	8	425,000	107,300
TOTAL	35	1,286,185	872,761
Cattle on Feed June 2014 (1000+ Feedlot Capacity)		10,767,000	
WPM Industry Adoption		**11.95%**	

Table 2.5: Calculation of 5.82% Industry Adoption of WPM.

State	Number of Sites	Herd Size	Estimated Bird Population
CO	4	271,000	40,702
IA	3	9,000	2,010
KS	4	129,500	118,511
MO	2	3,600	6,489
TX	4	214,000	4,300
TOTAL	17	627,100	172,012
Cattle on Feed June 2014 (1000+ Feedlot Capacity)		10,767,000	
WPM Industry Adoption		5.82%	

The economic impact from WPM at the slaughter level supply curve results in a rightward shift of the curve, which is λ in Figure 2.3. Under the two WPM programs of 5.82% and 11.95% adoption at the slaughter level the curve shifts 0.145% and 0.298%, respectively (Table 2.6). The effects of WPM at livestock facilities were introduced into the EDM by shocking EW_B^S in equation 2.91. The rightward shift of the slaughter level supply curve causes the price to decrease and quantity to increase. As a result derived supply curves at the wholesale and retail market levels also shift rightward of η and μ, respectively, as shown in Figure 2.3. The rightward shift of the supply curve at both wholesale and retail levels causes prices to decrease and as well as quantities to increase. At the farm level the derived demand curve for feeder cattle has a rightward shift of δ resulting in both price and quantity increasing at the market level as was presented in Figure 2.3.

Table 2.6: Exogenous Beef Feedlot Supply Shifters Corresponding to a Ban on Antimicrobial us and the Implementation of Wildlife Population Management.

Cost Adjustments Associated with Producing	Antimicrobial Ban	5.82% WPM Adoption	11.92% WPM Adoption
Retail Beef	0.000%	0.000%	0.000%
Wholesale Beef	0.000%	0.000%	0.000%
Slaughter Cattle	-3.463%	0.145%	0.298%
Feeder Cattle	0.000%	0.000%	0.000%

RESULTS

Antimicrobial Ban: Equilibrium Displacement Model Results

Table 2.7 presents the changes in livestock and meat prices and quantities from equation 2.119 from a ban on antimicrobial technology use in beef cattle production relative to a base of 0% change in the use antimicrobial technology. The results presented are consistent with previous discussion on the banning of antimicrobial technology use where it was expected that prices would increase and quantities would decrease. The economic impacts for both the wholesale and retail levels prices and quantities are larger in years 1-4 when supply is inelastic, but as the market is able to adjust to more elastic supply conditions the impacts decrease (Schroeder and Tonsor, 2011). The pork, lamb and poultry sectors see gains in both prices and quantities at all marketing levels, except in the export markets for pork and poultry which could be due to consumers substituting away from higher priced beef products to substitute goods such as pork and poultry. This would cause the wholesale market to reduce the export of such goods.

Table 2.7: Antimicrobial Ban - Equilibrium Displacement Model Estimated Percent Changes in Endogenous Variables.

Variable	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Retail Beef Quantity	-2.84%	-2.48%	-1.98%	-1.41%	-0.89%	-0.50%	-0.26%	-0.13%	-0.06%	-0.03%
Retail Beef Price	3.39%	2.84%	2.18%	1.50%	0.91%	0.49%	0.24%	0.12%	0.05%	0.02%
Retail Pork Price	0.25%	0.17%	0.10%	0.05%	0.03%	0.01%	0.00%	0.00%	0.00%	0.00%
Retail Domestic Lamb Price	0.32%	0.23%	0.15%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
Retail Imported Lamb Price	0.04%	0.03%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Poultry Price	0.91%	0.54%	0.28%	0.12%	0.05%	0.01%	0.00%	0.00%	0.00%	0.00%
Wholesale Beef Quantity	-5.27%	-4.98%	-4.37%	-3.47%	-2.47%	-1.59%	-0.96%	-0.56%	-0.32%	-0.18%
Wholesale Beef Price	4.18%	4.08%	3.69%	3.02%	2.20%	1.45%	0.88%	0.51%	0.29%	0.16%
Slaughter Cattle Quantity	-6.04%	-6.13%	-5.89%	-5.22%	-4.23%	-3.17%	-2.25%	-1.56%	-1.07%	-0.74%
Imported Wholesale Beef Quantity	-3.97%	-3.87%	-3.50%	-2.85%	-2.07%	-1.37%	-0.84%	-0.49%	-0.28%	-0.16%
Exported Wholesale Beef Quantity	-1.76%	-2.13%	-2.40%	-2.44%	-2.21%	-1.81%	-1.37%	-0.99%	-0.70%	-0.48%
Imported Wholesale Beef Price	-2.17%	-1.75%	-1.31%	-0.88%	-0.53%	-0.29%	-0.15%	-0.07%	-0.03%	-0.02%
Slaughter Cattle Price	0.75%	1.71%	2.64%	3.27%	3.39%	3.06%	2.50%	1.92%	1.42%	1.03%
Feeder Cattle Quantity	-2.50%	-2.80%	-2.93%	-2.82%	-2.46%	-1.97%	-1.48%	-1.08%	-0.78%	-0.56%
Feeder Cattle Price	-24.29%	-18.79%	-13.65%	-9.08%	-5.48%	-3.04%	-1.59%	-0.80%	-0.40%	-0.20%
Retail Pork Quantity	0.46%	0.41%	0.32%	0.23%	0.14%	0.08%	0.04%	0.02%	0.01%	0.00%
Wholesale Pork Quantity	0.29%	0.27%	0.23%	0.17%	0.11%	0.06%	0.03%	0.02%	0.01%	0.00%
Wholesale Pork Price	0.23%	0.18%	0.12%	0.07%	0.04%	0.02%	0.01%	0.00%	0.00%	0.00%
Slaughter Hogs Quantity	0.13%	0.12%	0.11%	0.08%	0.06%	0.03%	0.02%	0.01%	0.00%	0.00%
Imported Wholesale Pork Quantity	0.19%	0.19%	0.16%	0.13%	0.09%	0.05%	0.03%	0.01%	0.01%	0.00%
Exported Wholesale Pork Quantity	-0.20%	-0.16%	-0.11%	-0.07%	-0.04%	-0.02%	-0.01%	0.00%	0.00%	0.00%
Imported Wholesale Pork Price	0.14%	0.11%	0.08%	0.05%	0.03%	0.01%	0.01%	0.00%	0.00%	0.00%
Slaughter Hogs Price	0.31%	0.25%	0.19%	0.12%	0.07%	0.04%	0.02%	0.01%	0.00%	0.00%
Domestic Retail Lamb Quantity	0.04%	0.04%	0.03%	0.03%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%
Wholesale Lamb Quantity	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
Imported Retail Lamb Quantity	0.42%	0.32%	0.22%	0.14%	0.08%	0.04%	0.02%	0.01%	0.00%	0.00%
Wholesale Lamb Price	0.05%	0.03%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Lamb Quantity	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
Slaughter Lamb Price	0.02%	0.02%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Feeder Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Feeder Lamb Price	0.02%	0.02%	0.02%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%
Retail Poultry Quantity	0.36%	0.34%	0.29%	0.22%	0.14%	0.08%	0.04%	0.02%	0.01%	0.00%
Wholesale Poultry Quantity	0.15%	0.16%	0.16%	0.14%	0.10%	0.06%	0.03%	0.02%	0.01%	0.00%
Exported Wholesale Poultry Quantity	-0.28%	-0.19%	-0.11%	-0.06%	-0.02%	-0.01%	0.00%	0.00%	0.00%	0.00%
Wholesale Poultry Price	1.04%	0.73%	0.45%	0.24%	0.11%	0.04%	0.01%	0.00%	0.00%	0.00%

The slaughter cattle marketing level sees a slight increase in prices for year 1 (0.75%) and continues to increase to 3.39% in year 5 (Table 2.7). In years 6-10 slaughter cattle prices decline as supply becomes more elastic. Slaughter cattle quantities decrease by 6.04% in year 1 and continue to decrease from 6.13% in year 2 to 0.74% in year 10. The biggest impact to the beef cattle sector is to feeder cattle prices which decrease 24.29% in the first year of banning the use of antimicrobial technologies. In subsequent years feeder cattle prices continue to decline from 18.79% in year 2, 13.65% in year 3, and 9.08% in year 4. With supply becoming more elastic the impacts adjust to be less than a 5.48% decrease in feeder cattle prices in years 5-10. Feeder cattle quantities decrease by 2.50%, 2.80% and 2.93% in years 1, 2 and 3 respectively with a steady decline from 2.82% to 0.56% in years 4-10.

Producer and consumer surplus measures were calculated for each of the ten years using equations 2.1 and 2.2. Table 2.8 shows that overall, the meat industry losses in producer surplus from year 1-10. In the short run (year 1) impacts are much larger than in the long run (year 10) impacts which are expected due to the long run supply being more elastic then short run supply. The beef industry losses the most from a ban on the use of antimicrobial technology in beef cattle production with the largest impacts coming in years 1-4 and to a lesser extent losses in years 5-10. Conversely, pork, lamb and poultry producers see a slight gain in producer surplus as consumers substitute away from higher priced beef products. Beef consumers do have a loss in consumer surplus in years 1-10. Consumer surplus for pork, lamb and poultry does increase but overall consumer surplus for the meat industry decreases with the largest impacts being in years 1-4.

Table 2.8: Antimicrobial Ban – Producer and Consumer Surplus Changes ($ millions).

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Cumulative Present Value
Beef Producer Surplus											
Retail	-747.86	-1,033.14	-1,182.17	-1,148.13	-750.76	-318.39	-124.07	-45.73	-16.30	-5.70	-4,574.07
Wholesale	-1,886.85	-1,991.31	-2,015.93	-1,909.59	-1,672.84	-1,058.61	-484.84	-212.96	-91.59	-39.06	-9,588.03
Slaughter	-1,976.26	-1,763.33	-1,498.20	-1,235.50	-1,044.97	-959.63	-724.68	-353.30	-170.49	-82.25	-8,241.59
Farm	-10,404.33	-8,036.93	-5,833.58	-3,883.48	-2,347.70	-1,304.10	-682.77	-345.56	-172.13	-85.27	-29,127.89
Total Beef	-15,015.31	-12,824.71	-10,529.88	-8,176.70	-5,816.28	-3,640.73	-2,016.36	-957.55	-450.51	-212.28	-51,531.58
Pork Producer Surplus											
Retail	222.29	157.92	99.04	55.03	27.17	12.07	4.95	1.93	0.73	0.27	521.53
Wholesale	86.70	70.17	51.32	32.86	18.11	8.60	3.67	1.48	0.58	0.22	242.31
Slaughter	81.25	66.55	49.30	32.02	17.93	8.70	3.74	1.51	0.59	0.23	231.41
Total Pork	390.25	294.65	199.65	119.90	63.21	29.36	12.36	4.92	1.90	0.72	995.24
Lamb Producer Surplus											
Retail Domestic	2.63	1.86	1.20	0.68	0.32	0.13	0.04	0.01	0.00	0.00	6.18
Wholesale	0.22	0.18	0.13	0.08	0.04	0.02	0.01	0.00	0.00	0.00	0.60
Slaughter	0.08	0.08	0.07	0.05	0.03	0.02	0.01	0.00	0.00	0.00	0.31
Farm	0.08	0.09	0.09	0.07	0.05	0.03	0.01	0.01	0.00	0.00	0.36
Total Lamb	3.01	2.21	1.49	0.88	0.45	0.19	0.07	0.02	0.01	0.00	7.45
Poultry Producer Surplus											
Retail	451.45	293.17	170.09	82.71	30.03	9.48	2.83	0.81	0.23	0.06	944.20
Wholesale	645.80	465.24	296.16	157.96	65.10	20.29	5.91	1.67	0.46	0.13	1,494.67
Total Poultry	1,097.25	758.41	466.24	240.67	95.13	29.77	8.74	2.48	0.69	0.19	2,438.87
Total Meat Industry Producer Surplus	-13,524.79	-11,769.44	-9,862.49	-7,815.24	-5,657.50	-3,581.40	-1,995.19	-950.13	-447.92	-211.37	-48,090.02
Consumer Surplus											
Retail Beef	-3,076.75	-2,601.08	-2,015.61	-1,392.99	-848.93	-462.09	-231.11	-109.34	-50.02	-22.44	-9,470.92
Retail Pork	331.06	277.96	213.01	145.03	86.80	46.27	22.60	10.42	4.63	2.01	1,000.61
Retail Lamb	0.58	0.51	0.42	0.30	0.20	0.11	0.06	0.03	0.01	0.01	1.94
Retail Poultry	484.92	400.15	298.48	194.78	109.87	54.38	24.40	10.25	4.14	1.63	1,397.47
Total Meat Industry Consumer Surplus	-2,260.19	-1,922.46	-1,503.70	-1,052.88	-652.07	-361.32	-184.05	-88.65	-41.24	-18.79	-7,070.91

Note: Producer and consumer surplus is calculated relative to 2013 prices and quantities for livestock and meat.

Wildlife Population Management Adoption - Equilibrium Displacement Model Results

The implementation of a wildlife population management (WPM) program on livestock facilities was depicted in Figure 2.3. The figure shows that a rightward shift of the slaughter cattle supply curve will cause prices to decrease at the slaughter, wholesale and retail levels. Table 2.9 shows that prices at the slaughter, wholesale, and retail levels decrease by 0.03%, 0.18% and 0.14%, respectively for a 5.82% industry adoption of WPM. Similarly, for an 11.95% industry adoption of WPM Table 2.10 shows that prices at the slaughter, wholesale, and retail levels do decrease by 0.06%, 0.36% and 0.29%, respectively. Figure 2.3 also shows that the same rightward shift of the slaughter cattle supply curve will cause quantities at the slaughter, wholesale, and retail levels will increase. As Table 2.9 shows a 5.82% industry adoption of WPM will cause beef quantities at the slaughter, wholesale, and retail levels to increase by 0.25%, 0.22%, and 0.12%, respectively. Similarly, with an 11.95% industry adoption of WPM beef quantities increase by 0.52%, 0.45%, and 0.24%, respectively as Table 2.10 shows. At the farm level Figure 2.3 shows that derived demand for feeder cattle will have a rightward shift causing both prices and quantities to increase which are shown in Table 2.13 where price increases by1.02% and quantity by 0.11% for a 5.82% adoption of WPM were prices increase by 2.09% and quantity by 0.22% for an 11.95% adoption of WPM. Similar to a ban on antimicrobial technology use, in the short run impacts are larger due to inelastic supply than long run impacts where supply adjusts to more elastic conditions. In the pork, lamb and poultry sectors there are minimal changes to both prices and quantities from years 1-10.

Table 2.9: 5.82% WPM Adoption - Equilibrium Displacement Model Estimated Percent Changes in Endogenous Variables.

Variable	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Retail Beef Quantity	0.12%	0.10%	0.08%	0.06%	0.04%	0.02%	0.01%	0.01%	0.00%	0.00%
Retail Beef Price	-0.14%	-0.12%	-0.09%	-0.06%	-0.04%	-0.02%	-0.01%	0.00%	0.00%	0.00%
Retail Pork Price	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Domestic Lamb Price	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Imported Lamb Price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Poultry Price	-0.04%	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Beef Quantity	0.22%	0.21%	0.18%	0.15%	0.10%	0.07%	0.04%	0.02%	0.01%	0.01%
Wholesale Beef Price	-0.18%	-0.17%	-0.15%	-0.13%	-0.09%	-0.06%	-0.04%	-0.02%	-0.01%	-0.01%
Slaughter Cattle Quantity	0.25%	0.26%	0.25%	0.22%	0.18%	0.13%	0.09%	0.07%	0.05%	0.03%
Imported Wholesale Beef Quantity	0.17%	0.16%	0.15%	0.12%	0.09%	0.06%	0.04%	0.02%	0.01%	0.01%
Exported Wholesale Beef Quantity	0.07%	0.09%	0.10%	0.10%	0.09%	0.08%	0.06%	0.04%	0.03%	0.02%
Imported Wholesale Beef Price	0.09%	0.07%	0.05%	0.04%	0.02%	0.01%	0.01%	0.00%	0.00%	0.00%
Slaughter Cattle Price	-0.03%	-0.07%	-0.11%	-0.14%	-0.14%	-0.13%	-0.11%	-0.08%	-0.06%	-0.04%
Feeder Cattle Quantity	0.11%	0.12%	0.12%	0.12%	0.10%	0.08%	0.06%	0.05%	0.03%	0.02%
Feeder Cattle Price	1.02%	0.79%	0.57%	0.38%	0.23%	0.13%	0.07%	0.03%	0.02%	0.01%
Retail Pork Quantity	-0.02%	-0.02%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Pork Quantity	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Pork Price	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Hogs Quantity	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Imported Wholesale Pork Quantity	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Exported Wholesale Pork Quantity	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Imported Wholesale Pork Price	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Hogs Price	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Domestic Retail Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Imported Retail Lamb Quantity	-0.02%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Lamb Price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Lamb Price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Feeder Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Feeder Lamb Price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Poultry Quantity	-0.02%	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Poultry Quantity	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Exported Wholesale Poultry Quantity	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Poultry Price	-0.04%	-0.03%	-0.02%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 2.10: 11.95% WPM Adoption - Equilibrium Displacement Model Estimated Percent Changes in Endogenous Variables.

Variable	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Retail Beef Quantity	0.24%	0.21%	0.17%	0.12%	0.08%	0.04%	0.02%	0.01%	0.01%	0.00%
Retail Beef Price	-0.29%	-0.24%	-0.19%	-0.13%	-0.08%	-0.04%	-0.02%	-0.01%	0.00%	0.00%
Retail Pork Price	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Domestic Lamb Price	-0.03%	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Imported Lamb Price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Poultry Price	-0.08%	-0.05%	-0.02%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Beef Quantity	0.45%	0.43%	0.38%	0.30%	0.21%	0.14%	0.08%	0.05%	0.03%	0.02%
Wholesale Beef Price	-0.36%	-0.35%	-0.32%	-0.26%	-0.19%	-0.12%	-0.08%	-0.04%	-0.02%	-0.01%
Slaughter Cattle Quantity	0.52%	0.53%	0.51%	0.45%	0.36%	0.27%	0.19%	0.13%	0.09%	0.06%
Imported Wholesale Beef Quantity	0.34%	0.33%	0.30%	0.25%	0.18%	0.12%	0.07%	0.04%	0.02%	0.01%
Exported Wholesale Beef Quantity	0.15%	0.18%	0.21%	0.21%	0.19%	0.16%	0.12%	0.09%	0.06%	0.04%
Imported Wholesale Beef Price	0.19%	0.15%	0.11%	0.08%	0.05%	0.03%	0.01%	0.01%	0.00%	0.00%
Slaughter Cattle Price	-0.06%	-0.15%	-0.23%	-0.28%	-0.29%	-0.26%	-0.22%	-0.17%	-0.12%	-0.09%
Feeder Cattle Quantity	0.22%	0.24%	0.25%	0.24%	0.21%	0.17%	0.13%	0.09%	0.07%	0.05%
Feeder Cattle Price	2.09%	1.62%	1.18%	0.78%	0.47%	0.26%	0.14%	0.07%	0.03%	0.02%
Retail Pork Quantity	-0.04%	-0.04%	-0.03%	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%
Wholesale Pork Quantity	-0.03%	-0.02%	-0.02%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%
Wholesale Pork Price	-0.02%	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Hogs Quantity	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Imported Wholesale Pork Quantity	-0.02%	-0.02%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Exported Wholesale Pork Quantity	0.02%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Imported Wholesale Pork Price	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Hogs Price	-0.03%	-0.02%	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Domestic Retail Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Imported Retail Lamb Quantity	-0.04%	-0.03%	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Lamb Price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Slaughter Lamb Price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Feeder Lamb Quantity	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Feeder Lamb Price	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Retail Poultry Quantity	-0.03%	-0.03%	-0.03%	-0.02%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%
Wholesale Poultry Quantity	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	0.00%	0.00%	0.00%	0.00%
Exported Wholesale Poultry Quantity	0.02%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wholesale Poultry Price	-0.09%	-0.06%	-0.04%	-0.02%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.00%

Economic welfare impacts from the implementation of a WPM program on livestock facilities were calculated using equations 2.1 and 2.2 and are shown in Tables 2.11 and 2.12. For both a 5.82% and 11.95% industry adoption of WPM the beef sector sees the largest gains in producer surplus in years 1-5 then to a lesser extent gains in years 6-10. The largest gain in producer surplus was at the farm level especially in years 1-6 for both 5.82% and 11.95% industry adoption of WPM. In pork, lamb and poultry producer surplus decreases due in large part to consumers being able to purchase beef products at a lower price. As is seen in consumer surplus under both WPM adoption scenarios beef consumers see gains in years 1-4 and even in years 5-10 where consumer surplus in pork, lamb and poultry decrease. Overall, both producer and consumer surplus for the meat industry increases with the largest gains being recognized in years 1-5.

Table 2.11: 5.82% WPM Adoption – Producer and Consumer Surplus Changes ($ millions).

Producer Surplus	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Cumulative Present Value
Beef Producer Surplus											
Retail	26.54	39.65	47.21	46.93	31.67	13.40	5.22	1.92	0.68	0.24	181.04
Wholesale	71.15	75.90	78.22	75.75	67.76	44.81	20.46	8.97	3.85	1.64	377.12
Slaughter	82.25	72.32	60.27	48.83	41.09	38.16	30.79	14.95	7.20	3.47	335.60
Farm	442.56	342.39	248.71	165.47	99.84	55.32	28.89	14.59	7.26	3.59	1,239.81
Total Beef	622.49	530.26	434.41	336.98	240.36	151.70	85.35	40.43	18.99	8.94	2,133.58
Pork Producer Surplus											
Retail	-9.32	-6.62	-4.15	-2.31	-1.14	-0.51	-0.21	-0.08	-0.03	-0.01	-21.87
Wholesale	-3.64	-2.94	-2.15	-1.38	-0.76	-0.36	-0.15	-0.06	-0.02	-0.01	-10.16
Slaughter	-3.41	-2.79	-2.07	-1.34	-0.75	-0.37	-0.16	-0.06	-0.02	-0.01	-9.71
Total Pork	-16.36	-12.36	-8.38	-5.03	-2.65	-1.23	-0.52	-0.21	-0.08	-0.03	-41.74
Lamb Producer Surplus											
Retail Domestic	-0.11	-0.08	-0.05	-0.03	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.26
Wholesale	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03
Slaughter	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01
Farm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02
Total Lamb	-0.13	-0.09	-0.06	-0.04	-0.02	-0.01	0.00	0.00	0.00	0.00	-0.31
Poultry Producer Surplus											
Retail	-18.90	-12.28	-7.13	-3.47	-1.26	-0.40	-0.12	-0.03	-0.01	0.00	-39.55
Wholesale	-27.08	-19.50	-12.42	-6.63	-2.73	-0.85	-0.25	-0.07	-0.02	-0.01	-62.67
Total Poultry	-45.98	-31.79	-19.55	-10.10	-3.99	-1.25	-0.37	-0.10	-0.03	-0.01	-102.23
Total Meat Industry Producer Surplus	560.03	486.03	406.43	321.82	233.69	149.21	84.46	40.12	18.88	8.90	1,989.30
Consumer Surplus											
Retail Beef	131.11	110.63	85.50	58.92	35.81	19.45	9.72	4.59	2.10	0.94	402.05
Retail Pork	-13.87	-11.64	-8.93	-6.08	-3.64	-1.94	-0.95	-0.44	-0.19	-0.08	-41.93
Retail Lamb	-0.02	-0.02	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.08
Retail Poultry	-20.32	-16.77	-12.51	-8.17	-4.61	-2.28	-1.02	-0.43	-0.17	-0.07	-58.58
Total Meat Industry Consumer Surplus	96.90	82.19	64.05	44.65	27.55	15.22	7.74	3.72	1.73	0.79	301.46

Note: Producer and consumer surplus is calculated relative to 2013 prices and quantities for livestock and meat.

Table 2.12: 11.95% WPM Adoption – Producer and Consumer Surplus Changes ($ millions).

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Cumulative Present Value
Beef Producer Surplus											
Retail	54.01	81.00	96.62	96.15	64.96	27.49	10.70	3.94	1.40	0.49	370.36
Wholesale	145.22	155.00	159.88	154.98	138.76	91.95	41.97	18.39	7.90	3.37	771.28
Slaughter	168.62	148.18	123.40	99.88	84.03	78.09	63.17	30.68	14.77	7.11	687.42
Farm	908.20	702.68	510.43	339.58	204.88	113.50	59.27	29.93	14.88	7.36	2,544.33
Total Beef	1,276.06	1,086.86	890.31	690.60	492.64	311.03	175.10	82.95	38.95	18.33	4,373.39
Pork Producer Surplus											
Retail	-19.11	-13.58	-8.52	-4.74	-2.34	-1.04	-0.43	-0.17	-0.06	-0.02	-44.85
Wholesale	-7.46	-6.04	-4.41	-2.83	-1.56	-0.74	-0.32	-0.13	-0.05	-0.02	-20.84
Slaughter	-6.99	-5.73	-4.24	-2.76	-1.54	-0.75	-0.32	-0.13	-0.05	-0.02	-19.91
Total Pork	-33.55	-25.34	-17.18	-10.32	-5.44	-2.53	-1.06	-0.42	-0.16	-0.06	-85.60
Lamb Producer Surplus											
Retail Domestic	-0.23	-0.16	-0.10	-0.06	-0.03	-0.01	0.00	0.00	0.00	0.00	-0.53
Wholesale	-0.02	-0.02	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.05
Slaughter	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03
Farm	-0.01	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	-0.03
Total Lamb	-0.26	-0.19	-0.13	-0.08	-0.04	-0.02	-0.01	0.00	0.00	0.00	-0.64
Poultry Producer Surplus											
Retail	-38.76	-25.19	-14.62	-7.12	-2.58	-0.82	-0.24	-0.07	-0.02	-0.01	-81.12
Wholesale	-55.53	-40.00	-25.47	-13.59	-5.60	-1.75	-0.51	-0.14	-0.04	-0.01	-128.53
Total Poultry	-94.29	-65.19	-40.09	-20.70	-8.19	-2.56	-0.75	-0.21	-0.06	-0.02	-209.65
Total Meat Industry Producer Surplus	1,147.95	996.15	832.92	659.50	478.97	305.92	173.28	82.31	38.73	18.25	4,077.49
Consumer Surplus											
Retail Beef	269.07	227.02	175.44	120.87	73.45	39.90	19.93	9.42	4.31	1.93	825.00
Retail Pork	-28.43	-23.88	-18.31	-12.47	-7.47	-3.98	-1.95	-0.90	-0.40	-0.17	-85.99
Retail Lamb	-0.05	-0.04	-0.04	-0.03	-0.02	-0.01	-0.01	0.00	0.00	0.00	-0.17
Retail Poultry	-41.67	-34.39	-25.66	-16.75	-9.45	-4.68	-2.10	-0.88	-0.36	-0.14	-120.13
Total Meat Industry Consumer Surplus											0.00
	198.92	168.71	131.44	91.62	56.52	31.22	15.88	7.64	3.55	1.62	618.70

Note: Producer and consumer surplus is calculated relative to 2013 prices and quantities for livestock and meat.

CONCLUSION

The use of antibiotics in livestock production has become increasingly implicated in human AMR infections. The reduction of antibiotics in livestock production has been suggested as a plausible risk management tool to reduce or eliminate the transmission of AMR pathogens, but as this study has shown such a reduction on antibiotics has significant economic impacts to both producers and consumers in the short and long run. The implementation of a wildlife population management program was analyzed as an alternative strategy to reduce AMR on livestock facilities. The economic analysis showed that WPM may be a suitable starting point for livestock producers to increase the biosecurity of their facilities with economic benefits occurring in both the short and long run for both consumers and producers. Mitigating the risk of wildlife vectored AMR transmission could further safeguard the farm-to-fork supply chain enhancing a consistent food supply and concurrently reduce the risk of AMR pathogen transmission to consumers.

The analysis conducted is a novel application of existing research applied to the rising concern for antimicrobial resistance in livestock production. The study explored the potential economic impacts of feedlot level management strategies designed to reduce the prevalence of AMR pathogens on livestock facilities. Using an equilibrium displacement model (EDM) of the U.S. meat industry (i.e., beef, pork, lamb and poultry), the study is able to explore the economic implications of implementing two particular feedlot management strategies for AMR reduction within livestock operations: 1) voluntary reductions in antimicrobial usage for growth promotion in livestock operations, and 2) wildlife population management strategies (WPM).

The study results showed that the reduction of antimicrobial technology use in feedlot cattle production would increase prices and decrease quantities. The most significant effect was the short-run impacts to feeder cattle prices which decreased 24.29% in the first year of reducing the use of antimicrobial technologies. In the long run, feeder cattle supply become more elastic and the impacts adjusted to be less than a 5.48% decrease in feeder cattle prices. Producer surplus measures showed that the beef industry losses $15,015.31 million in the short-run from a reduction on the use of antimicrobial technology in beef cattle production. Long-run producer surplus impacts showed a loss of $212.31 million. Lower long-run producer surplus impacts would be expected due to long run supply being more elastic then short run supply.

The reduction of antibiotics in livestock production has been suggested as a plausible risk management tool to reduce or eliminate the transmission of AMR pathogens, but as this study has shown such a reduction on antibiotics has significant economic impacts to both producers and consumers in both the short- and long-run. The implementation of a wildlife population management program was analyzed as an alternative strategy to reduce AMR on livestock facilities. Results indicate that an 11.95% industry adoption of WPM will cause a gain in producer surplus for the meat industry of $1.15 billion in the short run with long run gains of $18.33 million. The economic analysis shows that WPM may be a suitable starting point for livestock producers to increase the biosecurity of their facilities.

The implementation of an 11.95% industry adoption of a wildlife population management (WPM) program on livestock facilities resulted in prices decreasing and quantities increasing at the slaughter, wholesale and retail levels. At the farm level derived demand for feeder cattle increased for both price and quantity. Similar to a reduction on antimicrobial technology use, in the short run impacts are larger due to inelastic supply than long run impacts where supply adjusts to more elastic conditions. Overall, from an 11.95% industry adoption of a WPM program on livestock facilities showed that both producer and consumer surplus for the meat industry increases with the largest gains being recognized in years 1-5.

The increased concerns of antimicrobial resistance are valid for both the immediate and long-term health of humans, human medicine and livestock production. Considering the complexity of antimicrobial resistance, the significant economic implications from reducing the use of antimicrobials, and the sensitivity required to effectively analyze the situation highlights the necessity to contemplate the most appropriate path for the use of antimicrobials in both livestock and humans. Livestock producers may consider the mitigation of wildlife-livestock interaction at their facilities as one alternative method to decrease the prevalence of AMR pathogens.

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CHAPTER 3

Estimating the Economic Contribution of Bovine Viral Diarrhea Virus Biosecurity Strategies Using Whole Farm Planning

INTRODUCTION

The 2007 USDA's National Animal Health Monitoring System (NAHMS) survey reports that 66.7% of producers believe that bovine viral diarrhea virus (BVDV) has had a significant impact on the U.S. beef industry. In the same survey, the removal of BVDV infected calves from the herd may reduce sickness and/or treatment costs, will improve reproductive efficiency and reduce death loss according to 96.9%, 89.7% and 95.7% of all cattle producers surveyed, respectively (USDA, 2010a). Interestingly, 41% of all operations vaccinated any cattle or calves against BVDV and only 4.2% of operations tested for persistent infection of BVDV in their herd over the last three years. This can lead to the producer being exposed to risk from the uncertainty of BVDV impacts to cow-calf operations. The high rate of vaccination among operations, relative to testing, may indicate that producers believe vaccination may be a viable risk mitigation strategy to maintain animal health and control the spread of BVDV.

Alternative management strategies for BVDV have included testing and removing of persistently infected calves. According to the 2007 USDA NAHMS (USDA, 2010b), 57.2% of producers surveyed believe that removal of infected cattle will affect the health of the herd with an expected increase in value of $22.70 per head. Interestingly, 46.6% of the surveyed producers were unsure if removing calves would affect the value of the remaining calves in the herd.

Cow-calf producers are often faced with a significant amount of risk as found by Dhuyvetter and Langemeier (2010) and Krause (1992) where negative returns were recognized for a majority of the years evaluated in their studies. Fausti et al. (2003) discuss two types of risk: systematic and unsystematic. Systematic risk would be those factors that are uncontrollable from a management perspective and may include things such as market prices, production costs and weather. There are management tools available to assist in mitigating some of these risks by using hedging and insurance. Unsystematic risk are those factors (i.e., calf quality) which do not require the use of tools to control, and from a management perspective are controllable.

Several studies have suggested ways to better minimize risk with most focusing on the management of risk on the cost side of production (Ramsey et al., 2005), marketing and value-added programs (Bulut, Lawrence and Martin, 2006; Blank, Forero and Nader, 2009; Shulz and Dhuyvetter, 2009) and retained ownership (Pope et al., 2011; Fausti et al., 2003; Fausti and Gillespie, 2006; Lawrence, 2005; White et al., 2007; Gillespie et al., 2004; Lacy et al., 2003). Marketing and value-added programs (i.e., disease prevention strategies and health programs) have been found to generate premiums when calves are sold ranging from $1.37/cwt to $6.64/cwt (Forero and Nader, 2009; Zimmerman et al., 2012; Bulut and Lawrence, 2006; King et al., 2006; Schumacher, Schroeder, and Tonsor, 2012), but have found that buyers will also discount unhealthy calves from $6.31/cwt to $23.68/cwt (Schulz and Tonsor, 2010). As found by Pope et al. (2011), producers are not uniformly risk averse, but a risk averse producer is hesitant to change production practices. Even though higher returns may be recognized, the increased price and production risk could make producers reluctant to adapt their production practices.

In farm management, the typical objective is to achieve the optimum allocation of scarce resources between competing activates to achieve a given objective subject to the farm’s constraints, which is usually to maximize profits. The use of linear programming (LP) allows for the determination of a farm plan (as defined by a set of activities) that has the largest possible total gross margin, but does not violate any of the fixed resource constraints nor does not have any negative activity levels (Hazell and Norton, 1986). Although there are shortcomings to the implementation of LP, as discussed by Barnard and Nix (1979), in whole farm planning there has been developments to incorporate risk into the LP framework (Hazell, 1971; Tauer, 1983). There is a need for a better understanding of both the unsystematic risk and economic impacts of BVDV on U.S. cow-calf herds.

The main objective of this study is to determine the relative contribution of BVDV prevention strategies to minimize risk related to farm income and the uncertain financial impacts of BVDV incursion. The specific objectives of this study include:

1) Estimate the impact of BVDV introduction to representative U.S. cow-calf operations using an epidemiological disease spread model and the annual costs in cow-calf herds resulting from lost income, costs to treat morbid calves and decreased performance.
2) Evaluate the expected returns and risk for various BVDV biosecurity measures in U.S. cow-calf herds by using a linear programming model which incorporates risk.

This study expands on the work by Smith et al. (2014) by regionalizing their BVDV epidemiological model by major cow-calf producing regions. The output from the BVDV model are then incorporated into a LP framework which optimizes the allocation of scarce resources between competing activities to maximize expected returns. The information from this study is useful to the cow-calf industry as impacts and costs from various biosecurity measures are provided. Further, this study provides U.S. cow-calf producers the necessary information to see the tradeoffs between returns and risk of the alternate control strategies at the whole farm level.

METHODS

The following section consists of a general overview of the methods and models used in this research. The first part will give a description of the Reed-Frost epidemic model and previous research which has used the model to simulate the spread of BVDV. The second part will discuss the linear programming model and its development to incorporate risk with a focus on managing the control of BVDV spread in cow-calf herds (i.e., unsystematic risk).

Epidemiological Model

The most commonly used epidemiological model for disease spread is the Reed-Frost (RF) epidemic model. The RF model is a discrete time-step model for simple epidemics that comprises specific health states for susceptible, infectious and recovered (SIR) cases (Abbey, 1952; Nyamusika et al., 1994). The RF model can be used to develop and model the transmission of many infectious agents. Assumptions of the RF model are:

1. Infection is spread by adequate contact from one individual to another;
2. Non-immune individuals in a group that has adequate contact with an infected individual will develop infection and once recovered will have lasting immunity;
3. All individuals in the group have a fixed probability of adequate contact with the infected individual; and
4. Individuals of interested are segregated from other individuals outside the group (Abbey, 1952; Picard and Lefevre, 1991).

In the RF model, adequate contact is defined as the contact between an infectious and susceptible individual that results in the infection of the susceptible individual (Abbey, 1952). The probability of effective infectious contact (P) is dependent on the susceptibility or resistance of the host, the infectivity of the parasite, the length of exposure and infectious dose received and any environmental conditions necessary for the transfer of the organism (Abbey, 1952). Following the RF relationship, the probability of a susceptible individual becoming infected in any time period is given by:

$$P = (1 - Q^{C_t}). \tag{3.1}$$

where C^t represents the number of infected cattle during a given time period (Stott et al., 2003). With C_t being the number of infected individuals capable of transmitting the disease, then Q^{C_t} is the probability that any given susceptible individual will avoid an effective contact with any of the cases.

The Reed-Frost model has been used to simulate the spread of BVDV within farms for dairy herds (Innocent et al., 1997a and 1997b; Cherry, Reeves, and Smith, 1998; Viet et al., 2004a and 2004b; Viet et al., 2005; Viet et al., 2006; Ezanno et al., 2007) and recently there has been a development of models for the spread of BVDV within an infected cow-calf herd (Cleveland, 2003; Stott et al., 2003; Smith et al., 2009, 2010 and 2014). The development of these models has been useful to evaluate the spread of BVDV and its impacts to the infected herd. Larson et al. (2005) used a partial budget analysis to examine the effectiveness of testing for BVDV, but the results suggest that management practices may be an influencing factor to the efficacy of BVDV testing. Stott et al. (2003) developed an epidemiological and economic model of Scottish cow-calf herds to incorporate risk into whole farm planning to evaluate the contribution of disease prevention to whole farm income.

Linear Programming Model

Production agriculture faces a variety of price, yield and resource risk which can greatly impact income levels (Hazell and Norton, 1986). Incorporating risk into the linear programming model can allow for the analysis of potential risk mitigation strategies to better equip agricultural producers. Hazell and Norton (1986) discuss various ways to incorporate risk into the LP modeling framework including quadratic programming, maximin and minimax criteria.

The linear programming model minimization of total absolute deviations (MOTAD), developed by Hazell (1971), takes into account the combination of the decision maker's activities that will minimize the risk for a given level of expected income subject to the farm's constraints. The MOTAD model proposed using variance estimates based on the sample mean absolute deviation which can be estimated from time-series or cross-sectional data. This allows for the relationship between farm income and the variance of farm income for a given farm to be incorporated into the LP modeling framework (Oglethorpe, 1995).

A variation of MOTAD, developed by Tauer (1983) called Target MOTAD, maximizes expected returns subject to minimum absolute deviations from a target income level. The advantage of using Target MOTAD is that for a risk averse decision maker the results are efficient allowing the model to rank possible solutions by the individual producer's risk preference (Boisvert and McCarl, 1990; Stott et al., 2003). The Target MOTAD model formulation used in this study is as follows:

$$\max E = \sum_{\mathrm{j}=1}^{n} c_j X_j \tag{3.2}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \qquad \text{all } j = 1 \text{ to n} \tag{3.3}$$

$$T - \sum_{j=1}^{n} c_{jt} X_j - Z_t \leq 0 \qquad \text{all } t = 1 \text{ to n} \tag{3.4}$$

$$\sum_{t=1}^{n} p_t \, Z_t \leq \lambda \qquad \text{all } t = 1 \text{ to n} \tag{3.5}$$

$$X_j \geq 0 \qquad \text{all } j = 1 \text{ to n}$$

where:

E = expected returns;

c_j = gross margin per unit of enterprise *j*;

X_j = level of enterprise *j*;

T = target level of returns;

a_{ij} = amount of resource *i* required by one unit of enterprise *j*;

b_i = availability of resource *i*;

p_t = probability of state of nature in time period *t*;

Z_t = deviation below the target return level *T* in time period *t*; and

λ = expected deviation below the target return level *T*.

The Target MOTAD model is described as a two attribute model to evaluate returns and risk for a decision maker. A decision maker is seeking to maximize expected returns above variable costs, but avoid having returns fall below a predetermined target return level subject to a given level of expected negative deviations below the specified target return level (Prevatt, 2013; McCarl and Spreen, 1997). Ten years of returns for each enterprise are assumed to have equal probability of occurrence in the model. Associated risk for each enterprise's returns are measured by the probability weighted average of the negative deviations which are incorporated into the MOTAD matrix. The risk measure parameter (λ) controls the total amount of negative deviations from the target return level. By systematically varying the risk measure, this allows for the sum of annual negative deviations to be calculated and the return-risk efficient solutions to be traced creating a frontier.

The return-risk frontier allows the individual producer to make the tradeoff between the risk and returns that best suits their preference for risk. For this analysis, the Target MOTAD framework is modified to account for the implementation of various BVDV biosecurity strategies. Cow-calf returns in the MOTAD matrix are adjusted according to simulated epidemiological results to capture the relative risk associated with each biosecurity strategy. The intent of the biosecurity strategies are to reduce the risk of a BVDV incursion and provide the highest return for the operation given an expected target return level.

DATA

Epidemiological and LP models require representative farm enterprises for U.S. cow-calf producers. Representative farm enterprises are created through the use of McBride and Mathews (2011) report and USDA-ERS commodity costs and returns data (USDA-ERS, 2015). McBride and Mathews (2011) identify the U.S. cow-calf regions as: West (W), Northern Plains (NP), Southern Plains (SP), North Central (NC), and Southeast (SE) as shown in Table 3.1.

Table 3.1: Major U.S. cow-calf regions.

ARMS Cow-Calf Regions[1]	States	Cows per farm
Northern Plains	ND, SD, NE, KS	105
North Central	IA, MO	56
Southern Plains	OK, TX	75
Southeast	AK, KY, TN, VA, MS, AL, GA, FL	59
West	MT, WY, CO, NM, CA, OR	155

[1] McBride and Mathews (2011) Table 3.4.

Smith et al. (2014) developed an epidemiological model to calculate the cost-effectiveness of biosecurity strategies for BVDV in cow-calf herds. The model is not region specific; therefore, this study seeks to expand on the work by Smith et al. (2014) by regionalizing their model according to major cow-calf producing regions. Additionally, this study will expand on the economic analysis by evaluating various biosecurity strategies in a whole farm planning context to better improve management and control of BVDV spread and incursions and simultaneously allow producers to manage risk. This is the first known study to take a whole farm economic analysis approach to evaluate potential biosecurity measures to estimate the return and risk of a BVDV incursion for representative U.S. cow-calf regions.

To regionalize the Smith et al. (2014) model, feeder cattle prices are compiled for each region using available monthly price data for 4-500 lbs., 5-600 lbs. AND 6-700 lbs. steers and heifers based on major livestock reporting markets for the U.S. cow-calf regions (see Table 3.2).

Table 3.2: 10-year average feeder cattle prices (2004-2013) ($/cwt).

	Northern Plains[1]		Southern Plains		North Central		Southeast		West	
Parameter	**Mean**	**SD**[2]	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Steers										
4-500 lbs	147.22	24.24	138.71	24.76	147.24	24.10	142.72	23.83	140.67	25.44
5-600 lbs	135.64	20.90	124.45	21.61	137.82	20.16	131.11	19.63	129.91	21.24
6-700 lbs	128.23	19.27	120.70	20.75	132.45	19.41	127.74	18.92	124.84	19.69
Heifers										
4-500 lbs	131.78	21.17	135.48	39.94	128.69	21.69	125.36	18.90	126.09	20.97
5-600 lbs	123.34	18.22	115.86	17.88	123.24	17.57	120.94	16.98	119.10	18.92
6-700 lbs	119.41	17.38	112.41	15.86	121.12	17.98	118.50	17.15	115.95	18.45

[1] Region specific feeder cattle prices used were West = Colorado, Northern Plains = Kansas, Southern Plains = Texas, and North Central = Missouri as reported by the Livestock Marketing Information Center (LMIC). Southeast region prices were for Tennessee (http://economics.ag.utk.edu/publications/livestock/2014/SPI2014.pdf).
[2] Standard Deviation.

Annual costs for BVDV in cow-calf herds is based on region specific lost income, costs to treat morbid calves and decreased performance. Calculation of lost income from morbid calves is determined by taking the difference between estimated performance of diseased and non-diseased animals and multiplied by the region specific feeder cattle price in Table 3.2. Lost income resulting from calf mortality is the sum of abortions, early embryonic deaths in cows that failed to rebreed, congenital defects, transient infection mortalities and persistent infection mortalities (Smith et al., 2014).

The development of representative farms in each major cow-calf producing region will aid in characterizing the appropriate activities of the decision maker and the applicable constraints to be represented in the MOTAD LP models. Activities in the LP model are developed to represent standard farm enterprises for each of the five cow-calf regions modeled. Resource constraints for each region are based on those reported by the USDA-ERS Cow-Calf report (McBride and Mathews, 2011). Technical coefficients for the model are on a per unit basis as reported by the USDA-ERS (2015) commodity costs and returns (see Table 3.3 and 3.4).

Table 3.3: Main constraints and relationships represented in the MOTAD LP model for U.S. cow-calf operations.

Constraint	Northern Plains	Southern Plains	North Central	Southeast	West
Cropland (acres)[1,2]	660	164	208	246	158
Pasture (acres)[1]	1359	1272	310	207	4028
Pasture per Head (acres)[1]	11	13	3	3	19

[1] McBride and Mathews (2011)
[2] The difference between acres operated and private pasture/range acres.

It is assumed that most producers have a calving season close to 60 days and would typically sell calves in the month of September at a weaned weight of approximately 600 and 590 pounds for steers and heifers, respectively (Smith et al., 2014). Data are compiled for each farm enterprise to estimate the sample mean and deviations based on production data available through the USDA-ERS commodity costs and returns from 2004-2013 and are incorporated into the MOTAD LP matrix.

For the MOTAD LP model, production information for the Northern Plains, Southern Plains, and Northern Central cow-calf regions will be used with the Northern Plains, Prairie Gateway and Heartland USDA-ERS commodity costs and returns regions production information. Cow-calf production information for the Southeast region uses USDA-ERS commodity costs and returns in the Mississippi Portal region and the Southern Seaboard region for both corn and soybean production. In the West region, USDA-ERS commodity costs and returns in the Basin and Range region are used for both wheat and cow-calf production with the

USDA-ERS commodity costs and returns. Because commodity costs and returns information are not available for corn and soybeans in the West region along with wheat in the Southeast region, U.S. production data are used. Price, yield, variable costs and labor for corn, soybeans, wheat, hay, and cow-calf production are summarized in Table 3.4.

Table 3.4: Main activities in the MOTAD LP model by U.S. cow-calf region (10-year average, 2004-2013).

	Variable Cost			Price			Yield			Labor
Activity	**Unit**	**Mean**	**SD**	**Unit**	**Mean**	**SD**	**Unit**	**Mean**	**SD**	**Hrs**
Northern Plains										
Corn	$/acre	235.46	68.34	$/bu	3.77	1.48	bu	124.20	10.64	2.5
Soybeans	$/acre	107.87	25.19	$/bu	9.23	3.11	bu	34.71	3.48	1.8
Wheat	$/acre	97.96	21.57	$/bu	5.71	1.79	bu	40.59	3.54	1.3
Hay[1]	$/acre	158.69	28.31	$/ton	135.41	41.68	tons	3.70	0.48	3.7
Cow-calf	$/hd	614.67	114.05	$/hd	666.02	106.08	lbs	600.00	10.00	6.7
Southern Plains										
Corn	$/acre	274.21	45.04	$/bu	4.02	1.57	bu	136.70	17.17	2.5
Soybeans	$/acre	200.19	28.25	$/bu	9.38	3.21	bu	42.99	5.74	1.8
Wheat	$/acre	133.85	17.17	$/bu	5.62	1.84	bu	30.71	5.01	1.3
Hay	$/acre	321.25	47.96	$/ton	135.41	41.68	tons	4.95	0.37	3.7
Cow-calf	$/hd	569.27	70.95	$/hd	648.80	113.44	lbs	600.00	10.00	6.7
North Central										
Corn	$/acre	272.23	72.13	$/bu	3.89	1.60	bu	157.30	15.75	2.5
Soybeans	$/acre	118.72	31.37	$/bu	9.61	3.28	bu	48.13	2.66	1.8
Wheat	$/acre	144.85	38.62	$/bu	5.24	1.59	bu	59.60	3.66	1.3
Hay	$/acre	360.31	70.45	$/ton	135.41	41.68	tons	2.85	0.48	3.7
Cow-calf	$/hd	689.93	128.09	$/hd	601.48	119.52	lbs	600.00	10.00	8.3
Southeast										
Corn	$/acre	211.80	31.58	$/bu	4.34	1.84	bu	116.90	13.96	2.5
Soybeans	$/acre	145.68	23.54	$/bu	9.64	3.29	bu	33.59	1.85	1.8
Wheat	$/acre	104.65	21.48	$/bu	5.62	1.76	bu	39.72	3.76	1.3
Hay	$/acre	267.97	132.23	$/ton	135.41	41.68	tons	3.39	0.44	3.7
Cow-calf	$/hd	432.22	62.10	$/hd	458.74	89.06	lbs	600.00	10.00	8.3
West										
Corn	$/acre	271.23	67.31	$/bu	3.91	1.59	bu	147.90	13.96	2.5
Soybeans	$/acre	125.15	44.90	$/bu	9.28	3.29	bu	44.90	1.85	1.8
Wheat	$/acre	124.96	24.69	$/bu	5.67	1.70	bu	54.82	3.76	1.3
Hay	$/acre	249.43	107.42	$/ton	135.41	41.68	tons	3.52	0.29	3.7
Cow-calf	$/hd	511.56	56.95	$/hd	657.28	108.93	lbs	600.00	10.00	6.7

[1] Hay prices used are the U.S. national average from 2004-2013 as reported by Livestock Marketing Information Center (LMIC, 2015). Hay yields are state averages as reported by the Livestock Marketing Information Center (LMIC, 2015) from 2004-2013 for Kansas, Texas, Missouri, Tennessee, and Colorado to coincide with sources for variable costs.

For each enterprise, labor and variable cost requirements are included in the MOTAD LP framework along with the selling activities of each enterprise where a 10-year average for both price and yield are used. Labor requirements for corn, soybean, wheat, hay and cow-calf production come from FINPACK (2010). Ward et al. (2008) discuss that changing management practices (i.e., increased biosecurity) requires specific detailed information about the farm's resource base, size, goals, human capital, age, education, enterprise diversity, and attitude toward risk. Therefore, it was assumed that both labor and variable costs (capital requirements) were farm specific information and would not be a binding constraint in the model nor the focus of the current analysis. Hay production data are not available from USDA-ERS. Thus, hay enterprise budgets from Kansas State University, Texas A&M, University of Missouri, University of Tennessee and Colorado State University are used to determine variables costs for hay production for the Northern Plains, Southern Plains, North Central, Southeast and West regions, respectively.

To incorporate the use of specific biosecurity measures into the LP model, technical coefficients are required. Technical coefficients used are reported in Smith et al. (2014) which incorporated various combinations of vaccination and testing strategies for BVDV (see Table 3.5).[1] Vaccination costs are updated by conducting a survey of online distributor prices as used by Smith et al. (2014).

The various biosecurity strategies include not having any biosecurity measures in place (Strategy M) and strategy N which vaccinates only the breeding livestock. Strategy T tests all calves before breeding, all imported adult cows, calves and stockers, but does not vaccinate any livestock. For both strategies Y and Z, all breeding animals are vaccinated and all calves before breeding, all imported adult cows and calves are tested, but only strategy Z tests imported stockers. Labor and biosecurity costs are dependent on the strategy employed. Strategies N, T, Y and Z cost \$11.90, \$14.61, \$16.36 and \$16.51 per head and required 0.017, 0.068, 0.051 and

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[1] Technical coefficients give the resource use per unit for each enterprise (McCarl and Spreen, 1997). For example, to produce one cow in the Northern Plains region requires 6.7 hours of labor.

0.085 hours of labor per cow, respectively. For each strategy, Target MOTAD simulations are run and results are compiled to develop return-risk frontiers to evaluate the economic feasibility of the strategies and determine those strategies that best optimize expected returns for each cow-calf region depending on the producers risk preference.

Table 3.5: BVDV Biosecurity strategies analyzed for each U.S. cow-calf region.

Strategy	Vaccination of breeding animals	Test imported adults	Test imported calves and calves of pregnant imports	Test all calves before breeding	Test imported stockers
M					
N	X				
T		X	X	X	X
Y	X	X	X	X	
Z	X	X	X	X	X

Source: Smith et al., 2014

RESULTS

BVDV Simulation Results

The BVDV simulated results for the three 100 head cow-calf regions (NP, SP, W) had the same results for additional abortions (6.06), morbidity (7.24), mortality (3.43) and endemic persistently infected (3.94). The 50 head regions (NC, SE) had the same results for additional abortions, morbidity, mortality and endemic persistently at 2.61, 4.13, 1.97, and 1.83, respectively. Differences in the simulated epidemiological results were found on the cost side which are incorporated in the LP model. For all regions, biosecurity strategy M had the highest average annual total cost (Table 3.6). This was expected as this strategy does not have any biosecurity measures implemented. Strategies with implemented biosecurity measures see the highest cost impacts in strategy N, then to a lesser extent in Y, Z and T. Strategies Y and Z have identical results which makes sense given the only difference is the testing of imported stockers which is accounted for in the LP models technical coefficients for variable cost (Y=$16.36 and Z=$16.51) and labor (Y=0.051 hours and Z=0.085 hours) per head for each strategy.

The regionalization of Smith et al.'s (2014) epidemiological model required region specific feeder cattle prices as presented in Table 3.2. The NP region had the highest feeder cattle price, \$147.22/cwt. Simulated results reveal that the same region has the highest average annual total cost for the simulated 100 head herds. Similar results are found for the 50 head herd regions (NC and SE) where NC has the highest feeder cattle price (\$147.24/cwt) and also has the highest average annual total cost. Regionalizing the epidemiological model according to region specific feeder cattle prices impacts the cost output from the model (Table 3.6).

Table 3.6: Simulated BVDV epidemiological output by region and biosecurity strategy.

	M[1]		N[2]		T[3]		Y[4]		Z[5]	
Region/Epidemiological Output	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Northern Plains (100 hd)										
Additional Abortions	6.06	8.90	5.28	8.13	1.30	4.17	1.11	3.79	1.11	3.79
Morbidity	7.24	12.10	6.02	10.64	1.31	3.82	1.14	3.49	1.14	3.49
Mortality	3.43	5.95	2.86	5.27	0.65	2.06	0.56	1.87	0.56	1.87
Endemic Persistantly Infected	3.94	6.08	3.37	5.47	0.55	1.79	0.48	1.63	0.48	1.63
Average Annual Total Cost	$1,026.53	$3,022.90	$934.42	$2,674.11	$350.17	$1,164.60	$366.17	$1,053.38	$366.17	$1,053.38
Southern Plains (100 hd)										
Additional Abortions	6.06	8.90	5.28	8.13	1.30	4.17	1.11	3.79	1.11	3.79
Morbidity	7.24	12.10	6.02	10.64	1.31	3.82	1.14	3.49	1.14	3.49
Mortality	3.43	5.95	2.86	5.27	0.65	2.06	0.56	1.87	0.56	1.87
Endemic Persistantly Infected	3.94	6.08	3.37	5.47	0.55	1.79	0.48	1.63	0.48	1.63
Average Annual Total Cost	$523.62	$1,648.58	$465.78	$1,428.38	$230.09	$668.32	$236.60	$604.54	$236.60	$604.54
North Central (50 hd)										
Additional Abortions	2.61	3.86	2.26	3.52	0.62	1.96	0.53	1.79	0.53	1.79
Morbidity	4.13	6.61	3.31	5.73	1.07	2.68	0.92	2.44	0.92	2.44
Mortality	1.97	3.38	1.59	2.98	0.54	1.50	0.46	1.36	0.46	1.36
Endemic Persistantly Infected	1.83	2.79	1.58	2.53	0.41	1.11	0.36	1.02	0.36	1.02
Average Annual Total Cost	$967.96	$2,829.11	$884.42	$2,502.86	$339.55	$1,089.54	$357.09	$985.81	$357.09	$985.81
Southeast (50 hd)										
Additional Abortions	2.63	3.89	2.26	3.52	0.62	1.96	0.53	1.79	0.53	1.79
Morbidity	4.01	6.50	3.31	5.73	1.07	2.68	0.92	2.44	0.92	2.44
Mortality	1.92	3.35	1.59	2.98	0.54	1.50	0.46	1.36	0.46	1.36
Endemic PIs	1.83	2.80	1.58	2.53	0.41	1.11	0.36	1.02	0.36	1.02
Average Annual Total Cost	$449.27	$1,381.32	$398.10	$1,219.88	$208.70	$572.06	$210.55	$517.68	$210.55	$517.68
West (100 hd)										
Additional Abortions	6.06	8.90	5.28	8.13	1.30	4.17	1.11	3.79	1.11	3.79
Morbidity	7.24	12.10	6.02	10.64	1.31	3.82	1.14	3.49	1.14	3.49
Mortality	3.43	5.95	2.86	5.27	0.65	2.06	0.56	1.87	0.56	1.87
Endemic Persistantly Infected	3.94	6.08	3.37	5.47	0.55	1.79	0.48	1.63	0.48	1.63
Average Annual Total Cost	$996.58	$2,925.43	$908.85	$2,587.99	$344.70	$1,126.12	$361.49	$1,018.76	$361.49	$1,018.76

[1] No biosecurity or control for BVDV.

[2] Annual vaccination of breeding animals.

[3] Testing all imports (including stockers) and calves of imports and testing all calves before breeding.

[4] Testing imports to the herd (excluding stockers) and calves of imports and testing all calves before breeding, and annual vaccination of breeding animals.

[5] Testing all imports (including stockers) and calves of imports and testing all calves before breeding, with annual vaccination of breeding animals.

Target MOTAD Results

Annual total costs from the BVDV epidemiological model output is incorporated into the MOTAD LP model to help identify a farm plan that would maximize the expected return for a given level of risk. Average annual total cost data (mean and negative deviations) along with mean gross margins for each region's cow-calf production were used in the MOTAD LP matrix to estimate the expected returns under varying risk levels. Risk levels in the Target MOTAD model are developed by first starting with a risk constraint equal to zero for a no risk solution and no negative deviations in any time period (i.e., risk averse producer) (Zimet and Spreen, 1986). Systematically, the risk constraint is increased until the highest optimal solution has been reached, which is identical to a linear programming solution and equal to a risk loving behavior where additional risk will not improve the expected return.

McBride and Mathews (2011) report gross cash income and variable cash expenses for the five cow-calf regions studied which give the expected returns and the starting values to be used in the modeling process. Modeled expected return levels for each region are adjusted up or down in order to model the best return-risk frontier to evaluate the various biosecurity strategies. Results are compiled into a return-risk frontier for each BVDV biosecurity strategy.

Table 3.7 displays the Target MOTAD model results and the associated target expected return levels. Depending on the producer's risk preference, as risk increases so does the expected returns, although at a decreasing rate. Modeled results indicate that for a risk averse producer, both crops and livestock enter in the optimal solution. However, the operation now consists of crops and no livestock for a risk loving producer. These results may be associated with what McBride and Mathews (2011) reported that a small portion of total farm production value ($) for the NC (23%), NP (25%), and SE (38%) regions only came from cattle. The W and SP regions are both a mix of crop and livestock for a risk averse producer, but as risk levels increase the operations still produce livestock and only crop enterprise levels vary. These findings may support why these regions have the lowest amount of crop land used in the LP model, the lowest expected returns of all five regions, and that 66% (W) and 67% (SP) of total farm production value comes from cattle (McBride and Mathews, 2011).

In all five regions, biosecurity strategy M (no biosecurity control measures) generate the highest expected returns which could be a result of no biosecurity costs. Evaluating expected returns by each biosecurity strategy shows that N (vaccination of breeding stock) generates the highest expected return for the SP, NC, and W regions. This is supported by the 2007 USDA NAHMS survey findings where 41% of livestock producers vaccinate against BVDV (USDA, 2010a). Biosecurity strategy T (testing for BVDV) had the highest expected returns for the NP and SE regions suggesting that testing for BVDV may be a viable option for these regions. This contradicts the findings from the 2007 USDA-NAHMS survey which reported only 4.2% of producers test for BVDV. The expected returns shows that strategy M in the NP and SE regions follows closely behind T which could be influenced by crop enterprise levels. Stott et al. (2003) recognize that implemented biosecurity measures can influence other parts of the farm operation and need to be accounted for in the whole-farm plan. The modeled results may suggest vaccination or a combination of vaccination and testing for BVDV to be viable prevention strategies to consider in the whole-farm plan.

The return-risk ratio was calculated for each region and biosecurity strategy between each risk level to develop the return-risk frontier as shown in Table 3.7 and Figure 3.1. Four of the five cow-calf regions analyzed had a return-risk ratio greater than one implying that selection of this risk level would contribute more than one dollar of expected returns for each additional dollar of risk. The West region’s return-risk ratio is less than one between all risk levels which suggests any risk level above zero would generate less than one dollar of expected return for each additional dollar of risk incurred.

Table 3.7: Target-MOTAD simulation results by biosecurity strategy and U.S. cow-calf region.

	M		N		T		Y		Z	
Region/ Risk Level	**Expected Returns**	**Return-Risk Ratio**[1]	**Expected Returns**	**Return-Risk Ratio**	**Expected Returns**	**Return-Risk Ratio**	**Expected Returns**	**Return-Risk Ratio**	**Expected Returns**	**Return-Risk Ratio**
Northern Plains ($76,000)[2]										
$0	$147,139		$145,922		$146,050		$145,836		$145,819	
$500	$153,382	$12.49	$152,641	$13.44	$152,719	$13.34	$152,589	$13.51	$152,578	$13.52
$1,000	$159,626	$12.49	$159,361	$13.44	$159,389	$13.34	$159,342	$13.51	$159,338	$13.52
$2,000	$161,676	$2.05	$163,109	$3.75	$163,109	$3.72	$163,109	$3.77	$163,109	$3.77
$4,000	$163,109	$0.72	$163,109	$0.00	$163,109	$0.00	$163,109	$0.00	$163,109	$0.00
Southern Plains ($24,000)[2]										
$0	$37,414		$36,116		$34,694		$34,567		$34,552	
$25	$37,934	$20.79	$36,635	$20.79	$35,214	$20.79	$35,087	$20.79	$35,072	$20.79
$50	$37,976	$1.70	$36,812	$7.07	$35,733	$20.79	$35,607	$20.79	$35,592	$20.79
$800	$37,976	$0.00	$36,812	$0.00	$36,546	$1.08	$36,493	$1.18	$36,489	$1.20
$1,500	$37,976	$0.00	$36,812	$0.00	$36,546	$0.00	$36,542	$0.07	$36,542	$0.08
North Central ($51,000)[2]										
$0	$85,335		$85,103		$83,304		$83,183		$83,172	
$500	$93,591	$16.51	$93,452	$16.70	$92,373	$18.14	$92,300	$18.23	$92,294	$18.24
$1,000	$99,881	$12.58	$99,827	$12.75	$99,303	$13.86	$99,272	$13.94	$99,269	$13.95
$1,500	$105,073	$10.39	$105,065	$10.48	$104,988	$11.37	$104,984	$11.42	$104,983	$11.43
$2,000	$105,967	$1.79	$105,967	$1.80	$105,967	$1.96	$105,967	$1.97	$105,967	$1.97
Southeast ($46,000)[2]										
$0	$53,578		$53,153		$53,578		$53,451		$53,441	
$300	$59,466	$19.63	$59,261	$20.36	$59,313	$19.12	$59,276	$19.42	$59,273	$19.44
$1,000	$62,038	$3.67	$62,036	$3.96	$62,096	$3.98	$62,036	$3.94	$62,035	$3.95
$4,000	$68,837	$2.27	$68,337	$2.10	$68,337	$2.08	$68,337	$2.10	$68,337	$2.10
$7,000	$73,370	$1.51	$73,370	$1.68	$73,370	$1.68	$73,370	$1.68	$73,370	$1.68
West ($55,000)[2]										
$0	$57,153		$54,604		$53,879		$53,513		$53,480	
$250	$57,381	$0.91	$54,832	$0.91	$54,107	$0.91	$53,740	$0.91	$53,708	$0.91
$500	$57,609	$0.91	$55,060	$0.91	$54,335	$0.91	$53,968	$0.91	$53,936	$0.91
$750	$57,837	$0.91	$55,288	$0.91	$54,563	$0.91	$54,196	$0.91	$54,164	$0.91
$1,000	$57,840	$0.01	$55,318	$0.12	$54,730	$0.67	$54,364	$0.67	$54,331	$0.67

[1] Return-risk ratio is the amount expected returns will increase for each additional dollar of risk the producer is willing to accept between the two relevant risk levels.

[2] Value in parenthesis is the target expected return level.

Figure 3.1 depicts the return-risk frontier for a North Central cow-calf producer. All biosecurity strategies evaluated had similar expected returns for each risk level, but biosecurity strategy M had the highest expected return at all risk levels and was followed closely by strategy N, with strategies T, Y and Z all having similar expected returns at the evaluated risk levels. As risk levels increase, the return-risk ratio increases, but at decreasing rate. At low risk levels, the operation is comprised of both crops and livestock enterprise levels. However, as risk levels increase the operation's enterprises switch to being crops based, potentially exposing the producer to more risk. A risk averse producer may seek to operate at a risk level between $0 and $1,500 with return-risk ratios ranging from $18.23 to $10.39 for strategies Z and N on the high and low end, respectively.

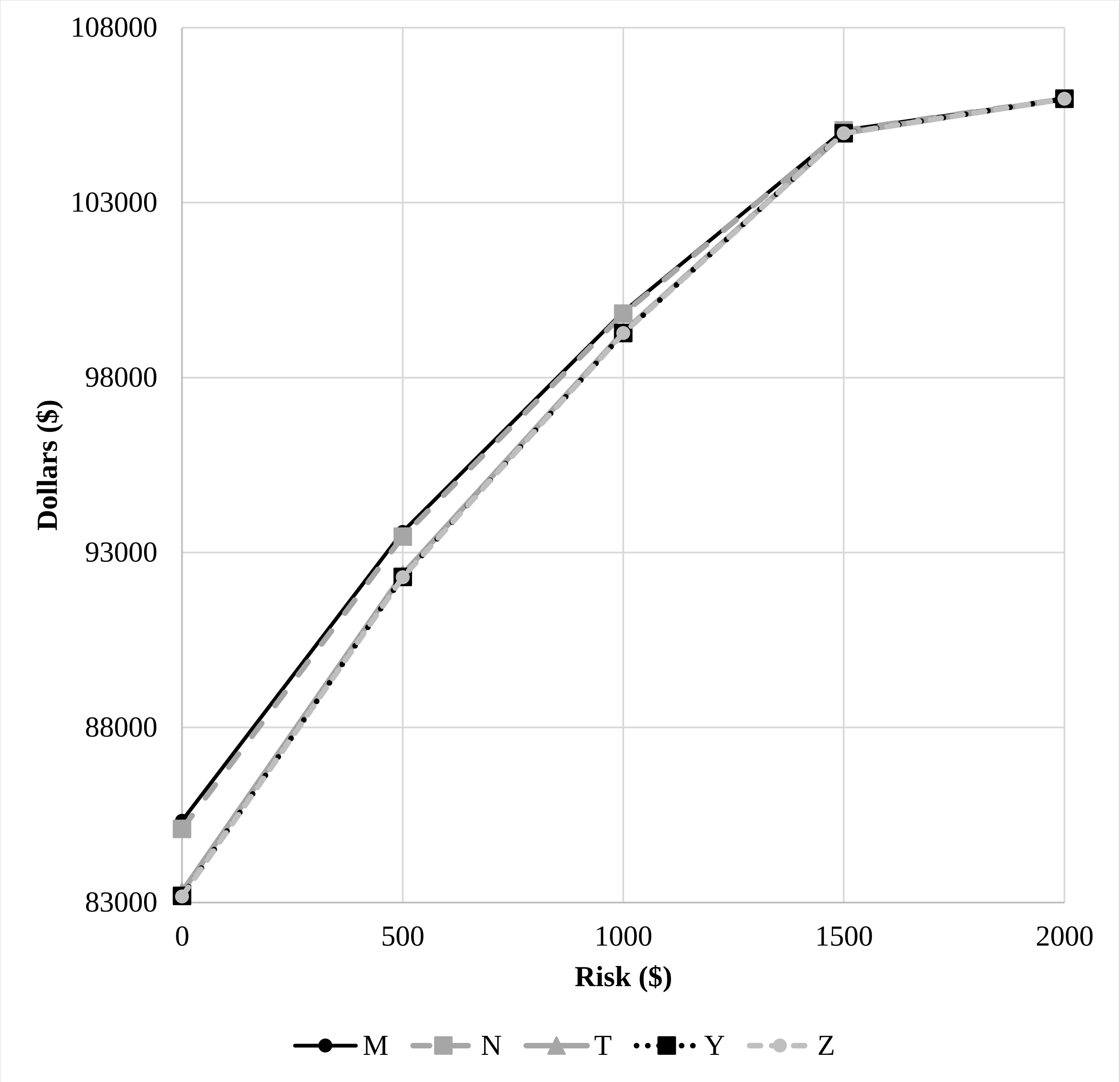

Figure 3.1: Return-risk frontier for the modeled BVDV prevention strategies on a North Central region 50 head cow-calf herd with a target expected return level of $51,000.

CONCLUSION

McBride and Mathews (2011) indicate that operators in the SP and NP regions generate $106,266 and $44,952 of off-farm income which are the highest and lowest of the five cow-calf regions, respectively. These same regions also had the lowest ($-7,855) and highest ($47,313) net farm income which supports the findings from this analysis that the SP and NP regions had the lowest and highest expected returns of the regions and biosecurity measures evaluated, respectively. Past literature has identified that small scale cow-calf operations (less than 100 head) rely on off-farm income. Future work should investigate how off-farm income contributes to cow-calf production and risk management strategies (USDA, 2011). Labor availability may be a contributing factor to expected returns and risk management because the amount of work time devoted to the operation increases as the herd size increases (Hoppe et al., 2010).

In the context of whole farm planning and risk management, vaccination, testing or a combination of both were shown to be effective biosecurity measures to control BVDV. Realistically, a producer can have multiple crop and livestock enterprises and is potentially faced with a myriad of diseases.

This study sought to estimate economic values of BVDV impacts for various biosecurity strategies, which may be useful for producers and the risk associated with the spread BVDV. The study linked an epidemiological model and a linear programming model. The epidemiological model used was developed by Smith et al. (2009, 2010 and 2014) which was regionalized for major U.S. cow-calf producing regions. BVDV model results for lost income, costs to treat morbid calves and decreased performance from BVDV were incorporated into the LP model framework to optimize the allocation of scarce resources between competing activities to maximize expected returns. Depending on the individual producer’s risk preference and management objectives, the results from this analysis should provide guidance to better improve management and control of BVDV spread and incursions and simultaneously allow producers to manage risk. Recent work by Damman et al. (2015) modeled BVDV spread and its productivity losses while Smith et al. (2014) and Stott et al. (2003) quantified the economic impacts of BVDV. Findings from these studies follow the general findings found in this analysis; the least cost biosecurity measure may not always be the most suitable option for some producers, but vaccination may be a valuable biosecurity strategy to limit or eliminate losses from the spread of BVDV (Moennig et al., 2005; Santarossa et al., 2005; Rat-Aspert and Fourichon, 2010).

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CHAPTER 4

Evaluating Productive Efficiency among U.S. Wheat Producers

INTRODUCTION

Over the past two decades there has been an increase in alternate crop production practices (e.g., organic). Organic food sales have increased from \$3.6 billion in 1997 to \$21.1 billion in 2008 with recent estimates stating sales of \$28 billion in 2012 (Greene et al., 2009; Greene, 2013). In 2011, the United States had 3.1 million acres of certified organic cropland which is approximately 0.7% of the total U.S. cropland acres. A majority of organic cropland acres produced fruits and vegetables and nuts accounting for 6% and 4% of the acres, respectively. A small portion of cropland produced corn (0.3%), soybeans (0.2%) and wheat (0.6%), respectively (Greene, 2013).

The United States is considered a major wheat producer on the world stage. Only China, the European Union and India produce more. Vocke and Ali (2013) report that in the United States wheat is the third largest crop produced behind corn and soybeans, with nearly 2.5 billion bushels produced. The 2009 USDA Agricultural Resource Management Survey (ARMS) report that the total area of U.S wheat production for the North Central, Northern Plains, Southern Plains, Central Plains, and Northwest regions was distributed as 9%, 41%, 9%, 28%, and 13%, respectively.

Changing production practices has played a role in impacting the amount of wheat acres planted as water conservation practices, such as reduced till and no-till farming, has allowed for more profitable crops (i.e., corn and soybeans) to be planted. A more recent emerging agricultural sector is organic crop production which, as defined by the USDA, is a production system focusing on resource cycling, ecological balance and biodiversity conservation. The USDA began including organic producers in the ARMS survey in 2005 to collect production practices, costs and returns for the agricultural sector (Greene and Ebel, 2012).

The main objective for this study will be to estimate and analyze efficiency measures of conventional and organic crop producers. The estimation of efficiency measures will be conducted by using a non-parametric approach commonly referred to as data envelopment analysis (DEA). The efficiency measures will be estimated at the farm level for conventional and organic U.S. crop producers surveyed in the 2009 USDA ARMS Wheat survey. The estimated efficiency results will be evaluated using Tobit analysis to identify those farm and producer factors that influence the efficiency of U.S. crop producers. Study findings will provide information to producers and industry stakeholders on productive efficiency and the economic forces influencing efficiency to improve the viability of conventional and organic crop producers

Background

Previous research on estimating efficiency measures has been done on specific outputs ranging from livestock to various crops. Mayen, Balagtas, and Alexander (2010) evaluated productivity and technical efficiency of organic and conventional dairy farms in the United States using 2005 ARMS survey data. They conclude there is little difference between the two production practices.

Using 2004 ARMS survey data, Tonsor and Featherstone (2009) estimated various efficiency measures for different swine operations by specialization. The study used a nonparametric approach to estimate relative measures of technical, allocative, scale, and overall efficiency. The authors found a variation in efficiency measures and differences across swine specializations.

In studies by Nehring and Fernandez-Cornejo (2005) and Nehring et al. (2013), technical efficiency of corn producers is estimated using an input distance function approach to compare the performance of households with and without off farm income. They found that off farm income does boost technical efficiency on smaller operations. Watkins et al. (2014) used DEA to calculate technical, allocative, economic, and scale efficiencies for Arkansas rice production. Results showed that most fields have high technical and scale efficiencies, implying inputs are used in minimum levels necessary to achieve given output levels.

Research has been conducted on analyzing the efficiency of wheat production in the United States and other countries with varying results. Ali and Khan (2014) used a stochastic frontier analysis for wheat producers in Pakistan and found technical efficiency of farms to range from 34% to 88% with an average of 62%. Krishna and Veettil (2014) used a semi-parametric estimation approach and found technical efficiency on Indian farms to be 89% and that zero tillage in wheat cultivation does positively impact technical efficiency. Neupane and Moss (2015) used a stochastic frontier model to analyze technical inefficiency of U.S. wheat production in Kansas, Nebraska, Oklahoma and Texas from 1965-2009. Results suggest technical inefficiency to range from 3% to 59% with a mean of 16%.

Other studies have taken a whole farm approach to estimate efficiency measures by using multiple outputs. In the United States, Andreu (2008) analyzed overall efficiency of 456 Kansas farms from 1998 to 2007 based on production and performance. The analysis used a multi-output, multi-input approach in an input-oriented DEA analysis. She found that technical, allocative and scale efficiencies were around 80% to 90% and overall efficiency was 68% for Kansas farms.

Yeager (2011) analyzed the efficiency of 256 Kansas farms from 1993-2010 to address the impact of risk preference on efficiency. The study used a nonparametric estimation approach with two outputs and five inputs to calculate cost and revenue based economic, overall, technical and scale efficiency measures. Results showed that inclusion of risk associated with variability in outputs and downside risk does account for a portion of the inefficiency observed in many of the farms.

Mugera and Langemeir (2011) and Mugera, Langemeir and Featherstone (2012) used a bootstrap DEA to estimate both technical and scale efficiency for Kansas farms from 1993-2007. Their findings suggest that farms are both scale and technically inefficient with results varying by farm size. Langemeier, Yeager and O'Brien (2013) examine the relationship between cost efficiency and feed grain production in Kansas finding that corn production was related to cost efficiency in eastern and western Kansas from 2002-2011.

A growing body of literature has sought to evaluate and compare the efficiency between conventional and organic production. Study results outside of the United States have been inconclusive. Guesmi et al. (2012) evaluated conventional and organic grape farms in Catalonia and found organic producers to be more efficient than conventional producers. Poudel, Yamamoto and Johnston (2012) used a nonparametric approach to analysis conventional and organic coffee farms in Nepal concluding that conventional producers were more efficient than organic producers. Lakner (2011) summarized the literature focusing on efficiency and productivity of organic farming systems in Germany and the European Union also finding conventional producers to be more efficient than organic producers. Lakner (2011) does note that efficiency estimates can be influenced by factors ranging from the crop produced to the sample size and environmental factors. Galluzzo (2014) evaluated efficiency in conventional and organic vine-growing Italian farms by using a nonparametric approach discovering efficiency to be about the same for both producers.

In the United States, evaluation of efficiency between conventional and organic producers has been limited. Lohr and Park (2006) develop technical efficiency measures for U.S. organic farmers using one output (total organic farming gross income) and two inputs (labor and acreage). Park and Lohr (2010) evaluate technical and allocative efficiency by using multiple inputs (labor and acreage) and outputs (revenue obtained from selling through organic channels and revenue received from conventional marketing channels). Both studies use data from the Organic Farming Research Foundation survey collected from U.S. certified organic farmers and a stochastic production frontier approach to evaluate efficiency. Findings from both studies show a variation in technical efficiency which can be influenced by experience. Neither study evaluated efficiency for conventional producers; therefore, this study seeks to use a multi-output, multi-input approach to estimate efficiency and compare measures for both conventional and organic producers. Results will be used in a Tobit analysis to evaluate influencing factors on efficiency between conventional and organic producers.

METHODS

Estimating efficiency measures can be accomplished through parametric or nonparametric approaches. Implementing the parametric estimation approach requires the selection of a functional form from which the deviation of the observed data from the functional form can be estimated to determine the efficiency measure. The nonparametric estimation approach does not require the selection of a functional form for the underlying technology making it less prone to misspecification (Watkins et al., 2014; Andreu, 2008; Fare, Grosskopf and Lovell 1994). This advantage also makes it more flexible and useful for estimating efficiency measures (Yeager, 2011). The nonparametric efficiency results are bound between zero and one which allows for the use of a Tobit regression model to examine how farm characteristics and technology use are correlated with the efficiency of each production practice.

The principle method used for nonparametric estimation of efficiency measures has been data envelopment analysis (DEA). DEA uses linear programming to construct a nonparametric piece-wise surface (or frontier) over the data which then allows for the efficiency measures to be calculated relative to this constructed surface. Several studies discuss the methodology of DEA (Fare, Grosskopf and Lovell, 1985 and 1994; Seiford and Thrall, 1990; Lovell, 1994; Seiford, 1996; Coelli et al., 2005).

Technical Efficiency

The ability of a firm to produce its maximum level of output given a set of inputs (i.e., output-oriented approach) or the ability of a firm to minimize the inputs used to produce a given level of output is found by estimating technical efficiency (i.e., input-oriented approach). The DEA model specification to estimate technical efficiency (TE) for a producer can be obtained by solving the following linear programming problem for N producers, each with $\boldsymbol{Y}$ outputs by using $\boldsymbol{X}$ inputs (Coelli et al., 1998):

$$TE = \min_{\lambda\,\theta} \theta_i$$

$$\begin{aligned} \text{subject to:} \quad & -y_i + \boldsymbol{Y}\lambda \ \geq 0, \\ & \theta_i x_i - \boldsymbol{X}\lambda \ \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned} \tag{4.1}$$

where θ_i is the estimated technical efficiency score for the ith producer, y_i is the output of producer i, $\boldsymbol{Y}$ represents the output matrix and $\boldsymbol{X}$ is the input matrix, x_i is a vector representing the amount of inputs used by firm i, λ is an N x 1 vector of constraints, and $N1$ is a convexity constraint. The constraint $N1'\lambda = 1$ ensures that TE is estimated under the variable returns to scale (VRS) assumption. Removal of the $N1'\lambda = 1$ constraint estimates TE under the assumption of constant returns to scale (CRS) (Watkins et al., 2014). The CRS model assumes that all firms are operating at an optimal scale where the VRS model does not. A technically efficient firm will have $\theta_i = 1$ and an inefficient firm will have $\theta_i \leq 1$ (Tonsor, and Featherstone, 2009).

Allocative Efficiency

Determining if a firm is utilizing inputs at an optimal proportion given the input prices can be found by estimating allocative efficiency. Allocative efficiency can be found by taking the ratio of the minimum cost under VRS over the product of the producers incurred costs and technical efficiency (θ_i). For each firm, the linear programming problem is solved under VRS to find the minimum possible cost as follows:

$$\begin{aligned} C_i^v &= \min w_i' x_i^* \\ \text{subject to:} \quad & -y_i + \boldsymbol{Y}\lambda \geq 0, \\ & \theta_i x_i^* - \boldsymbol{X}\lambda \geq 0, \\ & N1'\lambda = 1, \\ & \lambda \geq 0, \end{aligned} \tag{4.2}$$

where w_i' is a column vector of input prices paid by producer *i* and x_i^* is a vector of cost-minimizing inputs for producer *i* (Tonsor and Featherstone, 2009).

Scale Efficiency

Scale efficiency is a ratio of the minimum possible cost under CRS (C_i^c) to the minimum cost feasible under VRS (C_i^v). To find C_i^c, the same linear programming problem in equation 4.2

is used with the $N1'\lambda = 1$ constraint being omitted. The importance behind scale efficiency is that is compares a firm's current operational size to what would be most efficient to minimize average cost (Tonsor, and Featherstone, 2009).

Overall Efficiency

Overall efficiency combines the previously calculated efficiency measures by taking the product of technical, allocative and scale efficiencies. Overall efficiency is the ability of a firm to maximize output given a set of inputs (technically efficiency), the firm's ability to optimally allocate inputs given their respective prices (allocative efficiency) and the firm's ability to operate at a minimum average cost level (scale efficient) (Coelli et al., 2005; Andreu, 2008; Tonsor, and Featherstone, 2009). Overall efficiency provides a comprehensive look at a producer's performance from the input side (Andreu, 2008).

Tobit Model

The analysis is further continued with a second step where a Tobit analysis will regress the DEA estimated efficiency measures on farm and producer characteristics. Estimated efficiency measures are bound between zero and one which allows for them to be used as the dependent variable in the Tobit regression model. The dependent variable will be regressed on independent variables related to farm financial, production and economic characteristics. The Tobit analysis will aid in determining if relationships exist between the estimated efficiency measures and farm characteristics. The Tobit model used for the analysis is expressed as follows:

$$\begin{aligned} E_i^* &= \beta'\boldsymbol{X} + e_i, e_i \sim N[0, \sigma^2] && \text{if } 0 < E_i^* < 1 \\ E_i &= 0 && \text{if } 0 = E_i^* \\ E_i &= 1 && \text{if } 1 = E_i^*. \end{aligned} \tag{4.3}$$

The estimated efficiency from the DEA analysis is E_i^*. β' is a vector of estimated parameters, $\boldsymbol{X}$ is the vector of explanatory variables and e_i is the error term which is normally distributed (Greene, 2003). Explanatory variables used are chosen to avoid potential overlap with variables used in the efficiency estimation process and based on previous research by Wu and Prato (2006) Andreu (2008), Yeager (2011) and Tonsor and Featherstone (2009). The variables selected focus on operator characteristics, operational productivity, financial performance and management decisions (Andreu, 2008).

DATA

The study will be a novel use of the 2009 USDA ARMS wheat survey data in that it will develop an economic analysis that seeks to measure efficiency across a wide spectrum of representative U.S. crop producers. Use of the 2009 USDA ARMS Wheat survey data provides the necessary input and output categories for the estimation of efficiency measures. This will then allow for the second step in the analysis to investigate those farm characteristics that influence productive efficiency.

Sorting of data

In order to compile an accurate dataset for the analysis, a screening process is used to ensure a representative sample for the study. The original dataset is comprised of 1,603 survey respondents. First, all observations that had zero crop sales for the growing season are removed. Second, observations that had zero farm assets are removed as these producers are assumed to not be making production decisions. This type of operation may be an absentee land owner where production is done on a temporary basis or by custom hire (Andreu, 2008). Third, it was assumed that all inputs are essential for crop production and therefore, must be greater than zero (Andreu, 2008). To remove any outliers from the remaining observations in the dataset, observations within two standard deviations of the mean are kept. Those firms that are considered transitional operations (i.e., transitioning from conventional to organic) are removed as they could not be identified as either a conventional or organic producer. In the tenure category, which is the primary operator’s age, two observations were labeled as 2009 and 2010 which was not consistent with the data nor is feasible for the category and it was assumed that there was an error entering the original data and are removed from the dataset. After screening, 1,215 observations were used in this analysis.

The modified firm level data contains two outputs: total value of crops and total value of livestock production; six inputs: labor, fertilizer, lime and chemicals, seed and plant, capital, acres operated and livestock expense. Table 4.1 presents summary statistics for the variables used to estimate efficiency measures. Assuming that producers all face the same price, average input prices for each category are used in the DEA analysis. Kuosmanen, Cherchye, and Sipilainen (2006) discuss the advantage of using the same input prices for DEA analysis under the assumption of the law of one price, which in theory holds in the competitive market.

Table 4.1: Summary Statistics of Variables Used in Analysis.

			All Producers (N = 1,215)		Conventional Producers (N = 1,116)		Organic Producers (N = 99)	
Variable	**Description**	**Unit**	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**
Output								
tvpcrop	Total Value Crop Production	$	457,084.16	486,025.74	480,228.91	495,024.53	196,179.71	251,637.69
tvplive	Total Value Livestock Production	$	41,184.40	119,113.56	40,952.80	121,518.16	43,795.18	87,988.64
Input								
labor	Labor[1]	hrs	3,949.47	1,764.44	3,973.30	1,763.78	3,680.85	1,758.39
fert	Fertilizer, lime and chemicals	$	118,504.67	134,673.22	126,068.22	137,399.73	33,242.78	43,436.52
seed	Seed and plant	$	37,105.16	49,309.74	38,596.52	50,789.49	20,293.49	21,451.33
capital	Capital expense[2]	$	137,870.89	141,316.18	141,057.88	141,933.69	101,944.79	129,477.66
acres	Acres operated	acres	2,687.76	2,230.89	2,807.90	2,247.23	1,333.39	1,475.81
livexp	Livestock expense	$	28,297.71	199,493.77	29,487.00	207,758.86	14,891.12	41,347.27
Input Price								
pwage	Labor Price	$/hr	11.85	0.59	11.85	0.59	11.89	0.61
pfert	Fertilizer Price	$/acre	55.36	54.63	56.78	55.46	39.36	41.08
pseed	Seed Price	$/acre	20.38	23.45	20.02	23.56	24.33	21.87
pcapital	Capital Price	$/acre	73.86	82.06	70.16	79.95	115.56	93.69
pacres	Land Charge	$/acre	43.91		43.91		43.91	
plive	Livestock Price	$/lb	0.01	0.05	0.01	0.06	0.01	0.02

[1] Includes: primary operator, spouse, coop and non-family coop operators.

[2] Equipment, fuel and oil, supplies, maintenance, custom work, utilities, general business, insurance, total interest paid, and other unrecorded expenses.

Tobit Model Variables

Variables used to determine the influencing factors on efficiency of 2009 ARMS wheat producers can be found in Table 4.2. The debt to asset ratio (daratio) and farm assets (fast) are used to capture the financial position and input efficiency of each producer. Operator age (opage) is included to account for any differences between old and young farmers. To show the difference between age and experience, the variable tenure is included which is the total years of operation for the primary operator. The education of the primary operator (opeduc) is included to identify if progressively higher education impacts efficiency. Identifying if one region in the United States is more efficient than another region, dummy variables for Basin and Range (br), Northern Great Plains (ngp), Prairie Gateway (pg), Eastern Uplands (eu), and Fruitful Rim (fr) regions are included. Studies by Nehring et al. (2013) and Nehring and Frenandez-Cornejo (2005) have concluded that off farm income does have an impact on efficiency of crop producers. Thus, a variable for those producers where a majority of the income received is from off the farm (majofi) is incorporated in this study. The total value of product for wheat as a percent of total value of crop production (tvpwheat) is included to determine if raising wheat contributes to efficiency.

Table 4.2: Summary Statistics for Tobit Model Variables.

		All Producers (N=1215)		Conventional Producers (N=1116)		Organic Producers (N=99)	
Variable	**Description**	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**	**Mean**	**St. Dev.**
daratio	Farm business debt to asset ratio	0.15	0.17	0.15	0.17	0.16	0.17
tenure[1]	Years in operation	31.15	13.13	31.35	13.18	28.94	12.39
ownop	Acres owned to operated	0.47	0.42	0.46	0.41	0.63	0.48
fasst	Total farm assets (\$1,000)	\$ 1,914.50	\$ 1,920.13	\$ 1,938.09	\$ 1,909.19	\$ 1,648.55	\$ 2,030.60
opage	Primary operator's age	55.31	11.65	55.50	11.73	53.20	10.42
opeduc	Primary operator's education leve	2.95	0.84	2.96	0.84	2.90	0.91
pg[2]	Prairie Gateway	0.36	0.48	0.35	0.48	0.48	0.50
ngp[2]	Northern Great Plains	0.35	0.48	0.35	0.48	0.25	0.44
br[2]	Basin and Range	0.12	0.32	0.12	0.33	0.02	0.14
fr[2]	Fruitful Rim	0.11	0.31	0.11	0.32	0.06	0.24
eu[2]	Eastern Uplands	0.02	0.13	0.02	0.14	NA	NA
ss[2]	Southern Seaboard	0.05	0.22	0.04	0.20	0.18	0.39
majofi[3]	Majority off farm income	0.06	0.23	0.05	0.22	0.14	0.35
tvpwheat[4]	Percent total value wheat	0.54	0.37	0.56	0.37	0.30	0.30

Note: Tobit regression models were estimated using original efficiency point estimates.

[1] Year operator started minus 2009 for the year of the survey.

[2] Dummy variables equal to 1 if statement is applicable; 0 otherwise. Heartland region was not used in the analysis as there were no conventional or organic producers.

[3] Dummy variable for producers where the majority of income came from off the farm (1 = if off farm income was greater than net farm income; 0 otherwise).

[4] Total value of wheat production as a percent of Total value of crop production.

NA - No organic producers in the Eastern Uplands region.

RESULTS

Efficiency Estimates

In the analysis, three separate frontiers were estimated. One frontier was estimated using all 1,215 conventional and organic producers to evaluate efficiency measures. To evaluate any differences between the two production practices, the estimated efficiency measures were sorted into two groups: conventional (N = 1,116) and organic (N = 99). A second approach used in this analysis was to sort the 1,215 producers into conventional (N = 1,116) and organic (N = 99) producers prior to measuring efficiency. Next, efficiency measures were estimated for each production practice (i.e., two separate frontiers were developed; one for conventional producers and one for organic producers). Estimated efficiency measures were evaluated between the two frontiers. For each approach, constant returns to scale technical efficiency (CRSTE), variable returns to scale technical efficiency (VRSTE), scale efficiency (SE), allocative efficiency (AE) and overall efficiency (OE) were estimated. Results for the estimated efficiencies are found in Table 4.3.

Results for the frontier estimated efficiency amongst all 1,215 conventional and organic producers reveals that organic producers have higher CRSTE (0.4934) and VRSTE (0.5656) than conventional producers 0.4741 and 0.5189, respectively. For conventional producers, SE (0.9049), AE (0.4029) and OE (0.2053) are higher than organic producers SE (0.8672), (0.3749), and (0.1894), respectively.

Evaluating the results when separate frontiers are estimated for conventional and organic producers yields similar results. Organic producers have higher CRSTE and VRSTE when compared the conventional producers (Organic: 0.7228 CRSTE, 0.6136 VRSTE; Conventional: 0.5311 CRSTE, 0.4867 VRSTE). Technical efficiency results are consistent with those reported in the literature for North America which range from 0.459 to 1.00 (Bravo-Ureta et al., 2010). In general, organic producers have a higher CRSTE and VRSTE than conventional producers. This indicates that organic producers are better at producing their maximum output level given the inputs used. Although technical efficiency for organic producers may be higher than conventional producers, recent research by Seufert, Ramankutty and Foley (2012) and Ponti, Rijk, and van Ittersum (2012) shows that productivity for conventional producer is higher than organic producers. Both studies use a meta-analysis of conventional and organic production to show that organic yields of individual crops can be on average 75% to 80% of conventional yields. Organic producers may be more technically efficient, but are less productive than conventional producers (Cavigelli et al., 2009; Lansink, Pietola, and Backman, 2002).

Interestingly, AE and OE for organic producers (0.5056 and 0.3249, respectively) were higher than conventional producers (0.4518 and 0.2189, respectively) which was not the case for the previous frontier estimated. Organic producers having a higher AE than conventional seems counterintuitive as the measure determines if a firm is utilizing inputs at an optimal proportion given the input prices. Referring to Table 4.1 shows that the organic producers had higher input prices for both seed and capital expenses and a slightly higher labor price, but a lower fertilizer price as compared to conventional producers. The amount of inputs used by organic producers was lower than conventional which may explain the higher AE for organic producers. High TE and SE measures seem to be contributing factors to OE measures for both conventional and organic producers.

Conventional producers had a higher SE (0.9087) than organic producers (0.8479). Results indicate that on average if both conventional and organic producers were operating at optimal scale each could have produced the same level of output and reduced input costs by over

9% and 15%, respectively (Lopez, 2008). Conventional producers having a higher SE than organic producers makes sense as the average acres for conventional and organic producers was 2,807.90 and 1,333.39, respectively, potentially indicating economies of scale and lower per acre input costs for some inputs for conventional producers (MacDonald, Korb, and Hoppe, 2013).

Table 4.3: Summary Statistics of Efficiency Measures for Conventional and Organic Producers.

Efficiency[1]	Mean	St. Dev.	Minimum	Median	Maximum
All Producers (N = 1,215)					
Conventional Producers (N = 1,116)					
CRSTE	0.4741	0.2292	0.0270	0.4270	1.0000
VRSTE	0.5189	0.2287	0.0650	0.4675	1.0000
SE	0.9049	0.1350	0.0590	0.9541	1.0000
AE	0.4290	0.1500	0.0380	0.4250	1.0000
OE	0.2053	0.1377	0.0033	0.1753	1.0000
Organic Producers (N = 99)					
CRSTE	0.4934	0.2521	0.1190	0.4310	1.0000
VRSTE	0.5656	0.2521	0.1630	0.5020	1.0000
SE	0.8672	0.1622	0.2350	0.9366	1.0000
AE	0.3749	0.1766	0.0820	0.3440	1.0000
OE	0.1894	0.1593	0.0255	0.1363	1.0000
Conventional Producers (N = 1,116)					
CRSTE	0.4867	0.2307	0.0270	0.4350	1.0000
VRSTE	0.5311	0.2304	0.0660	0.4800	1.0000
SE	0.9087	0.1292	0.0670	0.9549	1.0000
AE	0.4518	0.1463	0.0460	0.4535	1.0000
OE	0.2189	0.1368	0.0051	0.1902	1.0000
Organic Producers (N = 99)					
CRSTE	0.6136	0.2674	0.1560	0.5840	1.0000
VRSTE	0.7228	0.2485	0.2200	0.7200	1.0000
SE	0.8479	0.1992	0.2780	0.9348	1.0000
AE	0.5056	0.2486	0.0830	0.4750	1.0000
OE	0.3249	0.2528	0.0537	0.2210	1.0000

[1] CRSTE, constant returns to scale technical efficiency; VRSTE, variable returns to scale technical efficiency; SE, scale efficiency; AE, allocative efficiency; OE, overall efficiency.

Table 4.4 presents the distribution of CRSTE, VRSTE, AE, SE and OE measures. Distribution of conventional and organic frontier efficiency estimates show that organic producers have a higher number of producers achieving CRSTE and VRSTE greater than 0.9

(11.11% and 16.16%, respectively) when compared to conventional producers (7.44% and 10.48%, respectively). For SE, conventional has a higher amount of producers above 0.9 than organic producers at 71.51% and 57.58%, respectively. Both AE and OE have similar results for producers above 0.9 with conventional producers at 1.08% and 0.54%, respectively, and organic producers at 1.01% and 1.01%, respectively. When comparing the individual frontiers for conventional and organic the results for conventional producers are similar to those discussed above. Organic changes as the number of producers above 0.9 for CRSTE (24.24%), VRSTE (37.37%), SE (57.59%), AE (7.07%), and OE (4.04%) all increase when compared to results under the estimated results using all producers in the frontier.

In evaluating OE amongst all the estimates, conventional has the most producers below 0.5 at approximately 96%. Organic producers under the frontier estimating results for all the producer has 94.95% below 0.5 for OE where the organic frontier has 78.79% below 0.5. This indicates that organic producers have a better ability to produce the actual level of output with the lowest amount of inputs (TE), use the optimal bundle of inputs given the price of the input (AE) and operate where average cost is minimized (SE).

Table 4.4: Frequency Distribution of Efficiency Measures by Range.

Efficincy	CRSTE		VRSTE		SE		OE		AE	
Range	No.	%	No.	%	No.	%	No.	%	No.	%
All Producers (N = 1,215)										
Conventional Producers (N = 1,116)										
< 0.2	87	7.80%	29	2.60%	3	0.27%	63	5.65%	659	59.05%
> 0.2 < 0.3	193	17.29%	155	13.89%	5	0.45%	143	12.81%	276	24.73%
> 0.3 < 0.4	219	19.62%	235	21.06%	7	0.63%	271	24.28%	99	8.87%
> 0.4 < 0.5	190	17.03%	195	17.47%	13	1.16%	302	27.06%	41	3.67%
> 0.5 < 0.6	132	11.83%	145	12.99%	26	2.33%	222	19.89%	15	1.34%
> 0.6 < 0.7	104	9.32%	122	10.93%	36	3.23%	69	6.18%	9	0.81%
> 0.7 < 0.8	69	6.18%	80	7.17%	66	5.91%	29	2.60%	9	0.81%
> 0.8 < 0.9	39	3.49%	38	3.41%	162	14.52%	5	0.45%	2	0.18%
> 0.9 < 1.0	22	1.97%	31	2.78%	703	62.99%	2	0.18%	1	0.09%
= 1.0	61	5.47%	86	7.71%	95	8.51%	10	0.90%	5	0.45%
Organic Producers (N = 99)										
< 0.2	7	7.07%	1	1.01%	0	0.00%	15	15.15%	66	66.67%
> 0.2 < 0.3	17	17.17%	11	11.11%	2	2.02%	21	21.21%	16	16.16%
> 0.3 < 0.4	21	21.21%	20	20.20%	0	0.00%	25	25.25%	10	10.10%
> 0.4 < 0.5	17	17.17%	17	17.17%	1	1.01%	18	18.18%	2	2.02%
> 0.5 < 0.6	9	9.09%	13	13.13%	4	4.04%	8	8.08%	2	2.02%
> 0.6 < 0.7	5	5.05%	8	8.08%	7	7.07%	6	6.06%	1	1.01%
> 0.7 < 0.8	9	9.09%	8	8.08%	12	12.12%	5	5.05%	1	1.01%
> 0.8 < 0.9	3	3.03%	5	5.05%	16	16.16%	0	0.00%	0	0.00%
> 0.9 < 1.0	2	2.02%	0	0.00%	44	44.44%	0	0.00%	0	0.00%
= 1.0	9	9.09%	16	16.16%	13	13.13%	1	1.01%	1	1.01%
Conventional Producers (N = 1,116)										
< 0.2	74	6.63%	25	2.24%	2	0.18%	40	3.58%	605	54.21%
> 0.2 < 0.3	181	16.22%	143	12.81%	6	0.54%	129	11.56%	306	27.42%
> 0.3 < 0.4	217	19.44%	229	20.52%	9	0.81%	221	19.80%	111	9.95%
> 0.4 < 0.5	194	17.38%	195	17.47%	9	0.81%	326	29.21%	49	4.39%
> 0.5 < 0.6	140	12.54%	148	13.26%	16	1.43%	249	22.31%	18	1.61%
> 0.6 < 0.7	105	9.41%	120	10.75%	36	3.23%	105	9.41%	9	0.81%
> 0.7 < 0.8	74	6.63%	86	7.71%	66	5.91%	27	2.42%	10	0.90%
> 0.8 < 0.9	40	3.58%	48	4.30%	167	14.96%	8	0.72%	3	0.27%
> 0.9 < 1.0	24	2.15%	30	2.69%	715	64.07%	1	0.09%	0	0.00%
= 1.0	67	6.00%	92	8.24%	90	8.06%	10	0.90%	5	0.45%
Organic Producers (N = 99)										
< 0.2	3	3.03%	0	0.00%	0	0.00%	8	8.08%	45	45.45%
> 0.2 < 0.3	11	11.11%	2	2.02%	2	2.02%	15	15.15%	12	12.12%
> 0.3 < 0.4	10	10.10%	11	11.11%	3	3.03%	16	16.16%	12	12.12%
> 0.4 < 0.5	17	17.17%	11	11.11%	7	7.07%	16	16.16%	9	9.09%
> 0.5 < 0.6	14	14.14%	12	12.12%	4	4.04%	12	12.12%	6	6.06%
> 0.6 < 0.7	6	6.06%	11	11.11%	2	2.02%	7	7.07%	4	4.04%
> 0.7 < 0.8	10	10.10%	10	10.10%	10	10.10%	7	7.07%	5	5.05%
> 0.8 < 0.9	4	4.04%	5	5.05%	13	13.13%	11	11.11%	2	2.02%
> 0.9 < 1.0	5	5.05%	4	4.04%	38	38.38%	2	2.02%	0	0.00%
= 1.0	19	19.19%	33	33.33%	20	20.20%	5	5.05%	4	4.04%

Table 4.5 presents efficiency scores by size of operation which was sorted by total value of production. In general, both conventional and organic producers see that as farm size increases the estimated efficiency measures increase. This follows results by Mugera and Langemeier (2011) for conventional producers, but does not follow those found by Park and Lohr (2010).

Efficiency measures for conventional producers has 62.90% of the producers with a farm size of $500,000 or less, where organic producers have 87.88%. Comparing OE between conventional and organic producers estimated with the single frontier shows that farms with size $500,000 or less have OE estimates increasing as farm size increases. For conventional producers, OE ranged from 0.0934 to 0.1950 where organic producers ranged from 0.0836 to 0.2469 on the low and high end, respectively. When separate frontiers are estimated organic producers OE increased substantially now ranging from 0.1836 to 0.4274, but conventional producers only increased slightly from 0.1088 to 0.2067 on the low and high end, respectively.

Conventional producers have 37.10% of the producers with a farm size of $750,000 or more where organic producers have only 12.12%. For those conventional producers in this farm size category, OE ranges from 0.2341 to 0.4870 when one frontier is estimated for all the producers. When one frontier is estimated for conventional producers only OE measures do not vary much from those estimates just discussed with a range of 0.2355 to 0.4894. Estimated OE for organic producers is 0.2247 and 0.5650 for each estimated frontier, respectively. There is a substantial increase in OE for organic producers under the separate estimated frontiers which provides evidence for the presence of efficiency degradation between the estimated frontiers and each farm size which required further statistical analysis (Mugera and Langemeier, 2011).

Table 4.5: Efficiency Measures by Farm Size.

Farm Size ($)	CRSTE	VRSTE	SE	AE	OE	N	Percent of Farms
All Producers (N = 1,215)							
Conventional Producers (N = 1,116)							
50,000	0.2822	0.5207	0.5420	0.3243	0.0934	53	4.75%
100,000	0.3571	0.4691	0.7363	0.3406	0.1213	82	7.35%
250,000	0.3963	0.4441	0.8815	0.3785	0.1436	251	22.49%
500,000	0.4467	0.4690	0.9470	0.4463	0.1950	316	28.32%
750,000	0.5238	0.5381	0.9718	0.4595	0.2341	176	15.77%
1,000,000	0.5596	0.5721	0.9777	0.4744	0.2635	83	7.44%
2,000,000	0.6553	0.6789	0.9678	0.4796	0.3167	129	11.56%
>2,000,000	0.8095	0.9087	0.8943	0.5947	0.4870	26	2.33%
Organic Producers (N = 99)							
50,000	0.3313	0.5871	0.5853	0.2523	0.0836	12	12.12%
100,000	0.4554	0.5442	0.8243	0.3867	0.1739	20	20.20%
250,000	0.4945	0.5511	0.8829	0.3568	0.1862	33	33.33%
500,000	0.5921	0.6020	0.9818	0.4352	0.2469	22	22.22%
>750,000	0.5349	0.5528	0.9672	0.4166	0.2247	12	12.12%
Conventional Producers (N = 1,116)							
50,000	0.3116	0.5515	0.5728	0.3475	0.1088	53	4.75%
100,000	0.3987	0.4985	0.7736	0.3887	0.1530	82	7.35%
250,000	0.4157	0.4646	0.8835	0.4380	0.1745	251	22.49%
500,000	0.4571	0.4803	0.9439	0.4640	0.2067	316	28.32%
750,000	0.5277	0.5420	0.9713	0.4595	0.2355	176	15.77%
1,000,000	0.5604	0.5731	0.9773	0.4739	0.2635	83	7.44%
2,000,000	0.6566	0.6795	0.9688	0.4777	0.3162	129	11.56%
>2,000,000	0.8095	0.9087	0.8943	0.5973	0.4894	26	2.33%
Organic Producers (N = 99)							
50,000	0.3917	0.8335	0.4699	0.4767	0.1836	12	12.12%
100,000	0.5224	0.6985	0.7412	0.4631	0.2574	20	20.20%
250,000	0.6063	0.6568	0.9095	0.4115	0.2616	33	33.33%
500,000	0.7363	0.7450	0.9849	0.5990	0.4274	22	22.22%
>750,000	0.7823	0.7933	0.9833	0.6927	0.5650	12	12.12%

To determine if there were any statistical differences between the estimated efficiency measures, a T-test for mean, median test, and Kruskal-Wallis test were conducted. The T-test is a parametric test comparing means of two groups. The Median test is a nonparametric test with a null hypothesis that there is no difference between medians of two groups (Banker et al., 2010).

The Kruskal-Wallis test is also a nonparametric test where the null hypothesis is that the rank of efficiency measures, based on the means, is the same between two groups (Mugera and Langemeier, 2011). All three statistical tests reveal that the single frontier (both conventional and organic producers) and the conventional frontier were not statistically significantly different at the 1% level. However, statistically testing between the estimated frontiers showed that all producers and organic producers were significantly different at that the 1% level where all producers and conventional producers was not. Testing between the conventional producers and organic producers were statistically significantly different at that the 1% level.

To statistically test any differences between the estimated efficiencies and farm size (measured in dollars), the Kruskal-Wallis test was conducted as it ranks efficiency measures for multiple groups. Results reveal that for conventional producers the null hypothesis is rejected at the 1% level indicating that farm size does matter when comparing efficiency measures which follows results by Mugera and Langemeier (2011). As for organic producers comparing efficiency measures across farm size is not rejected even at the 10% level indicating farm size does not matter. Park and Lohr (2010) found efficiency estimates of organic farms to be relatively similar ranging from 0.716 to 0.735 when ranked by farm sizes with less than seven acres and more than 120 acres, respectively.

Tobit Model Results

Tobit regression results of the influencing producer characteristics that impact efficiency measures are found in Table 4.6. The region variable for Heartland (hl) and Southern Seaboard were omitted from the analysis as there were no wheat producers in these regions once the USDA ARMS 2009 wheat survey data was sorted. The organic Tobit models have the variable Eastern Uplands (eu) omitted as there were no organic wheat producers in the region.

The overall efficiency (OE) Tobit model results show that the debt to asset ratio (daratio) was significant at the 5% level for conventional producers. This suggests having high solvency does negatively impact efficiency. The amount of acres operated to owned (ownop) was significant at the 5% level for conventional wheat producers which may suggest that the more acres operated will decrease OE. The variable for farm assets (fasst) was significant at the 5% level indicating that as the amount of farm assets increases so does overall efficiency of the farm. Of the regions in the Tobit model, Basin and Range (br) was significant at the 5% level for conventional producers suggesting that producing is this region negatively impacts OE. For those operations where a majority of the income was from off the farm OE was negatively impacted suggesting that it is better to focus efforts on the operation (Tonsor and Featherstone, 2009). The variable tvpwheat is significant at the 5% level and negatively impacts overall efficiency. This suggests that when the total value of wheat production as a percent of total value of crop production increases overall efficiency decreases implying that increased wheat production negatively impacts efficiency.

Tobit analysis results for organic producers showed that none of the variables were found to statistically significant which follows findings by Poudel, Yamamoto and Johnson (2012). A comparison of the coefficient signs between variables that were significant for conventional producers with organic producers reveals some similarities. The variables daratio, ownop, fasst, br, majofi, and tvpwheat have the same signs between the conventional and organic Tobit analysis with the only difference being the variable br when one frontier is estimated for organic producers and tvpwheat when one frontier is estimated for the single frontier. Lohr and Park (2006) found that experience positively contributes to efficiency which was also found by

Dhungana, et al. (2010) and Coelli and Battese (1996). Results from this study show that variables related to experience (i.e., tenure and opage) were not statistically significant.

Table 4.6: Overall Efficiency Tobit Analysis.

	All Conventional and Organic Frontier			
	Conventional	Organic	Conventional Frontier	Organic Frontier
Variable	**(N = 1,116)**	**(N = 99)**	**(N = 1,116)**	**(N = 99)**
daratio	-0.1369 *	-0.1065	-0.1482 *	-0.2795
tenure	0.0003	-0.0033	0.0000	-0.0018
ownop	-0.0578 *	-0.0226	-0.0481 *	-0.0486
fasst	0.0000 *	0.0000	0.0000 *	0.0000
opage	-0.0005	0.0035	-0.0002	-0.0003
opeduc	0.0041	-0.0249	0.0024	-0.0282
pg[1]	0.0085	0.0119	0.0052	0.0354
ngp	-0.0179	-0.0623	-0.0246	-0.0529
br	-0.0393 **	-0.0204	-0.0445 **	0.1862
fr	-0.0081	-0.0646	-0.0126	-0.0420
eu[2]	0.0495		0.0486	
majofi[3]	-0.0491 *	-0.0146	-0.0380 *	-0.0556
tvpwheat[4]	-0.0838 *	0.0936	-0.0861 *	-0.0041
constant	0.2917 *	0.1845	0.3122 *	0.5452 *
sigma	0.1248	0.1542	0.1248	0.2527
Log likelihood	723	41	723	-11

∗∗ and ∗ denote statistical significance at 5% and 10%, levels, respectively.

[1] Dummy variables equal to 1 if statement is applicable; 0 otherwise. Heartland region was not used in the analysis as there were no conventional or organic producers.

[2] No organic producers in the Eastern Uplands region.

[3] Dummy variable for producers where the majority of income came from off the farm (1 = if off farm income was greater than net farm income; 0 otherwise).

[4] Total value of wheat production as a percent of total value of crop production.

CONCLUSION

This analysis looked at various efficiency measures for conventional and organic crop producers in the 2009 USDA ARMS Wheat survey. The study was conducted in two stages where the first stage consisted of estimating efficiency measures by using a non-parametric approach commonly referred to as data envelopment analysis. The second stage used the estimated efficiency measures in a Tobit analysis to identify those farm and producer factors that influence the efficiency of U.S. crop producers.

Estimating efficiency measures were conducted with three separate efficiency frontiers: a single frontier with all producers (both conventional and organic), one with conventional producers and one with organic producers.

Results for the frontier estimated efficiency amongst all the 1,215 conventional and organic producers reveals that organic producers have higher CRSTE (0.4934) and VRSTE (0.5656) than conventional producers 0.5189 and 0.4741, respectively. For conventional producers SE (0.9049), AE (0.4029), and OE (0.2053) are higher than organic producers at 0.8672, 0.3749, and 0.1894, respectively.

Evaluating the results when separate frontiers are estimated for conventional and organic producers yields similar results for CRSTE and VRSTE where organic producers (0.7228 and 0.6136) are higher than convention producers (0.5311 and 0.4867), respectively. In general, organic producers have a higher CRSTE and VRSTE than conventional producers. This suggests that organic producers are better at producing their maximum output level given the inputs used. Although organic producers may be more technically efficient, research shows that they are less productive than conventional producers (Cavigelli et al., 2009; Lansink, Pietola, and Backman, 2002). AE (0.5056) and OE (0.3249) for organic producers were higher than conventional producers (0.4518 and 0.2189) which was not the case for the previous frontier estimated. Organic producers having a higher AE than conventional producers suggests they are better at using inputs at an optimal proportion given the input prices. Summary statistics showed that the amount of inputs used by organic producers was lower than conventional which may explain the higher AE for organic producers. High TE and SE measures seem to be contributing factors to

OE measures for both conventional and organic producers. Conventional producers had a higher SE (0.9087) than organic producers (0.8479). If both conventional and organic producers were operating at an optimal scale each could have produced the same level of output and reduced input costs by over 9% and 15%, respectively (Lopez, 2008).

Statistical tests were conducted to determine if any differences between the estimated efficiency frontiers existed. Statistical tests reveal that the single frontier with all producers and the conventional producers frontier were not statistically different from each other. However, the all producers frontier and the organic producers frontier were both significantly different at that the 1% level. The same statistical testing was conducted between the conventional producers frontier and organic producers frontiers and both were found to be statistically significantly different at that the 1% level.

Tobit analysis results indicated that as the debt to asset ratio increases it negatively impacts efficiency suggesting reduction of the farms debt will improve efficiency. For conventional wheat producers, as the amount of rented acres relative to acres owned increases, overall efficiency will decrease indicating owning land improves efficiency. Increasing farm assets does positively impact overall efficiency of the farm. Investing in more efficient equipment may improve overall efficiency potentially leading to increased productivity. The Basin and Range region was found to be significant for conventional producers and negatively impacts overall efficiency which suggests that, from an efficiency standpoint, operations in the Basin and Range region are less efficient than other regions. Operations where a majority of the income was from off the farm overall efficiency was negatively impacted suggesting that it is better to focus efforts on the operation (Tonsor and Featherstone, 2009). Results showed that when the total value of wheat production as a percent of total value of crop production increases overall efficiency decreases implying that increased wheat production negatively impacts efficiency. Tobit analysis results for organic producers showed that none of the variables were found to statistically significant which follows findings by Poudel, Yamamoto and Johnson (2012).

Shortcomings of the study need to be discussed to avoid oversimplification of the research findings. The study took a whole farm approach to evaluate efficiency measures between conventional and organic wheat producers, but the dataset used in this analysis only specified if the producer was a conventional or organic producer. Future research would be to conduct efficiency analysis using more detailed information on those crops that are conventionally or organically raised by each producer. Research by Watkins et al. (2014) used field level data for rice producers in Arkansas to determine efficiency. Future research would be to include those field specific variables such as field size, soil type, and crop rotation for both conventional and organic wheat producers.

Research by Mayen, Balagtas, and Alexander (2010) used propensity score matching to compare organic dairy farms to similar conventional dairy farms that may choose to adopt organic production and the resulting impact on efficiency. Additional research would be to use propensity score matching for U.S. wheat producers to evaluate the impact on efficiency of a conventional wheat producer adopting organic wheat production practices. Another shortcoming is in the Tobit analysis to determine those contributing factors that influence efficiency. Research by Lohr and Park (2006) and Park and Lohr (2010) used producer specific variables such as the producer only farms organic acres, was the producer originally an organic producer, was the farm involved in collaborative research, does the producer have access to institutional support and information on organic production. Information specific to each producer was not collected in the available dataset and therefore not available for analysis purposes.

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CHAPTER 5

Conclusion

This dissertation consists of three separate essays addressing animal health topics and crop production efficiency. The first essay is designed to evaluated antimicrobial resistant pathogens as a growing global threat to human health and safety and the biosecurity of livestock production in the United States. Essay two evaluates the effectiveness of various biosecurity measures to control BVDV as it relates to whole farm planning and risk management. The third essay estimates efficiency measures for conventional and organic crop producers and evaluates those farm and producer factors that influence efficiency. The dissertation as a whole is to be an assessment of the economic impacts of select animal health topics and crop production efficiency with a strong emphasis on production agriculture.

The first essay shows that the use of antibiotics in livestock production has become increasingly implicated in human antimicrobial resistance (AMR) infections. The reduction of antibiotics in livestock production has been suggested as a plausible risk management tool to reduce or eliminate the transmission of AMR pathogens, but as this study has shown such a reduction on antibiotics has significant economic impacts to both producers and consumers in both the short- and long-run. The implementation of a wildlife population management program was analyzed as an alternative strategy to reduce AMR on livestock facilities. Results indicate that an 11.95% industry adoption of WPM will cause a gain in producer surplus for the meat industry of $1.15 billion in the short run with long run gains of $18.33 million. The economic analysis shows that WPM may be a suitable starting point for livestock producers to increase the biosecurity of their facilities. Mitigating the risk of wildlife vectored AMR transmission could further safeguard the farm-to-fork supply chain enhancing a consistent food supply and concurrently reduce the risk of AMR pathogen transmission to consumers.

The second essay evaluates in the context of whole farm planning and risk management vaccination, testing or a combination of both were shown to be effective biosecurity measures to control bovine viral diarrhea virus (BVDV). Realistically, a producer can have multiple crop and livestock enterprises and is potentially faced with a myriad of diseases. This study sought to give economic values to BVDV impacts for various biosecurity strategies, which may be useful for producers and the risk associated with the spread BVDV. The study linked an epidemiological model to a linear programming model. Results show that for a North Central region representative cow-calf producer, depending on the risk level and biosecurity strategy implemented, may seek to operate at a risk level between $0 and $2,000 with risk-return ratios ranging from $18.23 to $1.79 on the high and low end, respectively. Depending on the individual producer's risk preference and management objectives, the results from this analysis should provide guidance to better improve management and control of BVDV spread and incursions and simultaneously allow producers to manage risk.

The third essay looks at various efficiency measures for conventional and organic crop producers in the 2009 USDA Agricultural Resource Management Survey (ARMS) Wheat Survey. The study was conducted in two stages where the first stage consisted of estimating efficiency measures by using a non-parametric approach commonly referred to as data envelopment analysis. The second stage used the estimated efficiency measures in a Tobit analysis to identify those farm and producer factors that influence the efficiency of U.S. crop producers.

Results for the frontier estimated efficiency amongst all the 1,215 conventional and organic producers reveals that organic producers have higher constant returns to scale technical efficiency (CRSTE) (0.4934) and variable returns to scale technical efficiency (VRSTE) (0.5656) than conventional producers 0.5189 and 0.4741, respectively. For conventional producers scale efficiency (SE) (0.9049), allocative efficiency (AE) (0.4029), and overall efficiency (OE) (0.2053) are higher than organic producers at 0.8672, 0.3749, and 0.1894, respectively.

Tobit analysis results indicated that as the debt-to-asset ratio negatively impacts efficiency. For conventional wheat producers, as the amount of rented acres relative to acres owned increases, overall efficiency will decrease. Increasing farm assets does positively impact overall efficiency of the farm. Producing wheat in the Basin and Range region negatively impacts overall efficiency. Operations where a majority of the income was from off the farm overall efficiency was negatively impacted. Results showed that when the total value of wheat production as a percent of total value of crop production increases overall efficiency decreases. Tobit analysis results for organic producers showed that none of the variables were found to statistically significant which follows findings by Poudel (2012).

APPENDIX A

EDM Parameters

This appendix contains three tables of the EDM parameters that were used in chapter 2 of this dissertation. Table A.1 contains the variable definitions for the log differential equilibrium displacement model, Table A.2 contains the elasticity definitions and estimates for the log differential equilibrium displacement model and Table A.3 contains quantity transmission elasticity definitions and estimates for the log differential equilibrium displacement model.

Table A.1: Variable Definitions for the Log Differential Equilibrium Displacement Model.

Symbol	Definition
z_B^r	Change in consumer demand for retail beef consumption caused by an animal identification program
$\boldsymbol{z_B^w}$	Change in demand for wholesale beef caused by an animal identification program
$\boldsymbol{z_{Bi}^w}$	Change in demand for wholesale beef imports caused by an animal identification program
$\boldsymbol{z_{Be}^r}$	Change in export consumer demand for wholesale beef consumption caused by an animal identification program
$\boldsymbol{z_B^s}$	Change in demand for slaughter cattle caused by an animal identification program
$\boldsymbol{z_B^f}$	Change in demand for feeder cattle caused by an animal identification program
$\boldsymbol{z_K^r}$	Change in consumer demand for retail pork caused by an animal identification program
$\boldsymbol{z_K^w}$	Change in demand for wholesale pork caused by an animal identification program
$\boldsymbol{z_{Ki}^w}$	Change in demand for imported wholesale pork caused by an animal identification program
$\boldsymbol{z_{Ke}^w}$	Change in export consumer demand for wholesale pork caused by an animal identification program
$\boldsymbol{z_K^s}$	Change in demand for slaughter hogs caused by an animal identification program
$\boldsymbol{z_{Ld}^r}$	Change in consumer demand for retail domestic lamb consumption caused by an animal identification program
$\boldsymbol{z_{Li}^r}$	Change in consumer demand for retail imported consumption caused by an animal identification program

z_L^w	Change in demand for wholesale domestic lamb caused by an animal identification program
z_L^s	Change in demand for slaughter lamb caused by an animal identification program
z_L^f	Change in demand for feeder lamb caused by an animal identification program
z_Y^r	Change in consumer demand for retail poultry consumption caused by an animal identification program
z_Y^w	Change in demand for wholesale poultry caused by an animal identification program
z_{Ye}^w	Change in export consumer demand for wholesale poultry caused by an animal identification program
w_B^r	Changes in costs of supplying retail beef caused by an animal identification program
w_B^w	Changes in costs of supplying wholesale beef caused by an animal identification program
w_{Bi}^w	Changes in costs of supplying wholesale beef imports caused by an animal identification program
w_B^s	Changes in costs of supplying slaughter cattle caused by an animal identification program
w_B^f	Changes in costs of supplying feeder cattle caused by an animal identification program
w_K^r	Changes in costs of supplying retail pork caused by an animal identification program
w_K^w	Changes in costs of supplying wholesale pork caused by an animal identification program
w_{Ki}^w	Changes in costs of supplying wholesale pork imports caused by an animal identification program
w_K^s	Changes in costs of supplying slaughter hogs caused by an animal identification program
w_{Ld}^r	Changes in costs of supplying retail domestic lamb caused by an animal identification program
w_{Li}^r	Changes in costs of supplying retail imported lamb caused by an animal identification program
w_L^w	Changes in costs of supplying wholesale lamb caused by an animal identification program
w_L^s	Changes in costs of supplying slaughter lamb caused by an animal identification program
w_L^f	Changes in costs of supplying feeder lamb caused by an animal identification program
w_Y^r	Changes in costs of supplying retail poultry caused by an animal identification program
w_Y^w	Changes in costs of supplying wholesale poultry caused by an animal identification program

Table A.2: Elasticity Definitions and Estimates for the Log Differential Equilibrium Displacement Model.

Symbol	Definition	Estimate	
		Short Run	Long Run
η_B^r	Own-price elasticity of demand for retail beef	-0.86	-1.17
$\boldsymbol{\eta_{BK}^r}$	Cross-price elasticity of demand for retail beef with respect to the price of retail pork	0.10	
$\boldsymbol{\eta_{BLd}^r}$	Cross-price elasticity of demand for retail beef with respect to the price of domestic retail lamb	0.05	
$\boldsymbol{\eta_{BLi}^r}$	Cross-price elasticity of demand for retail beef with respect to the price of imported retail lamb	0.05	
$\boldsymbol{\eta_{BY}^r}$	Cross-price elasticity of demand for retail beef with respect to the price of retail poultry	0.05	
$\boldsymbol{\varepsilon_B^r}$	Own-price elasticity of supply for retail beef	0.36	4.62
$\boldsymbol{\eta_B^w}$	Own-price elasticity of demand for wholesale beef	-0.58	-0.94
$\boldsymbol{\varepsilon_B^w}$	Own-price elasticity of supply for wholesale beef	0.28	3.43
$\boldsymbol{\eta_{Bi}^w}$	Own-price elasticity of demand for wholesale beef imports	-0.58	-0.94
$\boldsymbol{\varepsilon_{Bi}^w}$	Own-price elasticity of supply for wholesale beef imports	1.83	10.00
$\boldsymbol{\eta_{Be}^w}$	Own-price elasticity of demand for wholesale beef exports	-0.42	-3.00
$\boldsymbol{\eta_B^s}$	Own-price elasticity of demand for slaughter cattle	-0.40	-0.53
$\boldsymbol{\varepsilon_B^s}$	Own-price elasticity of supply for slaughter cattle	0.26	3.24
$\boldsymbol{\eta_B^f}$	Own-price elasticity of demand for feeder cattle	-0.14	-0.75
$\boldsymbol{\varepsilon_B^f}$	Own-price elasticity of supply for feeder cattle	0.22	2.82
$\boldsymbol{\eta_K^r}$	Own-price elasticity of demand for retail pork	-0.69	-1.00
$\boldsymbol{\eta_{KB}^r}$	Cross-price elasticity of demand for retail pork with respect to the price of retail beef	0.18	
$\boldsymbol{\eta_{KLd}^r}$	Cross-price elasticity of demand for retail pork with respect to the price of domestic retail lamb	0.02	
$\boldsymbol{\eta_{KLi}^r}$	Cross-price elasticity of demand for retail pork with respect to the price of imported retail lamb	0.02	

η^r_{KY}	Cross-price elasticity of demand for retail pork with respect to the price of retail poultry	0.02	
ε^r_K	Own-price elasticity of supply for retail pork	0.73	3.87
η^w_K	Own-price elasticity of demand for wholesale pork	-0.71	-1.00
ε^w_K	Own-price elasticity of supply for wholesale pork	0.44	1.94
η^w_{Ki}	Own-price elasticity of demand for wholesale pork imports	-0.71	-1.00
ε^w_{Ki}	Own-price elasticity of supply for wholesale pork imports	1.41	10.00
η^w_{Ke}	Own-price elasticity of demand for wholesale pork exports	-0.89	-1.00
η^s_K	Own-price elasticity of demand for slaughter hogs	-0.51	-1.00
ε^s_K	Own-price elasticity of supply for slaughter hogs	0.41	1.80
η^r_{Ld}	Own-price elasticity of demand for domestic retail lamb	-0.52	-1.11
η^r_{LdLi}	Cross-price elasticity of demand for domestic retail lamb with respect to the price of imported retail lamb	0.29	
η^r_{LdB}	Cross-price elasticity of demand for domestic retail lamb with respect to the price of retail beef	0.05	
η^r_{LdK}	Cross-price elasticity of demand for domestic retail lamb with respect to the price of retail pork	0.02	
η^r_{LdY}	Cross-price elasticity of demand for domestic retail lamb with respect to the price of retail poultry	0.02	
ε^r_{Ld}	Own-price elasticity of supply for domestic retail lamb	0.15	3.96
η^r_{Li}	Own-price elasticity of demand for imported retail lamb	-0.41	-0.63
η^r_{LiLd}	Cross-price elasticity of demand for imported retail lamb with respect to the price of domestic retail lamb	0.78	
η^r_{LiB}	Cross-price elasticity of demand for imported retail lamb with respect to the price of retail beef	0.05	
η^r_{LiK}	Cross-price elasticity of demand for imported retail lamb with respect to the price of retail pork	0.02	
η^r_{LiY}	Cross-price elasticity of demand for imported retail lamb with respect to the price of retail poultry	0.02	
ε^r_{Li}	Own-price elasticity of supply for imported retail lamb	10.00	10.00
η^w_L	Own-price elasticity of demand for wholesale lamb	-0.35	-1.03

ε_L^W	Own-price elasticity of supply for wholesale lamb	0.16	3.85
$\boldsymbol{\eta_L^s}$	Own-price elasticity of demand for slaughter lamb	-0.33	-0.87
$\boldsymbol{\varepsilon_L^s}$	Own-price elasticity of supply for slaughter lamb	0.12	2.95
$\boldsymbol{\eta_L^f}$	Own-price elasticity of demand for feeder lamb	-0.11	-0.29
$\boldsymbol{\varepsilon_L^f}$	Own-price elasticity of supply for feeder lamb	0.09	2.26
$\boldsymbol{\eta_Y^r}$	Own-price elasticity of demand for retail poultry	-0.29	-1.00
$\boldsymbol{\eta_{YB}^r}$	Cross-price elasticity of demand for retail poultry with respect to the price of retail beef	0.18	
$\boldsymbol{\eta_{YK}^r}$	Cross-price elasticity of demand for retail poultry with respect to the price of retail pork	0.04	
$\boldsymbol{\eta_{YLd}^r}$	Cross-price elasticity of demand for retail poultry with respect to the price of domestic retail lamb	0.02	
$\boldsymbol{\eta_{YLi}^r}$	Cross-price elasticity of demand for retail poultry with respect to the price of imported retail lamb	0.02	
$\boldsymbol{\varepsilon_Y^r}$	Own-price elasticity of supply for retail poultry	0.18	13.10
$\boldsymbol{\eta_{Ye}^w}$	Own-price elasticity of demand for wholesale poultry exports	-0.31	-1.00
$\boldsymbol{\eta_Y^w}$	Own-price elasticity of demand for wholesale poultry	-0.22	-1.00
$\boldsymbol{\varepsilon_Y^w}$	Own-price elasticity of supply for wholesale poultry	0.14	14.00

Notes: All supply and demand elasticity estimates correspond to those used by Pendell et al. (2010). Short-run and long-run refer to years 1 and 10, respectively.

Table A.3: Quantity Transmission Elasticity Definitions and Estimates for the Log Differential Equilibrium Displacement Model.

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_L^{wr}	Percentage change in retail domestic lamb supply given a 1% change in wholesale lamb supply	0.908	0.103
τ_L^{rw}	Percentage change in wholesale lamb demand given a 1% change in retail domestic lamb demand	0.731	0.058
γ_L^{sw}	Percentage change in wholesale lamb supply given a 1% change in slaughter lamb supply	1.007	0.002
τ_L^{ws}	Percentage change in slaughter lamb demand given a 1% change in wholesale lamb demand	0.993	0.002
γ_L^{fs}	Percentage change in slaughter lamb supply given a 1% change in feeder lamb supply	0.864	0.142
τ_L^{sf}	Percentage change in feeder lamb demand given a 1% change in slaughter lamb demand	0.962	0.025
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

Notes: All quantity transmission elasticity estimates correspond to those used by Pendell et al. (2010).