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Big Government and your Big Mac

Analyzing the Impact of Corn and Soybean Subsidies on US Meat Markets

Nadav David Chudler

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Nadav David Chudler

Supervisor:	Professor Hans Andersson Swedish University of Agricultural Sciences Department of Economics
Assistant supervisor:	Professor Thomas Heckelei University of Bonn Department of Economics
Examiner:	Professor Sebastian Hess Swedish University of Agricultural Sciences Department of Economics

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Personal Declaration

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Big Government and your Big Mac: Analyzing the Impact of Corn and Soybean Subsidies on US Meat Markets

A Thesis Presented to
The Faculty of Economics at
The Swedish University of Agricultural Sciences

In Partial Fulfillment
of the Requirements for the Degree
of Masters of Science

by

Nadav David Chudler

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Nadav David Chudler

Professor Hans Andersson, Thesis Advisor
Swedish University of Agricultural Sciences

Professor Thomas Heckelei, 2. Thesis Committee Member
University of Bonn

Professor Sebastian Hess, 3. Thesis Committee Member
Swedish University of Agricultural Sciences

Abstract

Extensive literature exists regarding the externalities of industrial meat production in the United States. There is also a belief that the growth of these production systems were facilitated by high levels of subsidies for corn and soybean, the primary crops, or byproducts of which are used to feed livestock. This in turn suggests a linkage between feed crop subsidies and the externalities from meat production. Regardless of any impact these subsidies may have had on development of industrial meat production the only subsidies currently of relevance for corn and soybean are for insurance rate premiums. This paper proposes to examine the impact of these subsidies on the US meat markets using a modified stochastic equilibrium displacement model originally developed by Dhoubhadel, Azzam, and Stockton. The results found that these subsidies have a minimal effect on meat production levels. Therefore, if a reduced meat sector is desirable then other avenues, such as improved regulation or taxation, should be pursued.

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Acronyms

FCIP	Federal Crop Insurance Program
FCIC	Federal Crop Insurance Corporation
(S)EDM	(Stochastic) Equilibrium Displacement Model
DG	Distiller's Grain
DDGS	Distiller's Grain with Soluble
RFS2	Renewable Fuel Standard (expanded mandate)
RIN	Renewable Identification Number
GHG	Greenhouse Gas
US	United States

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Dedication

I dedicate this thesis to my siblings, Gilad and Daniella, whose encouragement, not only in pursuing my academic endeavor, but in ensuring that I remember to enjoy the life (and food) outside of it. A special dedication goes to my parents, Howard and Tikvah, whose support has been invaluable, not to mention the patience over the past 28 years with which they have put up with my bull… fertilizer.

Chapter 1 - Introduction

A myriad of research exists and continues to be published regarding the negative externalities of industrial meat production, which range from human health impacts, environmental degradation, and socioeconomic performance in communities near such operations (Daley, et al., 2010; Nguyen, Hermansen, & Mogensen, 2010, 2012; Scollan et al., 2010; Sneeringer, 2009; Walker et al., 2005; Osterberg & Wallinga, 2004; Kanaly et al., 2010; ISU/UISG, 2002) Reducing meat production would decrease the prevalence of these externalities, yet it has continued to rise over the past few decades (USDA Economic Research Service). This continues despite increased awareness of these problems.

There is a story become popular in the United States from Michael Pollan's book, *The Omnivore's Dilemma*, where he describes how the growth of the industrialized meat sector was aided by the drastic transformation of US agricultural policies beginning in the early 1970s (2006). During this period the federal government began the process of dismantling the New Deal farm programs of the 1930s. Government subsidies began to incentivize farmers to produce as much corn and soybean as possible[1], which are the primary crops (or the byproducts of which) used to feed cattle, hogs, and poultry. Propped by these subsidies, farmers began to rapidly expand corn and soybean even as their market prices continued falling. This influx of cheap corn and soybean encouraged the growth of large scale animal farms, in which feed took an increasingly large share of total costs. However, this is not an examination of how the history of subsidies affected the development of meat production, but what influence they currently have. Even if the historical account by Pollan is accurate[2] and that the meat industry captures part of the subsidy rent (Starmer, Witteman, & Wise, 2006, p. 28), it does not mean that industrial meat production is still dependent on these subsidies.

One should be aware that the subsidies Pollan talks about in his book, such as price support and direct payments, have been mostly eliminated in the United States. The salient

[1] Soybean did not begin receiving significant levels of subsidies until much later. However, soybean has been the typical crop used in rotation with corn fields. Hence, increasing corn acreage would result in increased soybean production as well.

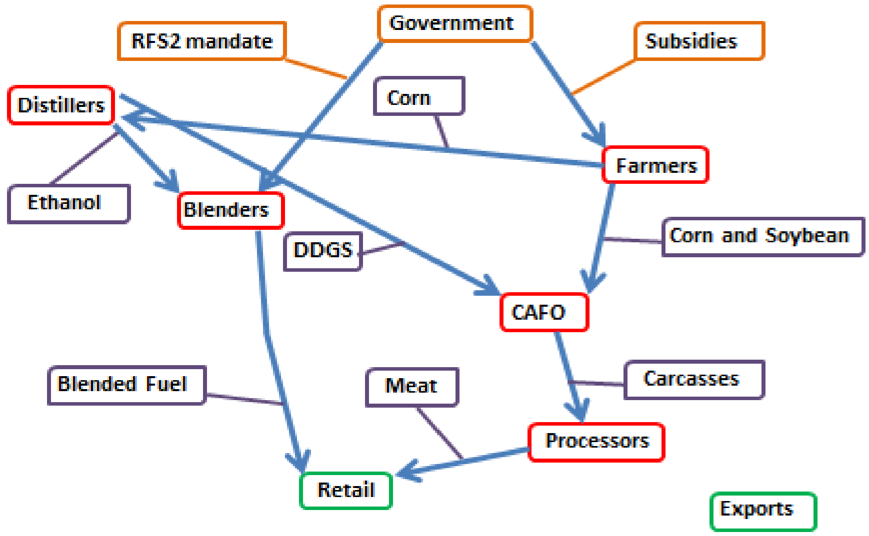
[2] The author wishes to emphasize that no specific claim is made here regarding the role corn and subsidies have played in the development of industrial meat production.

program in the 2014 US Farm Bill for corn and soybean is the insurance rate premium subsidies, which are based on historical acreage and yields (World Trade Organization). Of these programs farmers receive subsidies specifically on the premium rates of the Federal Crop Insurance Program (FCIP). It is these subsidies that are the primary focus of this paper. Specifically, this paper will examine the indirect impact insurance premium subsidies have on meat markets through their effects on livestock feed supply.

While consumers have benefited from an increased supply of cheap meat to the point of being the largest per capita consumers of meat during the 20^{th} century (Warman, 2003), there are multiple externalities associated with industrial meat production that government regulation has so far failed to internalize with significant costs to society (Osterberg & Wallinga, 2004). Therefore the author asserts the importance of examining policies that could potentially reduce the scale and scope of industrial meat production in the United States.

The objective of this paper is to quantify the impact a reduction in insurance premium subsidies for corn and soybean would have on meat and ethanol markets in the United States. This will be addressed by using a modified stochastic equilibrium displacement (SEDM) model originally used by Dhoubhadel, Azzam, & Stockton (2015), who analyzed the impact of a drought on US grain, livestock and ethanol markets. While this paper will later discuss in more depth the details of this model and the changes made to it, it is noted now that insurance rate premium subsidies for corn and soybean were introduced as the exogenous variables to be shocked. The following conceptual framework clarifies the connections between the various sectors and policies (See Figure 1.1).

Figure 1.1. Conceptual framework of model



Author's own depiction

The diagram above is useful to illustrate the relationships between key government policies and the various actors in the beef and ethanol commodity chains. The blue arrows represent flows of either policies or products from and to the different actors. The boxes represent either the actors and stages involved in the commodity chains or the products and policies produced by them. Products and policies are connected to the blue arrows indicating to which level of each commodity chain they are sold to (products) or have their impact on (policies). The colors depict the stages of each commodity chain and the commodities themselves, beginning with government and government policies in orange, the retail and export markets in green[3], and the actors in between with their products are in red and purple, respectively. One point that requires clarification is that depending on the meat sector being analyzed, the farm, industrial livestock operation[4], and meat processors will consist of one, two,

[3] For clarity in the graph, no arrows were drawn toward exports, but the model allows for exports of all commodities except for ethanol. Also the backgrounding phase of beef production has been omitted to reduce clutter. This would simply be a flow of cattle to the feedlot operators, denoted as CAFO (see footnote 4).

[4] The term CAFO (Concentrated Animal Feeding Operation) is used instead of industrial livestock operation for space consideration.

or three stages for the poultry, pork, and beef sectors, respectively, due to the level of integration in the industry.

The explanation of the diagram will progress from the top-down beginning with government and first covering the ethanol commodity chain. Here the Renewable Fuels Standard[5] (RFS2) mandates blenders to use a minimum amount of ethanol when blending fuel, which is sold to retail markets. This creates an inelastic source of demand for distillers, who use corn to produce ethanol and sell DDGS as a coproduct of the distillation process to the livestock sector.

The government subsidizes insurance premiums for corn and soybean which incentivizes farmers to grow more of those crops than they otherwise would. While much of the corn is sold to ethanol distillers, a significant amount is also sold to the livestock sector, as is soybean in meal form. Both are also exported abroad. Livestock is then sold to the meat processors, who then either supply meat to the retail sector or export it.

What the author expects to occur given a reduction in subsidies is as follows. Initially there would be a downward supply shift of corn, soybean, and soybean meal. Since corn demand from the ethanol sector is inelastic due to the RFS2 mandate, corn prices are likely to be even more impacted than soybean prices. Livestock producers will shift some of their consumption of corn and soybean meal to distiller's grains, with cattle raisers experiencing the biggest shift in consumption patterns due to the ability of cattle to consume more DDGS than hogs or poultry. Meanwhile, we would expect exports of all three feeds and soybean to decline, due to the higher elasticity of export demand than the domestic market. One would expect the quantity of meat and livestock at all levels to decrease while prices increase. The one exception may be the market for feeder cattle, the production of which uses pasture instead of feed crops. This sector is instead assumed to experience a negative demand shift from the feedlot level, which results in both a price and quantity decrease.

The hypothesis for the research objective is as follows: Regardless of any influence corn and soybean subsidies may have had on shaping present day industrial livestock operations, the author assumes that these sectors have grown to the point where they no longer depend indirectly on these subsidies. This point is supported by recent experience. The average real price of corn

[55] The RFS2 mandate and its implications are discussed in more detail in Chapter 2.

and soybean from 2008-2013 nearly doubled the average from 2002-2007 (farmdoc), yet the production of beef, pork, and poultry all increased during period[6] (USDA Economics Research Service). The author suggests industrial livestock operations simply benefit from the policy by capturing part of the subsidy rent. It is assumed that any changes to the equilibrium prices and quantities of the meat sectors will be very small relative to the changes in the feed grain markets following a reduction in insurance premium subsidy payments.

Moreover, when discussing the impact of subsidies on US meat markets it is important to take market power into account. These commodity chains are highly concentrated at the packing and retail levels (Azzam & Anderson, 1996; RTI International, 2007; Weng, 2012; Wise & Trist, 2010). Starmer, Witteman & Wise argued that this difference in market power has allowed the meat industry to capture significant rent from corn and soybean subsidies (2006). Therefore, while providing a background of the different markets in the model, the next chapter will also provide an overview of the role of market power within them.

The remainder of the paper is organized as follows: Chapter 2 offers a background of US agriculture policy, the commodity chains in the model, and a brief overview of the externalities associated with industrial meat production. Chapter 3 gives an overview of the relevant literature relevant to this research question and EDMs in general. Chapter 4 discusses the methodology employed to answer the research question. Chapter 5 presents the results from the simulation, and Chapter 6 concludes with the main findings of this research.

[6] The author notes that from 2010 to 2014 there has been an 8% beef production.

Chapter 2 - Overview of Markets and Externalities

2.1 Agriculture Policy

This section is divided into two parts, the first of which provides an overview of the history of US agriculture policy as it relates to corn and soybean up to present policy. An understanding of these policies and their impacts will assist the reader in understanding how insurance subsidies for corn and soybean farmers affect meat markets as well as how US agriculture has become increasingly focused on insurance programs. The second part will specifically examine the Federal Crop Insurance Program (FCIP) with an accompanying analysis of how these subsidies may be affecting production levels.

2.1.1 History of Agriculture Policy

The modern era of US agriculture policy began during the Great Depression under Roosevelt with the Agricultural Adjustment Act of 1933. Warman (2003) argued that until then there had been a history of ineffective government interventions. The key aim of these programs was to influence agricultural markets by affecting supply. The most important policies for achieving these goals were set-aside programs, acreage reduction and the creation of the US Granary. The first two directly reduced the amount of crops a farmer could produce whereas the latter utilized subsidies to moderate farm price volatility by buying and storing program crops from farmers during seasons of ample harvest and low prices, and selling those stocks in years of poor harvest and high prices (Pollan, 2006; Starmer, Witteman, & Wise, 2006; Warman, 2003).

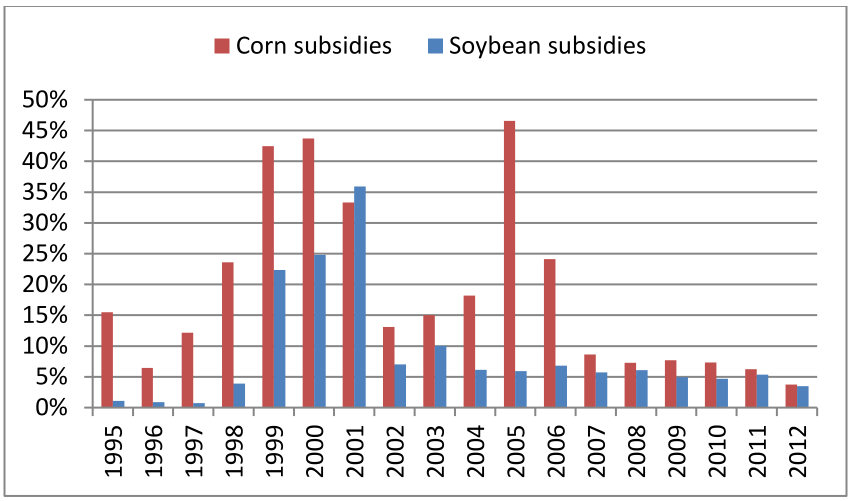
These policies were intended to provide a more predictable market for producers. In tandem with a set of other government policies including irrigation projects, roads, power networks and soil conservation programs, agriculture policy was instrumental in supporting agricultural production. Warman goes so far as to argue that the combination of these subsidies, price support programs, and infrastructural investments were more important in increasing farmer productivity than technological improvements such as hybrid crops and fertilizers (2006, pp. 186-187).

The government began to dismantle this system of agricultural support beginning in the 1960s, a process that culminated with the 1996 Farm Act. With the 1965 Food and Agricultural Act, the government started the process of removing supply constraints from farmers by introducing the target pricing system. When the market price fell below the government set target price farmers received a direct subsidy payment to make up the difference (Marlow, 2005). The next significant policy shift occurred with the 1985 Food Security Act with the transformation of the Marketing Loan program. This program was originally introduced to allow farmers to take out loans at the government set loan rate and sell their crops later when prices were higher, thereafter paying off the loan. If prices remained below the loan rate then farmers had to pay a fixed portion of the original loan, which essentially serving as a price floor for their crops. The 1985 act removed the fixedness of the repayment rate, allowing it to decrease as world market prices decreased (Marlow, 2005). This act also introduced the Loan Deficiency Payment, which allowed farmers to take a payment of the loan rate minus the repayment rate instead of taking the loan. One of the main goals of this act was to reduce stockpiles and increase commodity exports (Glaser 1986, p. 8). With this policy the government essentially divested from itself the power to regulate agricultural market prices (Marlow, 2005).

The government’s final departure from direct market price interference came about with the 1996 Farm Act. In a period of increasing prices and rising domestic and export demand, the law removed set-aside requirements thereby increasing the land available for productive purposes. Coupled with this, the law eliminated some planting restrictions, which allowed farmers to plant soybean on up to 15% of base acres allocated to other crops without affecting their bases or program payments (Ash, Livezey, & Dohlman, 2006). The act also introduced the Production Flexibility Contract payments, which were decoupled from current production and decreased over time. The plan was to gradually wean farmers off government support (Dmitri, Effland, & Conklin, 2005) and acclimate them to making their production decisions based on market signals (Marlow, 2005).

However the 1997 Asian financial crisis and resulting crash in export demand pushed US farmers into a deep crisis, requiring emergency measures from the government (Starmer, Witteman, & Wise, 2006). The implementation of the Counter-Cyclical Payment and Direct Payment programs manifested radical increases in government payouts to farmers. The former program was coupled to prices but was based on historical acreage, whereas the latter was a decoupled flat payment per land unit owned (USDA ERS). Instead of weaning farmers from government subsidies, the result of the 1996 Farm Act was a dramatic increase in payments. In the 9 years from 1998-2006 corn subsidies were US$5 billion or higher in 6 of those years, and totaled to more than US$10 billion in 2005. In the three years prior to 2008 soybean subsidies averaged approximately US$145 thousand. In 7 of the 9 years that followed, subsidies reached over US$1 billion, peaking at nearly US$5 billion in 2004 (Environmental Working Group). It should seem intuitive that subsidies on this scale regardless of degree of decoupling should have some effect on markets. Using subsidy data from the Environmental Working Group, historical production from the USDA Economic Research Service, and historical market price data from farmdoc, Figure 2.1 shows the amount of subsidy farmers received per bushel as a percentage of the market price.

Figure 2.1. Corn and soybean subsidies as % of market price[7]



Adapted from: (Environmental Watch Group; farmdoc.illinois.edu; USDA ERS)

While the recent trend has been that subsidies have been a small percentage of market prices, it is clear that in some years corn and soybean farmers received a significant part of their income from subsidies. From 1998 to 2006, corn farmers received at least 20% of their income from subsidies 6 times, peaking at over 45% in 2005. While less than corn, soybean also benefited greatly from subsidies in select years. This graph demonstrates what Starmer, Witteman, & Wise (2006) refer to as a paradoxical state in which, "U.S. farm policy maintains the semblance of free-market orientation by ostensibly keeping most payments decoupled from

[7] Unless otherwise specified all dollar figures are in real terms. Nominal figures were converted using the CPI chart from inflationdata.com. All values are chained to the 1983-1985 average price level.

production, and by allowing farmers greater planting flexibility. At the same time, however, it maintains high taxpayer transfers to farmers (p. 9).” They go on to estimate the costs of corn and soybean production from 1986 to 2005 and found that between 1986 and 1996 corn and soybean were sold on average 17% and 5% below the estimated costs of production. In the period after the 1996 Farm Act (1997 to 2005), these margins increased to 23% and 15% for corn and soybean respectively (Ibid. p. 28). This is clearly an indirect subsidy for meat producers using these crops and their byproducts to feed their livestock.

As stated earlier in the introduction, the direct and counter-cyclical payments were eliminated and replaced with the Price Loss Coverage and Agriculture Risk Coverage programs in the 2014 Farm Bill (WTO 2014). These new programs cover shallow losses on yields or revenues not covered by the federal crop insurance program (O'Donoghue, 2014). Unfortunately, at the time of this writing, the author was unable to find any research on these programs other than brief descriptions of how they function. Therefore the only part of agriculture insurance to be discussed in the next section is the FCIP itself.

2.1.2 Federal Crop Insurance Crop Insurance

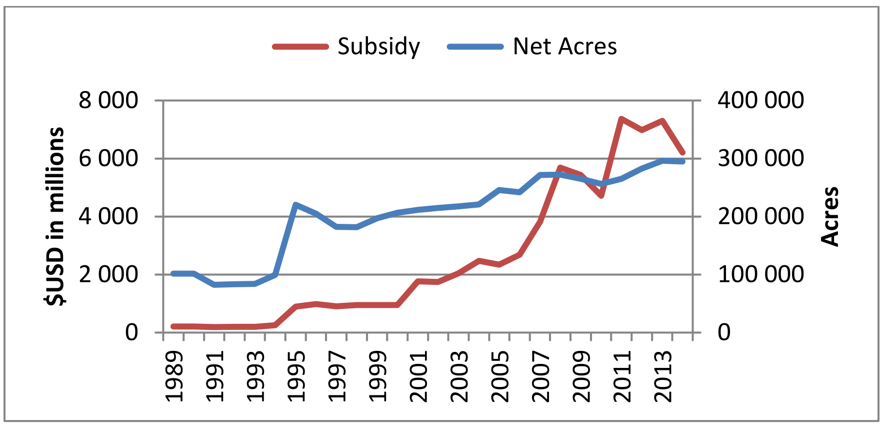
Overview

The FCIP was founded in 1938 and is administered by the Federal Crop Insurance Corporation (FCIC). Originally the FCIC was responsible for charging farmers an actuarially fair premium, which means that total premiums should cover expected total indemnities, and the government funded the administration and organization of the program. (Pearcy & Smith, 2013). The FCIP is a government subsidized and regulated insurance scheme, but the actual insurers are private companies. Producers choose whether to insure revenue or yields, and receive a payment when they fall below specified thresholds. Coverage levels begin from catastrophic risk coverage (50% of expected yield/revenue) to up 75% or 85%, depending on specific cases (OECD, 2008, p.53). These payments are decoupled from production, as they are derived from historical base acres and yields, which most often based on their 1998-2001 production levels (Olson, 2014).

The government completely subsidizes the premium for catastrophic risk coverage, after which producers pay a portion of the premium price for higher levels of coverage. The amount of premium the government subsidizes ranges from 100% to 38% (Shields, 2015, p.11). The government subsidizes premium rates at an average of 62% over the past few years (Glauber, 2013)[8].

The US Government began to enhance the role of the FCIP with the 1994 Crop Insurance Reform Act, which is reflected in the overall growth of the program. Since the 1990s there has been rapid growth in total subsidies paid, acres and crops covered, liabilities and indemnities (See Figures 2.2 and 2.3) (Sumner & Zulauf, 2012). Despite the relative stabilization of acres covered by insurance in the past decade, liabilities have continued to grow as crop prices increase and farmers choose higher coverage levels. In 1995, "nearly all insured acres were at 65 percent or lower coverage, but by 2011 about 75 percent of insured acres were at 75 percent or higher coverage" (Sumner & Zulauf, 2012, pp. 2-3). It is clear that the FCIP is a central component of current farm policy.

Figure 2.2. The growth of the FCIP - Subsidies and Acreage[9]



Adapted from (US Risk Management Agency)

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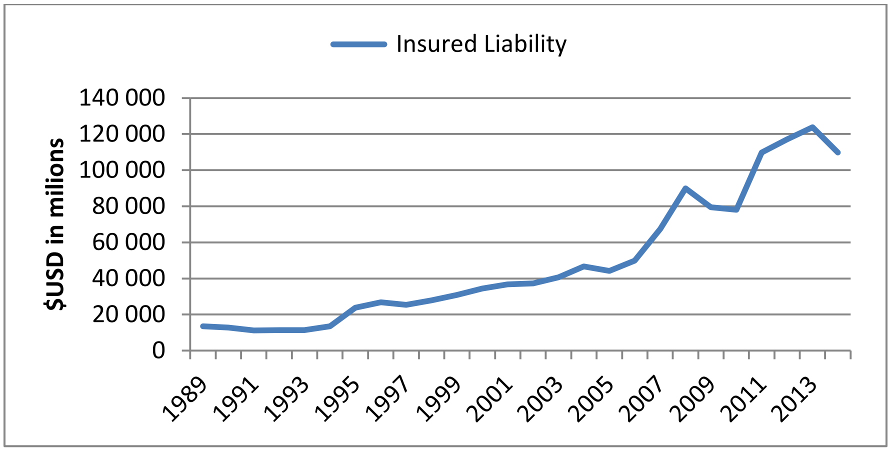
[8] It should be noted that there are other subsidies under the program including those provided to the insurance companies covering costs of administration and operation, as well as any indemnities above the premium received (OECD, 2008, p.53). However, this is not an issue of concern for this paper.

[9] Figures 1.3, 1.4, and 1.5 are shown in nominal dollar figures.

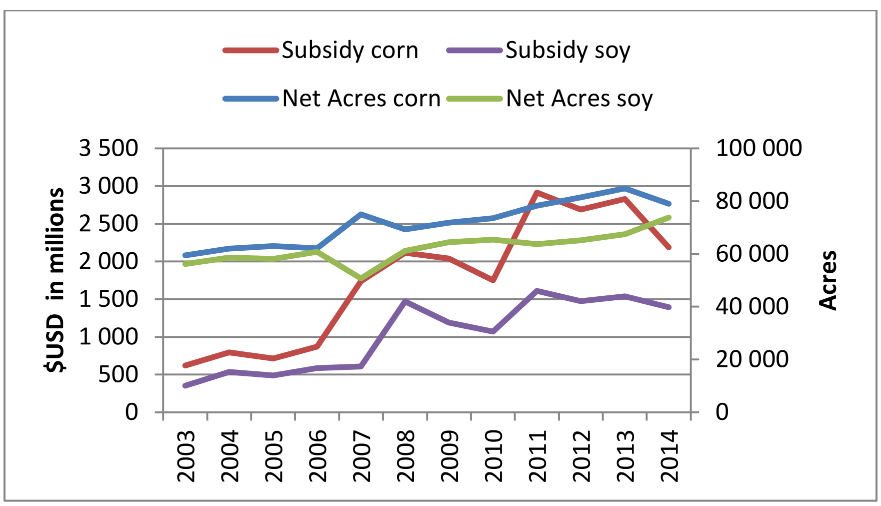
Figure 2.3. The growth of the FCIP - Liabilities



Adapted from (US Risk Management Agency)

Corn and soybean have historically been two of the greatest beneficiaries of the FCIP. Along with wheat, they make up approximately 2/3 of the total land area covered by insurance. From 1990 to 2012 the total area of corn and soybean under the FCIP has increased from 26 and 17 million acres to 81 and 65 million, respectively. As a percentage of total land planted for each crop, the increases were from 35% and 29% to 84% for both crops (O'Donaghue, 2014, p. 4). By 2014 the percentage increased to 87% for Corn and 88% for soybean. Combined they made up more than half of all the land covered by the FCIP (Shields, 2015, p. 4). Figure 2.4 demonstrates this rapid growth.

Figure 2.4. Growth of corn and soybean coverage in the FCIP



Adapted from (US Risk Management Agency)

Unfortunately the authors could only find program data for specific crops beginning from 2003. However one can still see that the amount of subsidies increased by more than 3 times for both crops in just 12 years. Total liabilities increased at similar rates (US Risk Management Agency). The importance of the support provided FCIP and its subsidies to corn and soybean farmers should be apparent, especially when one takes into account that the Counter-Cyclical and Direct Payment programs were eliminated with the most recent farm bill.

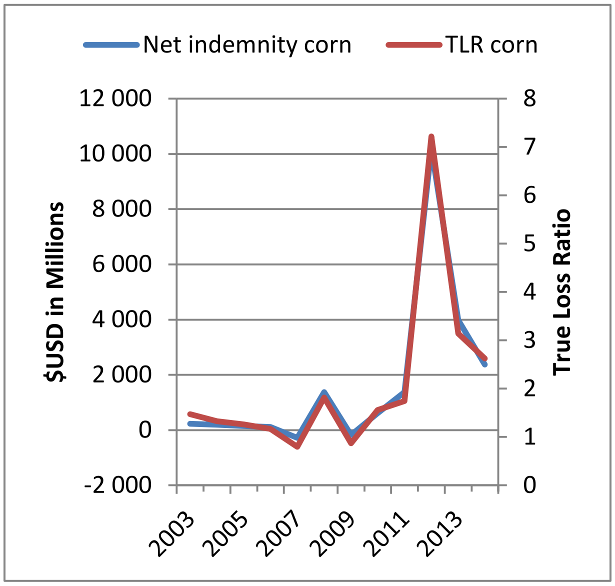
Supply response to insurance and premium subsidies

This section will attempt to convey the distortionary impact of insurance rate premium subsidies to the reader. Unfortunately, there is a dearth of research on this subject (Goodwin, Vandemeer, & Deal, 2003; Goodwin & Smith, 2013; Yu, 2015), but it is possible to qualitatively analyze the impact of subsidies into account when considering the literature on crop insurance and general risk theory simultaneously.

Before examining previous studies and theory there is one important issue to take into account regarding the crop insurance policy. Congress has ordered the Risk Management Agency, the government organization overseeing the FCIP, to set premium rates so that expected indemnities exceed total premiums by 7.5%, but this relates to pre-subsidy premiums (Babcock, Hart, & Hayes, 2004, p. 563). The reader should recall that on average the government has subsidized 60% of total premiums. This means that the true loss-ratio, or the ratio of indemnities to premiums, is much higher than 1.075 mandated by Congress. This is effectively a transfer of wealth from taxpayers to farmers (Goodwin, & Smith, 2013). We can see this in Figures 2.5 and 2.6 which show the net indemnity for corn and soybean farmers as well as the true loss ratio[10]. It is clear that in most years the difference between actual premiums paid and indemnities received resulted in a significant wealth transfer to farmers. For example, in 2012 the net indemnity paid to corn farmers totaled over US10 billion.

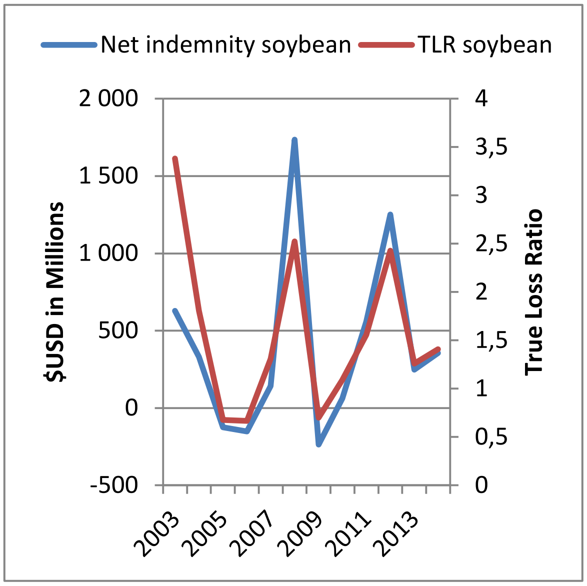
[10] When the true loss ratio is equal to 1 then total premiums – subsidies = total indemnities.

Figure 2.5. Net indemnity and true loss ratio of corn



Adapted from (US Risk Management Agency)

Figure 2.6. Net indemnity and true loss ratio of soybean



Adapted from (US Risk Management Agency)

Sumner & Zulauf discuss three primary channels by which crop insurance can affect production levels (2012, p.10).The first is that the combination of crop insurance reimbursing farmer losses and subsidized premiums decreasing farmer costs increase expected farmer income per acre. Economic theory suggests that higher expected profits will incentivize farmers to produce more of the crops receiving subsidies. The authors argue that, "it is reasonable to hypothesize that subsidized insurance premiums will have effects similar to that of a price subsidy" (p. 10). The second channel is via risk mitigation provided by crop insurance for producing on marginal lands, since poor harvests will be compensated. Thus, the potential losses may be significantly reduced. This can result in unused land or land used for other crops to be switched over to production of the insured commodity. The third avenue considers the overall reduction of risk faced by the farmer, who may therefore be incentivized to undergo riskier behavior focusing more on increasing productivity. When producers are exposed to potential losses they are more likely to utilize risk-mitigating practices that can decrease potential output in exchange for a reduction of potential losses. (Ibid).

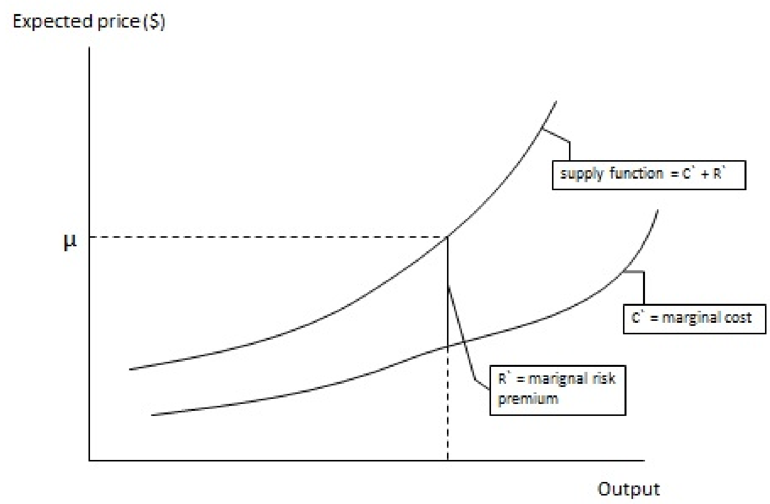
There are several studies that have examined the production effects of crop insurance, though not all took subsidies into account (Wu, 1999; LaFrance, Shimshack, & Wu, 2001;

Young, Vandeveer, & Schnepf, 2001; Goodwin, Vandeveer, & Deal, 2004; Goodwin & Smith, 2013). All found positive albeit small effects of the provision of crop insurance on production levels. However there are multiple reasons that can explain the limited results. Sumner & Zulauf argue that crop expansion is limited by rotational concerns and lack of available land for extending production area. They also assert that the production impacts of insurance on one crop are diminished due to the fact that most crops are now eligible for the insurance program. Finally they note the fact that most studies occurred before the 2008 expansion of the crop insurance program (2012, p.11). This last point has become especially relevant now that crop insurance is the only program left for corn and soybean farmers.

One more important aspect of the crop insurance program is the role of base updating. As mentioned previously, the historical averages from which average yields and acreage are typically based are from 1998-2001. The intention is to decouple payments from current production levels. However with the 2014 Farm Bill, farmers are allowed to update their base acreage and yields to the 2008-2012 averages (Olson, 2014). While this alone may not affect the decoupling effect of using historical production levels, farmer anticipation of further base updating in future farm bills can increase the distorting impact of these subsidies (Anton & le Mouel, 2002, p. 2). In other words, expectations of future base updating allowances may incentivize farmers to increase production now to increase their subsidy payments in later periods.

At this juncture it would be useful to graphically analyze the impact of insurance premium subsidies using a simple production under risk model (Figure 2.7). In this model we assume farmers are risk averse. The supply function, S is the sum of the marginal cost of production, C`, and the marginal risk premium, R`, or the farmer's marginal willingness to pay to avoid risk. If the farmer was risk neutral the supply curve would be equal to the marginal cost. The farmer produces at the output level where the expected price is equal to the supply function. Note that this output level is smaller than if the farmer produced where expected price is equal to marginal cost.

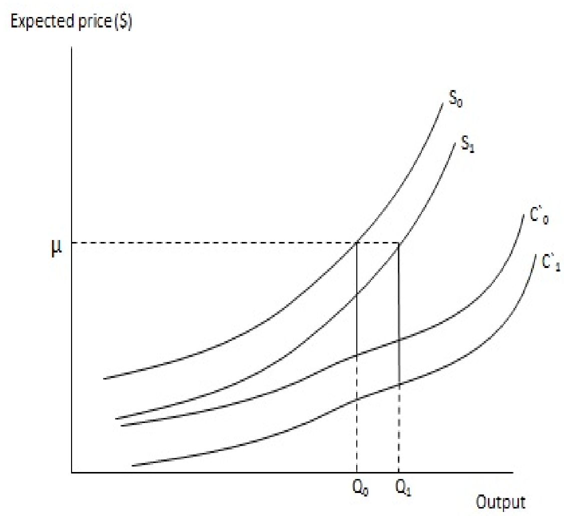
Figure 2.7. Production under risk - General framework



Source: Finger, 2014.

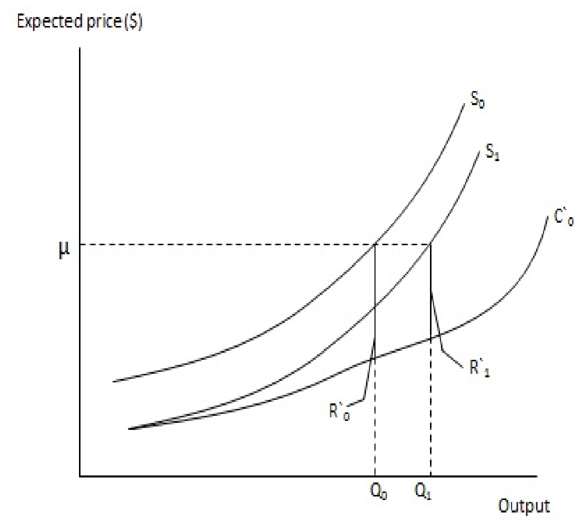
Following Yu we can imagine two basic scenarios in which farmer production would be influenced by the availability of insurance premiums (2015). The first scenario is for a farmer who is already a purchaser of crop insurance (Figure 2.8) and the second is for a farmer who is incentivized to purchase crop insurance because of the subsidies (Figure 2.9).

Figure 2.8. Production under risk: Scenario 1



Source: Author's own depiction

Figure 2.9. Production under risk: Scenario 2



Source: Author's own depiction

In scenario 1 the farmer is already purchasing crop insurance. If insurance premiums were increased, assuming the farmer maintains the same insurance coverage level, this would be reflected as a downward shift of the marginal cost curve, from $C`_0$ to $C`_1$ and an equal shift of the supply curve resulting in an increase of output from Q_0 to Q_1. In scenario 2 assume the increase in subsidies is large enough to impact the profitability of a farmer not purchasing crop insurance, i.e. beyond the point where the farmer is indifferent to buying crop insurance. This means that the impact of increased costs due to the unsubsidized portion of the premium payment, $C`_0$ to $C`_1$, is more than offset by the reduction in the farmer's risk premium, $R`_0$ to $R`_1$, which again results in an output increase from Q_0 to Q_1. In practice it is also possible that both effects can occur simultaneously. For example, an increase in subsidies may incentivize a farmer to purchase a higher level of coverage, which could simultaneously reduce productions costs and risk depending on the size of the subsidy increase.

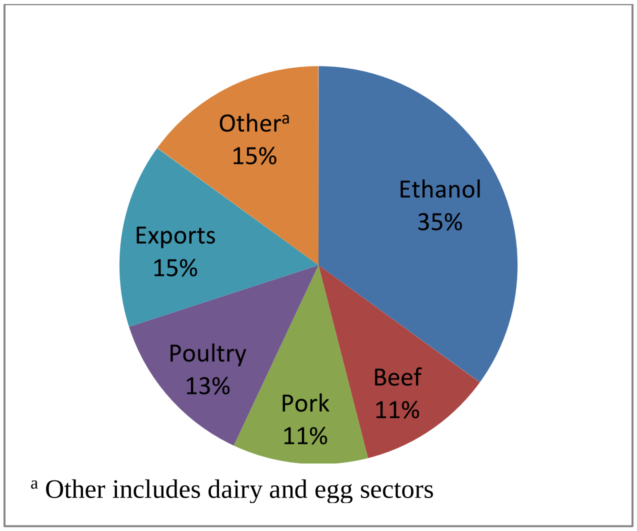
To this point this paper has focused on the history of agriculture policy, the crop insurance program, and the theories behind how the latter affects production level in order to convey the centrality of the program to corn and soybean farmers. At this juncture the paper will cover each of the key markets that make up the model used in the research. Allusions will be made to the crop insurance program and the impact of subsidies throughout.

2.2 Corn

Corn is the most important crop in the United States in terms of both land allocation and crop value (Ash, Livezey, & Dohlman, 2006). In 2014, 90 million acres of corn were planted for a value of $52.3 billion (USDA National Agriculture Statistics Service). The majority of corn is grown in the North Central United States, with this region producing about 80% of all corn in the nation. Iowa and Illinois alone account for about 30% of total national production (Hoffman, Baker, Foreman, & Young, 2007).

Nearly all the corn consumed domestically and exported abroad is used as an industrial input and livestock feed (Ibid). The biggest consumer of corn is the US ethanol industry, which has historically been supported by government policy. Domestic meat producers also consume a significant portion of the corn supply with much of the remainder exported (see Figure 2.10).

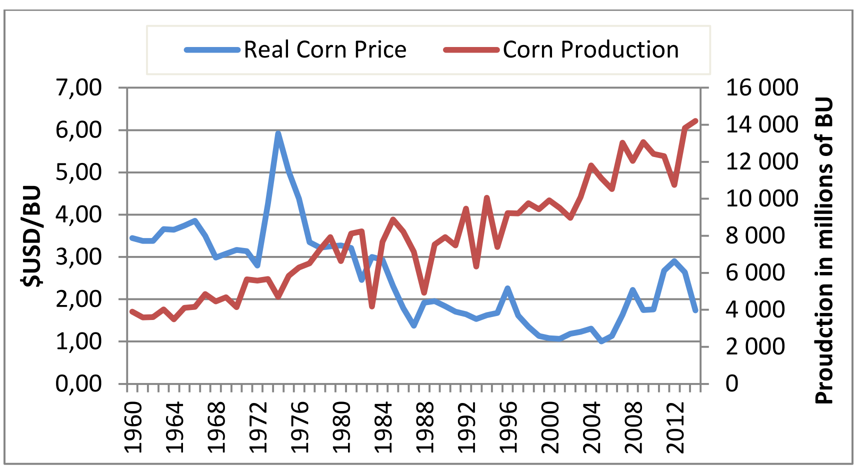
Figure 2.10. Corn consumption by sector



Adapted from (Conley, Nagesh, & Salame, 2012)

The general trend of corn since the early 1970s has been one of continued increases in production during a long period of general price decline (See Figure 2.11). The real price of corn decreased 78% from 1974 to 2004, while production increased by 151% during the period. This coincides with the shift in agricultural policy toward removing barriers to production and increasing farmer support.

Figure 2.11. History of corn production and prices



Adapted from (farmdoc.illinois.edu).

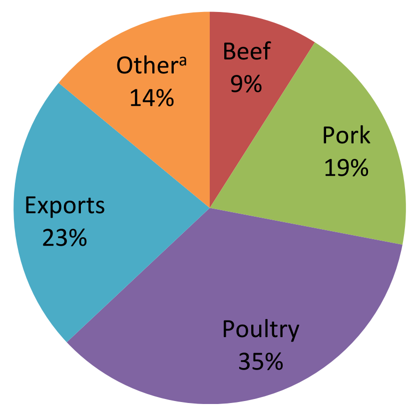
With respect to the FCIP, the crop insurance has become increasingly important for corn farmer over time due to increased subsidization. Farmers have also been switching coverage from yield to revenue insurance while also increasing the level of coverage, with the most common level of coverage at 70% (Ibid). When taking into account that most corn farmers rotate with soybean (Ash, Livezey, & Dohlman, 2006), any policy change that affects corn farmers also impacts soybean farmers. This in turn can reverberate through the meat commodity chains.

2.3 Soybean and Soybean Meal

Soybean is second only to corn in both area planted and total value of production. In 2014, total acreage amounted to 83,701,000 with a value of $40.2 billion. Like corn, it is primarily grown in the Upper Midwest of the United States where conditions are best for achieving high yields (Ash, Livezey, & Dohlman, 2006).

Soybean is not typically used for meat production. It's relevancy to the livestock industry is derived from its co-product, soybean meal. Approximately 90% of the soybean utilized domestically is crushed into soybean meal and soybean oil (Masuda & Goldsmith, 2009, p. 5). An advantage of soybean meal over other oilseed meals is the high yield relative to oil when crushing soybean. Soybean meal consists of 80% of the total soybean (Houck, Ryan, & Subotnik, 1972). Virtually all domestic soybean meal is used for livestock feed (See Figure 2.12). Less than 1% of the global soymeal supply is allocated for other uses than feed (Masuda and Goldsmith, 2009).

Figure 2.12. Soybean meal consumption by sector



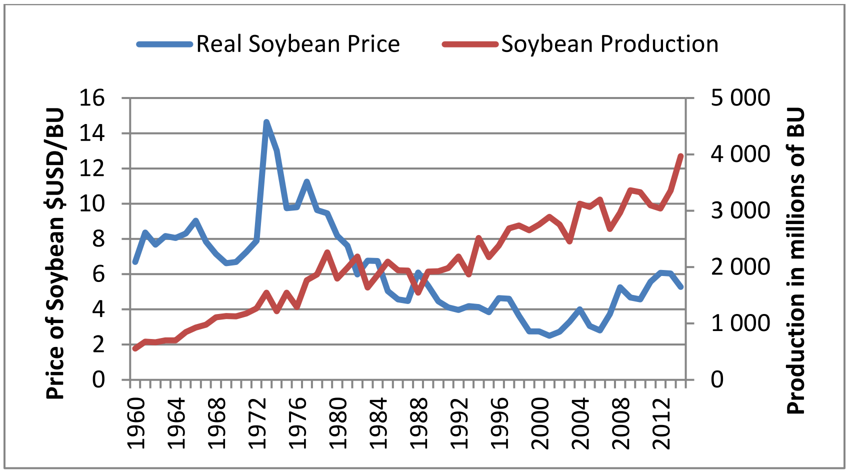
[a] Other includes dairy and egg sectors

Adapted from (United Soybean Board, 2012)

As with corn we notice a similar trend in production and prices of soybean beginning in the early 1970s with respect to prices and supply (See Figure 2.13). The real price of soybean decreased by 83% from 1973 to 2001, while production increased by 87% during the same period. While this is certainly not enough evidence to the claim that cheap prices and high levels of production were caused by subsidies, it does support the argument that the subsidies have contributed to this paradigm[11]. Regardless this is a setting under which livestock producers feeding their animals corn and soybean meal were benefiting from reduced costs and increased prices of feed.

[11] The author reiterates that there are other explanations for this phenomenon, such as technological change, increased economies of scale, and changes in consumer preferences.

Figure 2.13. History of soybean production and prices

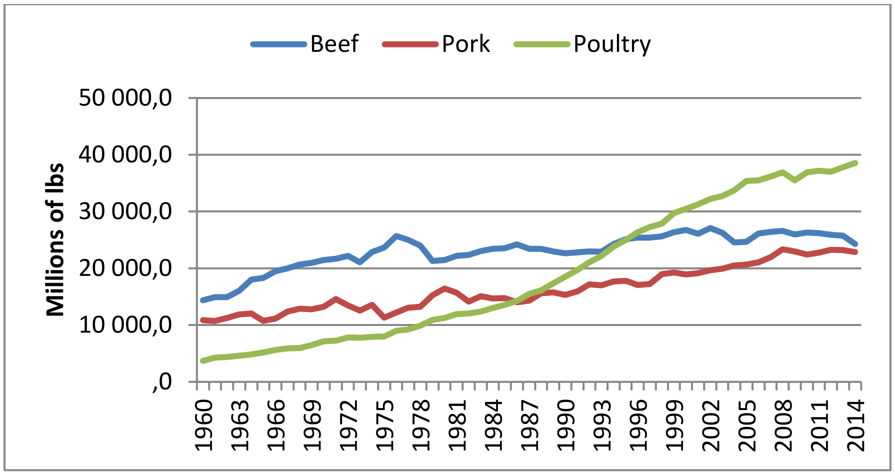


Adapted from (farmdoc.illinois.edu).

2.4 The Meat Sector

Like the corns and soybean markets the US meat sector has been characterized by steadily declining prices and increasing production over the past decades (USDA ERS). From 1970 to 2014 beef, pork, and poultry production increased from about 42 billion pounds to over 85 billion (Figure 2.14). This period has also experienced intensive consolidation of meat industries, especially in the poultry and pork sectors (RTI International, 2007; Starmer & Wise, 2007). Larger companies operating on smaller volumes but higher margins were better positioned to take advantage of what until very recently were feed grains sold below cost of production, giving them an advantage over farms producing their feed onsite (Wise, 2005). Consolidation allows companies to generate larger economies of scale and more cost-efficient operations (Schroeter, Azzam, & Aiken, 1997). Considering that feed is the costliest input in production, composing approximately 60%, 60% and 17% of the production costs for poultry, pork, and beef, any agriculture policy that influences lower prices of corn and soybean would be an implicit subsidy that bigger companies can capture more benefits from (Wise, 2005, p.3; RTI International, 2007, p. 1-4).

Figure 2.14. History of US meat production



Adapted from (USDA Economic Research Service)

There is now very little competition at the meatpacking and retail levels for beef, poultry and pork, which creates oligopsonistic power within the commodity chains (Azzam & Schroeter, 1995; Azzam & Anderson 1996; Azzam, 1997; RTI International, 2007; Weng 2012). Livestock operators are typically limited in who they can sell their animals to, due to geographical, contractual, and/or oligopsonistic constraints (Weng, 2012; Azzam & Schroeter, 1995; Azzam 1996; RTI International, 2007). Therefore price transition across the supply chains of meat products is important to examine. Starmer, Witteland, & Wise argue that the prevalence of contract farming, which has become dominant in the broiler and hog sectors, enables meat packers to impose price decreases more fully on farmers than the latter are able to capture price increases from the former (2006). However, Schroeter, Azzam, & Zang found in the beef industry that the retail level has stronger negotiating power than the processing level, the latter of which exhibits price-taking behavior (2000).

The rest of this section will cover each of the meat markets individually and in more depth.

2.4.1 Beef

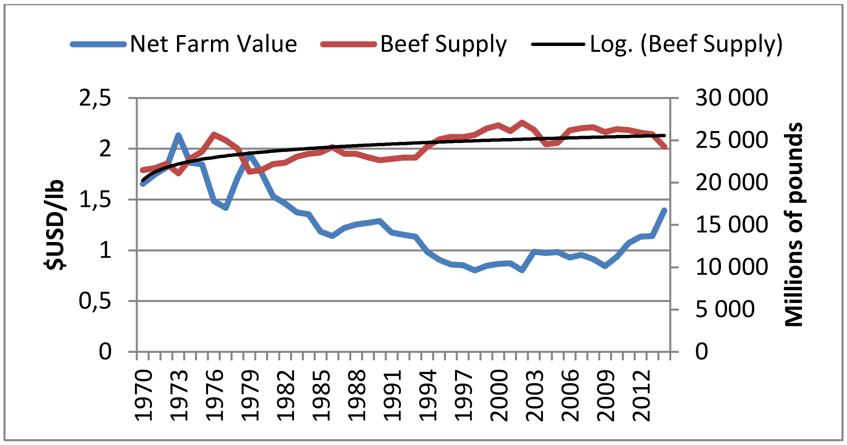
This paper follows RTI International's accounting of the US beef industry (2007). The only difference is that this paper considers the weaning and backgrounding phases of cattle production to be the same, as they are both predominantly pasture fed in both time periods. The cattle are sold either in the spring or fall to feedlots as feeder cattle. These operations are characterized by their high degree of specialization in which closely confined cattle are fed energy and protein-rich diets – mostly corn, distiller's grain and soybean meal – and are sold on to slaughterhouses, where the animals are processed into cuts before being sold on to wholesale and retail markets.

The sector is marked by increased concentration in production with larger operations becoming more dominant. About 79% of cow-calf farmers have operations of 100 cows or less, but operations of 500 cows or more supply 42% of cattle inventories (Ibid, p. 1-8). The feedlot sector is even more concentrated, with operations of 1,000 cattle or more making up 2.6% of operations but 85% of the market supply (Ellis, 2009, p. 9). Meanwhile, the top 4 beef packers in the US slaughter more than 80% of the cattle (RTI International, 2007, p. 1-11[12]). This demonstrates that market concentration increases the farther down the supply chain.

The history of US beef prices and quantities reflects this paradigm. With the first graph (Figure 2.15) we see both the price of the retail weight equivalent of cattle at the farm level along with the retail supply of beef over that time. A logged trendline has been added to demonstrate the rate of change. The price of retail beef began to sharply decline after 1973, except for a brief spike in prices at the turn of the 1980s. From 1973 to 2001 the real price of retail beef declined 62%, yet from the trendline we can see that beef supply increased, if slightly. The primary sources of this drop in prices discussed in the literature were a decline in consumer demand for beef (Marsh, 2003), technological change at the farm and slaughterhouse levels (Brester & Marsh, 2001), and cost reducing consolidation (RTI International, 2007). However, the significant drop of feed grain prices during this period must have also played an important role, not only as a reduction in costs, but as an incentive to consolidate (Starmer, Witteman, & Wise, 2007).

[12] Note that in the structure of RTI International reports the number before the hyphen represents the chapter, not a page number.

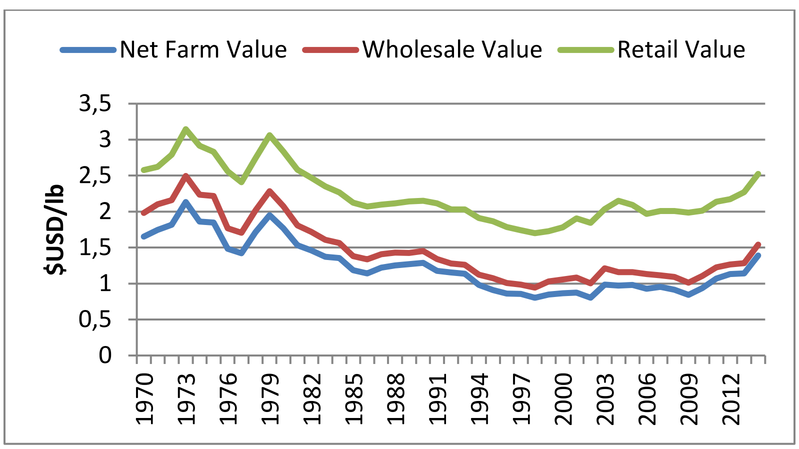
Figure 2.15. History of US beef supply



Adapted from (USDA ERS).

On a sector by sector level, we can clearly see that the wholesale-retail price margin increased while the farm-wholesale margin decreased (Figure 2.16). From 1973 to 2014 the former more than doubled from 26% to 63% while the latter diminished from 17% to 11%. This follows the finding by Schroeter, Azzam & Zang previously mentioned that retailers appear to exert more market power than the meatpackers (2000).

Figure 2.16. History of US beef prices



Adapted from (USDA ERS).

2.4.2 Poultry

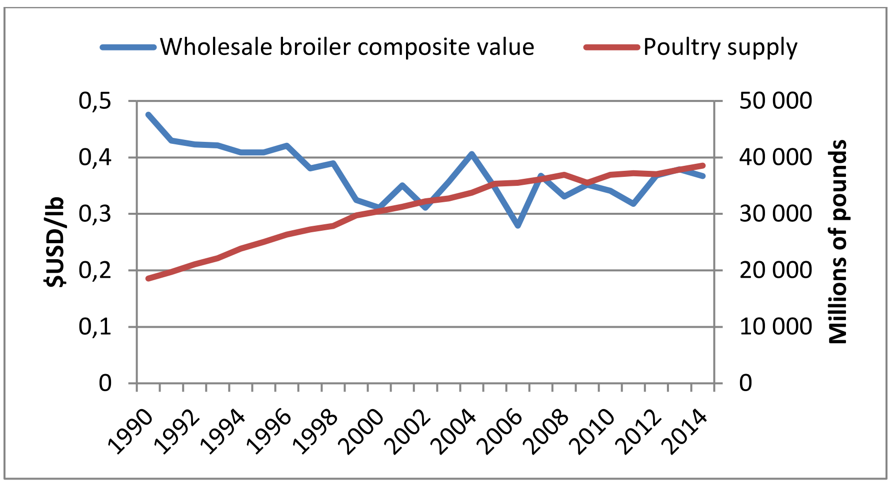
The description of the boiler market, which represents the bulk of the overall US poultry market, follows Weng (2012) and Starmer, Witteman, & Wise (2006). The industry is vertically integrated in its entirety where large agribusiness firms, “oversee all links in the production chain, including breeding and the hatching of chicks, the milling of feed grain, the grow-out stage, and the processing and packaging of finished birds" (Starmer, Witteman, & Wise, 2006, p. 12). Production is coordinated between these firms and independent growers via contractual arrangements (Weng, 2012). Integration has served the agribusiness firms on multiple levels: (1) integration reduced transaction costs within the chain (Starmer, Witteman, & Wise, 2006), (2) quality control and consistency was better achieved by firms exerting control over the entire production process (Henry & Ruanikar, 1960; Bugos, 1992; Paul, 1999; MacDonald et al., 2004), (3) larger firms are more apt to introduce technological change and growers under contract face less risk than otherwise in adopting these changes (Knoeber, 1989; Bugos, 1992; Knoeber & Thurman, 1995; Paul, 1999; MacDonald, et al., 2004). Moreover, contractual arrangements eliminated spot market risks for growers and volume control problems for processors (Paul, 1999; Aho, 1999). The result were incredible efficiency gains in broiler production that saw production costs decline 90% from between 1947 and 1999 (Aho, 1999; MacDonald et al., 2004), and the broiler sector attained its dominant position in the meat market today (Starmer, Witteman, & Wise, 2006).

Feed costs compose 60% of total production costs for broilers, with raw corn and soybean making up 78% of that feed cost (Ibid), which means that these two inputs represent nearly half the total cost of production. Therefore the subsidies in the preceding decades, which enabled farmers to sell their crops below the cost of production, implicitly subsidized poultry farmers. Starmer Witteman, & Wise estimates that from 1997 to 2005 the broiler industry saved $1.25 billion annually in feed costs due to agriculture policy in that period (2007, pp. 3-4).

Due to the highly integrated nature of the broiler industry, both in terms of company control and contractual relationships between firms and growers, competition in the industry has become minimal. The top 4 processing firms concentration ratio in 1997 was 58.52%. While this is smaller than for the beef and pork sectors (80% and 68% respectively) (Weng, 2012, p.4), this does not take into account the impact the contractual nature of the industry has on farmer choices. For one, the proliferation of contractual arrangements has crowded out other venues for farmers to sell their livestock (Starmer, Witteman, & Wise, 2007). Second is that contract terms are usually private, which prevents farmers from being able to compare prices and conditions across firms, thereby limiting their bargaining power (Carstensen, 2003). The result is a market structure in which processors are able to push downward price trends onto growers (Lee, 1996; Morison, 1996), but farmers have difficulty in capturing market price increases (Perry, Baker & Green, 1999).

Unlike for beef and pork, the pricing data found for poultry only goes back to 1980 for retail and 1990 for wholesale value, but it is still possible to see the important trends using only the data from 1990. Figure 2.17 shows a clear decline in broiler prices while the supply continues to increase[13]. This is what one would expect to see given the information just provided regarding the integration and cost cutting of the broiler industry. Of more interest is the history of pricing at both the retail and wholesale level of broilers (Figure 2.18). Unlike for beef and pork, the price retail-wholesale price margin has actually declined over time[14], suggesting that processors exhibit more market power than retailers. This is especially pronounced in the last 15 years during which the wholesale-retail margin declined from 190% to 126%.

Figure 2.17. History of US broiler supply

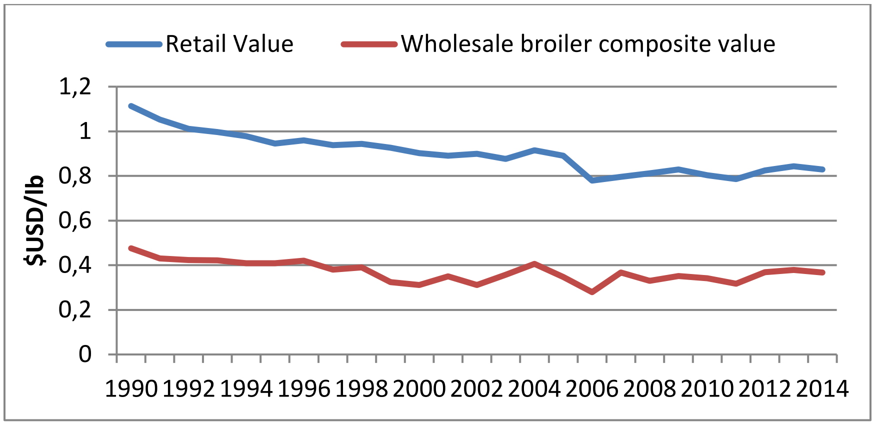


Adapted from (USDA ERS).

[13] For a longer period look at broiler supply please refer back to Figure 1.14.

[14] The trendlines give a negative linear slope of -0.001 for retail prices and -0.0004 for wholesale prices.

Figure 2.18. History of US broiler prices



Adapted from (USDA ERS).

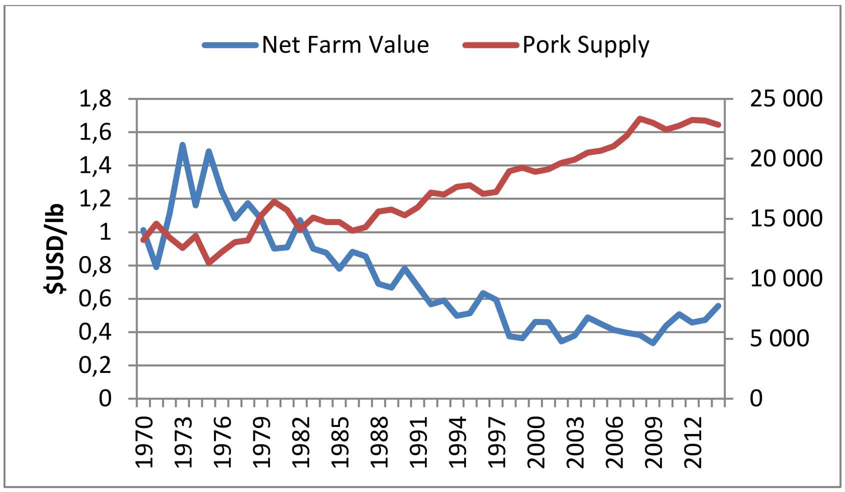
2.4.3 Pork

The exposition of the US hog and pork sector follows RTI International (2007) and Trist & Wise (2010). While there are three stages in hog production: farrow-to-wean, wean-to-feeder, and feeder-to-slaughter, these divisions are not so distinct in reality (RTI, 2007). As such, this paper and the corresponding model account for farrow-to-feeder as one stage. Similar to poultry feed costs compose about 60% of total production costs (Ibid, p. 1-4). At the farm level much of the efficiency improvement has come from improving sow fertility, both in terms of litter size and number of litters in a sow lifetime (Ibid, p. 1-8).

The structure of the hog industry resembles the broiler sector, though it is not nearly as integrated because production and marketing contracts are becoming more commonly used between processors and farmers. On a growing scale, packers own their hogs and contract with producers as a source of labor and infrastructure (RTI International, 2007; Wise & Trist, 2010). Meanwhile, there has been significant concentration of the hog and pork sector at both the farm and processing level. From 1966 to 2001, while the number of hogs remained consistently at the same level, the number of farms reduced from 1 million to just over 80,000, with less than 5,000 of those farms accounting for more than half the total hog population. The largest operations house 16.7 hogs per hectare (Osterbgerg & Wallinga, 2004, p. 1703). Feed savings have likely aided in this consolidation, as factory farms who purchase feed below production costs have a competitive advantage over operations that grow their own feed, as the latter are not eligible for subsidies on crops grown to feed their own livestock (Starmer, Witteman, & Wise, 2007). The processing sector is also concentrated with the top 4 firms controlling 68% of the market (Weng, 2012).

The historical data closely resembles that of the beef sector (Figures 2.19). A key difference is the clear increase in price despite a significant price decline over the time period. Again the subsidization of corn and soybean likely played a role in this dynamic, as it contributed to reduced feed costs for hog farmers (Starmer, Witteman, & Wise, 2007).

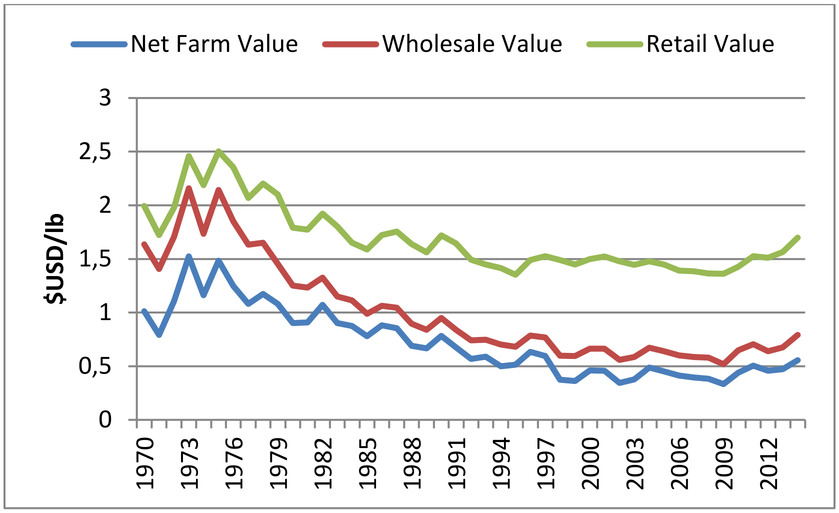
Figure 2.19. History of US pork supply



Adapted from (USDA ERS).

The pricing history of pork reveals a paradigm which differs from the beef sector (Figure 2.20). The increasing gap between retail and processing prices is clear. From 1975 to 2014 the processing-retail price margin increased from 17% to 114%. This suggests that there is an even greater market power differentiation between retail and processing in the pork sector than in beef. Also of note is that what may appear to be a diminishing farmer-wholesale price margin is actually misleading. Following a period of decline until the mid-1980s, the price margin began to increase again. From 1975 to 1986 the farm-processing price margin dropped from 44.5% to 21%. From that year on the spread grew erratically, but since 1997 the price margin has never dropped below 37.7% with only 4 of those years being below 47%. This may suggest that the increased concentration in the packing sector and use of contracts has deteriorated the negotiating power of hog farms, even as they grow in size.

Figure 2.20. History of US pork prices



Adapted from (USDA ERS).

2.5 Ethanol and Distiller's Grain

When discussing the impact of policy choices on corn on meat markets it is important to take the ethanol sector into account. The ethanol industry represents nearly 40% of corn disappearance in the United States which is significant competition for feed grain with livestock producers (Schnepf, 2013, p. 9). A co-product of the ethanol production process in the dry milling process, which constitutes more than 90% of US mills, are distiller's grains[15], which is a source of both energy and protein (Hoffman & Baker, 2010). This section will provide an overview of both ethanol and the distiller's grain market.

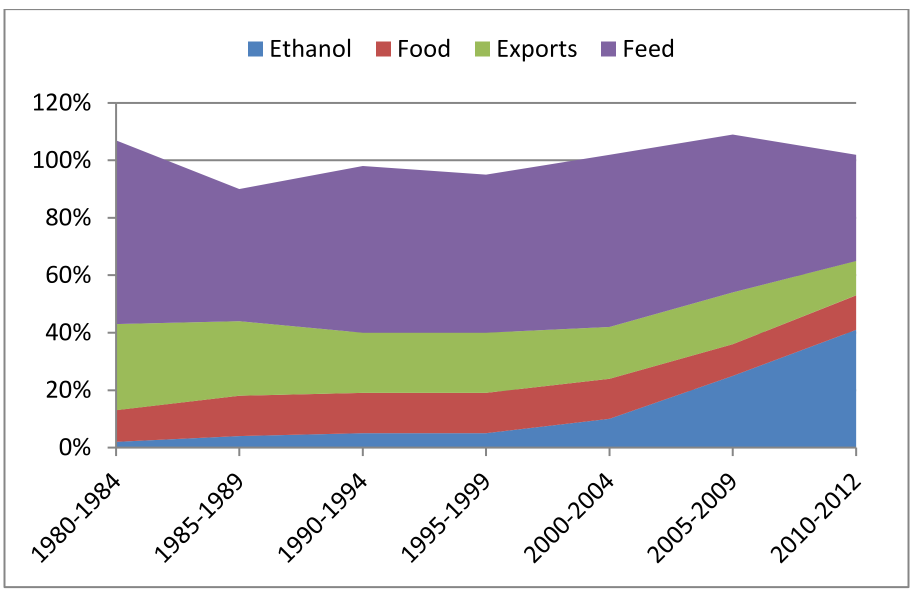
Ethanol is an alcohol that is produced during the fermentation and distillation of sugars. Corn has a high starch content, which can be easily converted into sugar and then used for making ethanol. The dominance of corn as the primary feedstock for US ethanol production has been due to its historically cheap price, which is critical for producers, as feedstock costs represent more than 50% of total ethanol production costs[16] (Schnepf, 2007).

[15] Note that there are several types of distiller's grains with varying properties. This paper will refer to the most common form of distiller's grain, the dried distiller's grain with solubles (DDGS), or just the general term of distiller's grain (DG).

[16] This figure is taken after co-products like DDGS are sold.

The growth of the ethanol industry has been dependent on a history of targeted government policies. Production has increased over 600% since the early 2000s (Schnepf & Yacobucci, 2013, p. 1). The salient policy in present times is the expanded Renewable Fuels Standard (RFS2), which was enacted in the 2007 Energy Independence and Security Act. This law mandates that as of 2015, fuel blenders must utilize 15 billion gallons of corn ethanol in the production of gasoline (Schnepf & Yacobucci, 2013). One bushel of corn is required to produce 2.8 gallons of ethanol, so this law essentially mandates the allocation of about 5.35 billion bushels of corn to ethanol production, which is a significant amount of inelastic demand for corn. Schnepf & Yacobucci discuss the correlation between increasing corn prices and ethanol demand since 2005 (2013). However, there is a credit system to the RFS2 mandate, in which blenders who utilize more ethanol than required by the quota, receive RIN credits that can be used to help meet the quota in the following year. These credits are also eligible to be sold on the open market to other blenders yet to meet their quota (Ibid). It is possible to see the growth of corn consumption by the ethanol sector to the detriment of the meat sector and exports in Figure 2.21.

Figure 2.21. Corn consumption by sector[17]



Adapted from (Schnepf 2013).

[17] Total values over 100% can be attributed to consumption of stocks.

One important aspect to be discussed with regards to potential ethanol consumption is the "blend wall." Ethanol is compatible with gasoline infrastructure so long as it consists of no more than 10% of the fuel (E10). Until now, carmakers have refused to offer warranties on cars running on fuel with more than 10% ethanol blend. Coupled with infrastructural constraints this creates an effective wall which inhibits the growth of further ethanol demand (Schnepf & Yacobucci, 2013). It is estimated that the current RFS2 mandate of 15 gallons exceeds the current "blend wall" demand (Schnepf, 2013). Without a change of the ethanol blend standard or rapid increase in transportation, future growth of the ethanol sector is to be severely limited.

Even though the ethanol industry represents significant competition with the meat sector for corn, it also contributes DDGS as another feedstuff for livestock[18]. To a degree this even represents a symbiotic relationship, as selling DDGS is "crucial to controlling ethanol production costs, as they offset feedstock costs" (Hoffman, Baker, Foreman, & Young, 2007). Due to the fixed output relationship between ethanol and DDGS, increased production of the former results in an increased supply of the latter (Hoffman & Baker, 2010). However, the substitutability of DDGS for corn and soybean is limited by the digestive capacity of livestock, especially monogastric animals like pigs and poultry, which have trouble digesting the fiber dense food (Hoffman, Baker, Foreman, & Young, 2007).

2.6 Externalities of Industrial Meat Production

The industrialization and intensification of meat production in the United States has not been sufficiently regulated to protect human health or the environment. Kanaly et al., claim that these large scale feeding operations have produced significant and extensive consequences, for which the costs have been externalized (2010). They further argue that externalities from the agriculture sector carry four distinct features: "(1) their costs are often neglected, (2) they often occur with a time lag, (3) they often damage groups whose interests are not well represented, and (4) the identity of the source of the externality is not always known (Pretty et al., 2000; Pretty et al. 2003)" (Kanaly et al., 2010, p. 7).

It is beyond the scope of this paper to extensively address the different types of externalities and their economic impacts, but a brief overview will be provided. Two specific

[18] There is a fixed proportion of ethanol to DDGS production which is 0.18 bushels per gallon.

externalities that will be discussed are greenhouse gas (GHG) emissions, and the negative impacts on human health caused by intense animal contact and antibiotic resistant bacteria.

The primary sources of GHG emissions from the livestock sector is from enteric fermentation by ruminants (mainly cattle in the US), and manure and urine excretion (Scollan et al., 2010). The US Environmental Protection Agency estimates that 3% of total US GHG emissions come from cattle alone and that each feedlot cattle produces approximately 46kg of methane a year. With an approximately 13 million feedlot cattle, that amounts to 600 million kg of CH_4 (2014), a GHG that traps heat 20x more effectively than carbon dioxide (Kanaly, et al., 2010). Addressing GHG emissions from livestock is key component of limiting the impact of climate change (Scollan et al., 2010).

There is cause to be worried about the human health implications of the large scale animal feeding operations. The increased amount and intensity of human contact with livestock increases the chances of disease transmission. In fact, the majority of emerging human diseases have been sourced by animals (Taylor et al., 2001). Of note are the H1N1 and H5N1 flu viruses, with which the first infected humans contracted the diseases from contact with animals (pigs and poultry). At the time of this paper's writing there has been significant coverage of the MERS virus, which is currently believed to have originated from contact with camels (US Centers for Disease Control and Prevention).

Not only are humans vulnerable to contracting diseases from animal contact, industrial feed practices are also mitigating our ability to combat bacteria with modern antibiotics. Many of the antibiotics used on livestock are also applied to humans thereby increasing the chances of cross-resistant bacterial strains emerging (Kanaly, et al., 2010). Livestock are given several times the amount of antibiotics than are consumed by people in the United States, much of which is used to promote animal growth and preemptive treatment of illness, which is necessary given the unsanitary and stressful conditions they are exposed to in industrial operations (Osterberg, D., & Wallinga, D., 2004). The costs of a major outbreak of an antibiotic resistant bacterium could be staggeringly high. Frenzen, Drake, & Angulo, estimated the annual cost of E-Coli O157 to be US$405 million (2005).

There are also many externalities indirectly associated with industrial meat production. The production practices for livestock feed, which frequently consists of intense use of fertilizers and pesticides. This can cause problems not only locally, but over long distances as well (Runge, 2002). The most extreme example of this is the hypoxic zone in the Gulf of Mexico, fed primarily by the fertilizers washing downriver from the Midwestern Corn Belt (Osterberg, D., & Wallinga, D., 2004). Kanaly et al., argue that reducing crop production for animal feed would be one of the most potent measures for mitigating GHG emissions from the agriculture sector (2010, p. 8).

Other studies have attempted to estimate the costs (monetary and otherwise) of externalities of industrial meat production, monetarily and otherwise. Sneeringer found that a doubling of industrial livestock production in a region increases infant mortality by 7.4% (2009, p.124). Daley et al. found in their meta-analysis comparing the health impacts of grass-fed to grain-fed beef, that the former is better for human health. Grass fed beef consists of healthier fatty acids, contains less harmful cholesterol, increased antioxidant content, and enhances the precursors for vitamins A and E (2010). Pretty (2005) estimated the externalities of industrial meat production in the UK to be 64.8, 12.8, and 5.7 pence per kg of beef, pork, and poultry. Nguyen, Hermansen & Mogensen estimate the environmental costs of industrial pig production to be 1.9 Euro per kg. It is clear that the costs of industrial meat production is not being fully captured by producers, and that it may be desirable to implement policies that make them internalize more of these externalities.

To summarize this chapter, the author has attempted to convey the interdependence of the US feed grains, livestock, and ethanol sectors and the role of agriculture policy within this dynamic. This paper has attempted to illustrate how changes in agriculture policy coincided with steep declines of soybean and corn prices while their supplies continued to grow, a phenomenon that would prove beneficial for large scale livestock producers contributing to social and environmental costs not paid for by these operations.

The author has also attempted to provide a basic framework for understanding how insurance rate premium subsidies can affect the supply of corn and soybean. By both reducing costs and risks of production, microeconomic theory suggests that farmers are incentivized to expand their production given an increase in these subsidies. Taken in reverse, a reduction in subsidies should result in a decrease in corn and soybean supply, causing increased costs for meat producers, which in turn would reduce meat supplies. Therefore, decreasing insurance premium subsidies for corn and soybean may be a useful policy measure to limit the externalities caused by industrial meat production.

Chapter 3 - Literature Review

While it can be useful to analyze a multimarket model using a flow chart, such as from Figure 1.1 in Chapter 1, they do not, "imply causality in the determination of the endogenous variables of the model. In general, all equations are simultaneous and the model must consequently be solved jointly for all the endogenous variables" (Sadoulet & de Janvry, Chapter 11, pp. 6-7). It is with this in mind that Chapter 3 covers the relevant literature for this paper. The first part will provide a brief introduction to the equilibrium displacement model. The second section discusses the theory and development of the (S)EDM framework. The third section of the will discuss prior research of special relevance to this paper. The overall intent of this chapter to communicate the utility of equilibrium displacement models to answer the question driving this paper.

3.1 Introduction to Equilibrium Displacement Models

The EDM framework began with Muth (1964) who wanted to develop a framework for analyzing an industry with vertically related markets. Muth demonstrated the framework for a single commodity 2-factor model, with both inputs having their own supply and demand functions. Gardner's work (1975) expanded on Muth's model to analyze how exogenous shocks on demand, supply, and input demand of food affected the farm-retail price spread. Halloway (1991) then undertook an analysis using Gardner's general framework to test for oligopolistic power.

EDMs have most frequently been used to analyze the price, quantity and welfare impacts of policy scenarios (Sumner & Wohlgenant, 1985; Ambarwati et al., 2006; Brester, Marsh, & Atwood, 2006; Dhoubhadel, Azzam, & Stockton, 2015; Lusk, 2015). Another area of study has been the impacts of research and development or marketing (Mullen, Alson, & Wohlgenant, 1989; Lemiuex & Wohlgenant, 1990; Halloway, 1991; Wohlgenant, 1993;; Zhao et al., 2000). More recently EDMs have been used to analyze the impact of climactic shocks on agriculture (Fathelrahman, Davies, Davies, & Pritchett, 2014; Dhoubhadel, Azzam, & Stockton, 2015).

A previous EDM that examined the interdependence of the grain, oilseeds, livestock, and ethanol markets are those of Bhattacharya, Azzam, and Mark (2009). Specifically, this paper investigates how the impact of a demand shock from the ethanol sector reverberates through the other markets. The increased demand for corn caused an increase in the price of the crop. This led to a decrease in demand for corn by the livestock sector, which responded by more of other feed crops. The movement from corn consumption by the livestock sector was reinforced by the increased production of distiller's grain from the ethanol sector. This was especially important for the beef and dairy industries because of the cow's better ability to digest DG.

While the results from this study are valuable because the directional changes of prices and quantities are similar to those expected by this paper, it is not possible to directly relate the study by Bhattacharya, Azzam, and Mark to this paper. The shock they employed is an indirect increase in corn demand via more ethanol production rather than a direct negative supply for the crop (as well as soybeans).

3.2 Stochastic Equilibrium Displacement Models

The description of equilibrium displacement models follows that of Piggot (1992), Zhao et al., (1997), and Wohlgenant (2011). An EDM is a system of equations in logarithmic differential form which enables comparative static analysis from the movement of the initial equilibriums given a shock to one or more parameters in the system (Wohlgenant, 2011). In other words, it is a system of equations that have been totally differentiated and expressed in elasticities (Bhattacharya, Azzam, & Mark, 2009). What this means is that following a percentage shock to one or more parameters in the system (i.e. insurance premium subsidies), the percentage changes of price and quantities are calculated for the system of equations to reach a new equilibrium. An important aspect of an EDM is that it makes no assumptions about the functional form of the supply and demand equations, as the relative price and quantity changes are estimated using linear elasticities as parameters (Piggot, 1992).

As an example, assume a single market model for corn:

$$\text{Supply of corn: } Q_s = S(P,Z) \qquad (1)$$

$$\text{Demand for corn: } Q_d = D(P) \qquad (2)$$

$$\text{Market equilibrium: } Q_s = Q_d \qquad (3)$$

where P is the price of corn and Z represents a vector of exogenous shocks on the supply of corn, which in this case is only the insurance premium subsidy. We then express this system of equations in log differential form:

$$\text{Supply of corn: } EQ_s = \varepsilon_s * EP + \varepsilon_{s,z} * EZ \quad (4)$$

$$\text{Demand for corn: } EQ_d = \eta_d * EP \quad (5)$$

$$\text{Market equilibrium: } EQ_s = EQ_d \quad 6)$$

where ε_s and η_d are the own price supply and demand elasticities for corn, $\varepsilon_{s,z}$ is the supply elasticity of corn with respect to the insurance premium subsidy, and E represents percentage changes of the variables. In this simple model EZ, a percentage change in the subsidy, would be shocked and the three equations would be simultaneously solved, giving EQ and EP, or the percentage change in the equilibrium price and quantity of corn.

There are multiple advantages to using the EDM. First the model parameters are elasticities, market shares, and cost shares, for which many of these values can be taken from prior research, saving researchers the time and resources necessary to recalculate these parameters (Piggot, 1993; Bhattacharya, Azzam, and Mark, 2009; Wohlgenant, 2011). Another advantage is an EDM can be easily replicated and expanded upon by other researchers unlike complex econometric models, which are often not readily shared (Bhattacharya, Azzam, and Mark, 2009).

One aspect to consider is that when the functional form of the supply and demand equations is non-linear then the approximations are prone to errors. According to Zhao et al., if one assumes convexity in the demand curve and concavity in the supply curve around the equilibrium points then the estimated values for EP will always be overestimated when $EP < 0$ and underestimated when $EP > 0$. However, no conclusions can be made with respect to the direction of errors in approximating EQ (1997, p.1246). However, when the exogenous shocks are small, so are the approximation errors (Alston and Wohlgenant, 1990), which enables the researcher to focus on the policy implications of the model rather than functional form (Wohlgenant, 2011).

A significant problem associated with EDMs is that the values chosen by the research for the elasticities and shares are assumed to be precise (Davis and Espinoza, 1998). A typical way of overcoming this problem has been conducting a simple sensitivity analysis by providing a table with alternative parameter values and the different EP and EQ resulting from them. The authors highlight several issues with such an approach: (1) given different sets of parameters there is ambiguity regarding the true values of EP and EQ. (2) Even though having a set of values may be more informative than a single point, no information is provided regarding central tendencies. (3) It is impossible to determine the statistical significance of the results. (4) Any results are at the discretion of the parameters chosen by the researcher, so there is a concern for researcher bias (p. 870).

The authors propose simulating the model with a distribution applied around the priori parameters chosen. Using sampling techniques posterior distributions of EP and EQ can be generated, which then allow the researcher to utilize the central tendencies and dispersion to generate the confidence intervals and p-values to test various hypotheses regarding EP and EQ (Ibid). One difficulty this paper has had in following this framework is with respect to the fourth issue brought up by Davis and Espinoza regarding researcher bias in the chosen parameter values due to a general lack of available elasticities. Instead of using multiple values for given elasticities, when available, the research chose the elasticities that would cause the most significant difference from the initial hypothesis[19]. For example, if multiple values were available for the elasticity of retail beef supply, the one that would cause a bigger change in equilibrium quantity and price was chosen. This is because the research is based on the assumption that insurance premium subsidies affect the feed markets, yet to the author's knowledge there has been no prior econometric estimation of the elasticities for these subsidies on soybean and corn production. The elasticities used were therefore calibrated by the author and thus likely influenced by the researcher's own biases. However, the reader should recall that the working hypothesis is that the impact of these subsidies is not enough to significantly influence the meat markets. Therefore, if the hypothesis is confirmed using elasticities more likely to disprove it, the findings should have more validity.

Chebyshev inequalities are constructed at a given confidence level to produce confidence intervals for the mean EP and EQ values obtained in the simulation. As discussed by Davis and Espinoza:

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[19] The exceptions are the supply elasticities for corn and soybean, which will be discussed in the next chapter.

> Chebyshev's inequality is in general form prob($L \leq C \leq U$) $\geq 1 - 1/k^2$, where the lower bound is $L = \bar{x} - k\psi$, the upper bound is $U = \bar{x} + k\psi$, $\bar{x}$ is the mean of the observations on any variable x,ψ is the standard deviation of the variable x, k is a constant scaling variable for the standard deviation, and C is a hypothesized value of x. (1998, p. 875)

We then solve for k at a specified confidence interval, w, where $1 - 1/k^2 = w$. The value for k is then plugged in to the equations for U and L to generate the w confidence interval for the estimated mean values. To find the max p-values for the hypothesized value of C, we find k so that $\bar{x} \pm k\psi = C$, where the operator sign is + if $\bar{x}$ is negative – when otherwise. We then solve for the max p-value = $1/k^2$ (Ibid). However, when C =0, so that the null hypothesis is H_0: x = 0 this process simplifies so that the max p-value = $1/(\bar{x} / \psi)^2$. With the p-value it is possible to determine the statistical significance of the results. In conclusion the SEDM provides more detailed results than the basic EDM.

3.3 Supply Side EDM Studies of the Relevant Markets

Previous research this paper gives special attention to are those of Lusk (2015) and Dhoubhadel, Azzam & Stockton (2015). The former used an EDM to analyze the impact of eliminating insurance premium subsidies on the welfare of producers and consumers, while the latter analyzed the impact of a drought on the US grain, oilseed, and livestock markets. The model used in this paper is also based on this research.

To the knowledge of this author, Lusk is the first to quantify the market impact of insurance premium subsidies. Lusk implemented an EDM to analyze the welfare impacts of three policy scenarios on different sectors of the agro-food economy. The one discussed by this paper is the elimination of the entire insurance premium subsidy program. The model links 9 retail goods with 24 vertically integrated and interrelated inputs. For example, corn can be used as an input to produce cereals or fed to livestock, which are then an input for producing meat.

What is especially interesting regarding Lusk’s work is his approach to estimating the supply impact of eliminating insurance premium subsidies, in which the supply shock is assumed to be the ratio of the total subsidy to the commodity’s total cost (p. 35). As a percentage shock, the total removal of insurance premium subsidies amounts to 5.553% and 5.11% reduction for corn and soybean supplies. The model used in this paper incorporates a different approach for calculating the elasticity of the insurance premium subsidy, which will be discussed in the next chapter.

Unfortunately, Lusk did not provide the equilibrium changes resulting from the shock, rather focusing on welfare changes. However, the author does state that corn prices increased by 4.75%. A key finding is that every group in the model other than tax payers benefit from the subsidies, which would suggest why the subsidies persist despite an overall net benefit from removing them (p.45).

The research in this paper differs from Lusk in several important ways: (1) By eliminating the entire program the impact on corn and soybean would be mitigated, as farmers are incentivized to switch to other crops still eligible for insurance premiums. (2) Lusk's model allows for more crop substitution (7 in total) including wheat and barley. This paper only includes corn, DDGS, and soybean meal, which are the bulk of inputs used as animal feed. (3) The results in Lusk's research are focused on welfare impacts, whereas this paper is concerned with price and quantity changes.

As stated previously, the model used in this research is based on the prior work by Dhoubhadel, Azzam, and Stockton (2015). The authors wanted to evaluate the impact of an RFS mandate waiver and RIN credits on the grain, oilseed, and livestock markets in the event of a drought. While the model and key differences between their model and this paper's will be presented in the next chapter, their results with respect to the impact of a drought disallowing for the RIN credit program will be presented here. The reason for analyzing the non-baseline scenario is that, as the authors found in their results, allowing for RIN credits makes ethanol demand more elastic, which in turn causes less movement from the original equilibrium for the corn market. Again, this paper has attempted to choose scenarios that are most likely to contradict the stated hypothesis in the first chapter; that reducing subsidies will have a minimal effect on meat markets.

The authors found that a drought causes a 2.9% and 1.9% reduction of corn and soybean quantities and corresponding 8.8% and 5.1% increase in prices. The impact on soybean meal was even more pronounced with a -5.5% and 7.4% change in quantity and price. Contrary to what one may expect, the price of DDGS decreased by 1.6%[20]. While quantities of the poultry and hog industries were barely affected with small price increases, the beef industry was severely affected by the drought. Quantities decreased by 10.4%, 9.1%, 6.8%, and 3.1% and prices increased 5.4%, 3.4%, 6.3%, and 4.9% from the farm to retail levels. However, it should be noted that in their model, the supply of cattle at the farm level is affected by a drought due to reduced availability of pasture, which would explain the farm level experiencing the biggest shock of the 4 levels of the beef chain.

The intent of this chapter was to convey the utility of using an equilibrium displacement model to answer this paper's research question of how insurance premium subsidies for corn and soybean impact livestock markets in the United States. The EDM enables the researcher to simultaneous solve all the equations for the important submarkets in the grain, oilseed, livestock, and ethanol sectors given an exogenous percentage shock allows for qualitative and quantitative analysis (Bhattacharya, Azzam, and Mark, 2009).

[20] It should be noted that the authors estimated a negative elasticity for corn demand from the livestock sector with respect to the price of DDGS, but had a positive elasticity in the reverse relationship. This was due to the fact that DDGS can be used as both a protein and energy source as well as data constraints when estimating the elasticities (Dhoubhadel, 2015). However, it likely explains what may seem an counter-intuitive price movement for DDGS.

Chapter 4 - Model Specifications

This chapter discusses the model used by the paper. The first section provides an overview of the structural model including the market sectors, supply and demand equations, and key assumptions of the model. The second section will discuss the EDM, how the elasticities were chosen and calibrated, and the key differences from the model implemented by Dhoubhadel, Azzam, & Stockton.

4.1 The Structural Model

Following Dhoubhadel, Azzam, & Stockton (2015, pp. 83-84), the structural model consists of three submodels: (1) the meat sector consisting of beef, pork, and poultry, (2) the grains and oilseed sector consisting of corn, soybean, soybean meal, and distiller's grains, and (3) the ethanol market[21]. Retail meat demand consists of supermarket and consumption out of the home (i.e. restaurants). Demand for each segment of the supply chain upstream from retail is the conditional demand from the downstream level. For example, the demand for feeder cattle at the farm level is the derived demand from feedlots. The model assumes fixed proportional input relationships between nonmaterial inputs and raw material inputs. The nonmaterial inputs are assumed to be perfectly elastic, and therefore are not included in any of the supply or demand equations. Livestock producers are able to substitute between corn, soybean meal, and DDGS at the feedlot level for cattle, farm level for hogs, and processing level for poultry. The only exogenous shifters considered in the model, denoted by Z_i, are the reductions to insurance premium subsidies for corn and soybean. A list of variable definitions can be found in Table 1.

[21] Each market was discussed in depth in the first chapter of this paper.

Table 4.1. Variable definitions

Variables	Definitions
Q_c^b	Quantity of corn for cattle producers
Q_c^p	Quantity of corn for hog producers
Q_c^o	Quantity of corn for poultry producers
Q_c^e	Quantity of corn for ethanol producers
Q_c^x	Quantity of corn for export
Q_c	Quantity of total corn
Q_{sb}^{do}	Quantity of soybean for domestic market
Q_{sb}^x	Quantity of soybean for export
Q_{sb}	Quantity of total soybean
Q_{sm}^b	Quantity of soybean meal for cattle producers
Q_{sm}^p	Quantity of soybean meal for pork producers
Q_{sm}^o	Quantity of soybean meal for poultry producers
Q_{sm}^x	Quantity of soybean meal for export
Q_{sm}	Quantity of total soybean meal
Q_{DG}^b	Quantity of DG for cattle producers
Q_{DG}^p	Quantity of DG for pork producers
Q_{DG}^o	Quantity of DG for poultry producers
Q_{DG}^x	Quantity of DG for export
Q_{DG}	Quantity of total DG
Q_E	Quantity of ethanol
Q_b^r	Quantity of beef at retail level
Q_b^v	Quantity of beef at processing level
Q_b^l	Quantity of slaughter cattle at feedlot level
Q_b^f	Quantity of feeder cattle at farm level
Q_p^r	Quantity of pork at retail level
Q_p^v	Quantity of pork at processing level
Q_p^f	Quantity of slaughter hogs at farm level
Q_o^r	Quantity of poultry at retail level
Q_o^v	Quantity of poultry at processing level
P_c	Price of corn
P_c	Price of soybean
P_c	Price of soybean meal
P_c	Price of DG
P_c	Price of ethanol
P_b^r	Price of beef at retail level
P_b^v	Price of beef at processing level
P_b^l	Price of slaughter cattle at feedlot level
P_b^f	Price of feeder cattle at farm level
P_p^r	Price of pork at retail level
P_p^v	Price of pork at processing level
P_p^f	Price of slaughter hogs at farm level
P_o^r	Price of poultry at retail level
P_o^v	Price of poultry at processing level
Z_C	Insurance premium subsidy for corn
Z_{SB}	Insurance premium subsidy for soybean

4.1.1 Corn

The structural model for corn consists of the downstream derived demand from the livestock and ethanol producers and export demand. The total demand for corn is given as the sum of these derived demand equations. Corn supply is given as a function of its own price, the price of soybean, and the insurance premium subsidy.

$$\text{Derived demand for corn from cattle: } Q_c^b = f_c^1(P_c, Q_b^s, P_{sm}, P_{DG}) \quad (1)$$
$$\text{Derived demand for corn from poultry: } Q_c^o = f_c^3(P_c, Q_o^v, P_{sm}, P_{DG}) \quad (2)$$
$$\text{Derived demand for corn from hog: } Q_c^p = f_c^2(P_c, Q_p^f, P_{sm}, P_{DG}) \quad (3)$$
$$\text{Derived demand for corn from ethanol: } Q_c^e = f_c^4(P_c, Q_e) \quad (4)$$
$$\text{Export demand for corn: } Q_c^x = f_c^5(P_c) \quad (5)$$
$$\text{Total demand for corn: } Q_c^d = Q_c^b + Q_c^p + Q_c^o + Q_c^e + Q_c^x \quad (6)$$
$$\text{Corn supply: } Q_c^s = f_c^6(P_c, P_{sb}, Z_c) \quad (7)$$

4.1.2 Soybean and Soybean Meal

The demand for soybean is composed of both domestic and export demand. The supply of soybean, like corn, is a function of its own price, the price of corn, and the insurance premium subsidy.

$$\text{Domestic demand for soybean: } Q_{sb}^{do} = f_{sb}^1(P_{sb}, P_{sm}) \quad (8)$$
$$\text{Export demand for soybean: } Q_{sb}^x = f_{sb}^2(P_{sb}) \quad (9)$$
$$\text{Total demand for soybean: } Q_{sb}^d = Q_{sb}^b + Q_{sb}^p + Q_{sb}^o + Q_{sb}^x \quad (10)$$
$$\text{Soybean supply: } Q_{sb}^s = f_{sb}^3(P_{sb}, P_c, Z_{sb}) \quad (11)$$

As discussed in chapter 1, the majority of soybean is crushed into soybean oil and soybean meal, the latter of which is used almost exclusively for livestock feed. The derived demand for soybean meal consists of the livestock and export markets. The total demand for soybean meal is the sum of these 4 equations. The supply of soybean meal is a function of its own price and the quantity supplied of soybeans.

$$\text{Derived demand for soybean meal from cattle: } Q_{sm}^b = f_{sm}^1(P_{sm}, Q_b^s, P_c, P_{DG}) \quad (12)$$
$$\text{Derived demand for soybean meal from poultry: } Q_{sm}^o = f_{sm}^3(P_{sm}, Q_o^v, P_c, P_{DG}) \quad (13)$$
$$\text{Derived demand for soybean meal from hog: } Q_{sm}^p = f_{sm}^2(P_{sm}, Q_p^f, P_c, P_{DG}) \quad (14)$$
$$\text{Export demand for soybean meal: } Q_{sm}^x = f_{sm}^4(P_{sm}) \quad (15)$$
$$\text{Total demand for soybean meal: } Q_{sm}^d = Q_{sm}^b + Q_{sm}^p + Q_{sm}^o + Q_{sm}^x \quad (16)$$
$$\text{Soybean meal supply: } Q_{sm}^s = f_{sm}^5(P_{sm}, Q_{sb}) \quad (17)$$

4.1.34 Distiller's Grains

Following the demand for soybean meal, the derived demand for DDGS consists of the demand from the livestock and export sectors. The total demand for DDGS is the sum of these derived demands. The supply of DG is fixed in proportion to the quantity of corn used to produce ethanol.

$$\text{Derived demand for DG from cattle: } Q_{DG}^{b} = f_{DG}^{1}(P_{DG}, Q_{B}^{s}, P_{c}, P_{sm}) \quad (18)$$
$$\text{Derived demand for DG from poultry: } Q_{DG}^{o} = f_{DG}^{3}(P_{DG}, Q_{o}^{v}, P_{c}, P_{sm}) \quad (19)$$
$$\text{Derived demand for DG from hog: } Q_{DG}^{p} = f_{DG}^{2}(P_{DG}, Q_{P}^{f}, P_{c}, P_{sm}) \quad (20)$$
$$\text{Export demand for DG: } Q_{DG}^{x} = f_{DG}^{4}(P_{DG}) \quad (21)$$
$$\text{Total demand for DG: } Q_{DG}^{d} = Q_{DG}^{b} + Q_{DG}^{p} + Q_{DG}^{o} + Q_{DG}^{x} \quad (22)$$
$$\text{DG supply: } Q_{DG}^{s} = 0.18 Q_{c}^{e} \quad (23)$$

4.1.4 Ethanol

Ethanol demand from blenders is assumed to be inelastic due to the RFS2 mandate and is represented by equation (24). The supply of ethanol by distillers is given by equation (25).

$$\text{Derived demand for ethanol from fuel blenders: } Q_{e}^{d} = f_{e}^{1}(P_{e})^{22} \quad (24)$$
$$\text{Ethanol Supply: } Q_{e}^{s} = f_{e}^{2}(P_{e}, P_{c}) \quad (25)$$

4.1.5 Beef

The beef marketing chain is composed of 4 submarkets from farm to retail, each with its own supply and demand derived from either the adjacent downstream or upstream level. As discussed by Dhoubhadel, Azzam, & Stockton (p. 84), the supplies are a function of material-input quantities rather than prices due to data availability for quantity transmission elasticities provided by RTI International (2007).

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[22] This is the given function for ethanol demand after the RFS2 mandate has been met. The current level of the mandate is above the demand for ethanol signified by the "blend wall," as discussed previously. Hence, at the current mandate ethanol demand is totally inelastic when RIN credits are not available.

Retail:

$$\text{Final demand for beef: } Q_b^{rd} = f_b^1\left(P_b^r, P_p^r, P_o^r\right) \quad (26)$$
$$\text{Retail supply of beef: } Q_b^{rs} = f_b^2(P_b^r, Q_b^v) \quad (27)$$

Processing:

$$\text{Derived demand for beef from retail: } Q_b^{vd} = f_b^3(P_b^v, Q_b^r) \quad (28)$$
$$\text{Meatpacker supply of beef: } Q_b^{vs} = f_b^4(P_b^v, Q_b^l) \quad (29)$$

Feedlot:

$$\text{Derived demand for fed cattle from meatpackers: } Q_b^{ld} = f_b^5\left(P_b^l, Q_b^v\right) \quad (30)$$
$$\text{Supply of fed cattle: } Q_b^{ls} = f_b^6(P_b^v, Q_b^f, P_c, P_{sm}, P_{DG}) \quad (31)$$

Feeder cattle:

$$\text{Derived demand for feeder cattle from feedlots: } Q_b^{fd} = f_b^7\left(P_b^f, Q_b^l\right) \quad (32)$$
$$\text{Supply of feeder cattle: } Q_b^{fs} = f_b^8(P_b^f) \quad (33)$$

4.1.6 Poultry

As discussed in chapter 1, poultry supply is fully integrated between the farm and processing level. Therefore this model consists of only the processing and retail supply and demand equations.

Retail:

$$\text{Final demand for poultry: } Q_o^{rd} = f_o^1\left(P_o^r, P_b^r, P_p^r\right) \quad (34)$$
$$\text{Retail supply of poultry: } Q_o^{rs} = f_o^2(P_o^r, Q_o^v) \quad (35)$$

Processing:

$$\text{Derived demand for poultry from retail: } Q_o^{vd} = f_o^3(P_o^v, Q_o^r) \quad (36)$$
$$\text{Meatpacker supply of poultry: } Q_o^{vs} = f_p^4(P_o^v, P_c, P_{sm}, P_{DG}) \quad (37)$$

4.1.7 Pork

The pork sector is more integrated than the beef marketing chain, but not as completely as the poultry industry. Therefore there are 3 segments to the pork marketing chain from farm to retail.

Retail:

$$\text{Final demand for pork: } Q_p^{rd} = f_p^1\left(P_p^r, P_b^r, P_o^r\right) \qquad (38)$$

$$\text{Retail supply of pork: } Q_p^{rs} = f_p^2(P_p^r, Q_p^v) \qquad (39)$$

Processors:

$$\text{Derived demand for pork from retail: } Q_p^{vd} = f_p^3\left(P_p^v, Q_p^r\right) \qquad (40)$$

$$\text{Meatpacker supply of pork: } Q_p^{vs} = f_p^4(P_p^v, Q_p^f) \qquad (41)$$

Farm:

$$\text{Derived demand for slaughter hogs from meatpackers: } Q_p^{fd} = f_p^5\left(P_p^l, Q_p^v\right) \qquad (42)$$

$$\text{Supply of slaughter hogs: } Q_p^{fs} = f_p^6(P_p^v, P_c, P_{sm}, P_{DG}) \qquad (43)$$

4.2 The Stochastic Equilibrium Displacement Model

As discussed in the previous chapter, total differentiation of the structural model and putting the equations in differential logarithmic form provide a system of equations representing percentage changes of the variables. For example, the equations for soybean and corn supply, the two equations in the system that are directly shocked by the exogenous variables, are as follows:

$$dlnQ_i^s - \varepsilon_i dlnP_i - \varepsilon_i^j dlnP_j = \varepsilon_i^z dlnZ_i \qquad (44)$$

where the subscript *i* represents the crop for which the supply function is specified (corn or soybean) and j denotes the other crop. $dlnQ_i^s$ is the percentage change in quantity supplied. $\varepsilon_i dlnP_i$ signifies the own price elasticity of supply multiplied by the percentage change in price of crop i, $\varepsilon_i^j dlnP_j$ expresses the cross price elasticity of supply multiplied by the percentage change in the price of the other good, and $\varepsilon_i^z dlnZ_i$ is the supply elasticity of the crop with respect to insurance premium subsidy multiplied by the percentage change in subsidy.

Except for the supply of corn and soybean, which are set equal to the value of the negative shock from a reduction in insurance premium subsidies, all equations are set equal to 0. The model can then be solved using matrix algebra. Let X be the vector (43x1) of percentage change of the endogenous variables, B the vector of exogenous shocks to the system (43x1), and A the (43x43) matrix of model parameters, consisting of elasticities and quantity shares. The system can then be written as AX = B. The percentage changes of the endogenous variables given the exogenous shock can then be solved for as $X = A^{-1}B$.

Following Davis & Espinoza (1998), a stochastic framework is implemented so that statistical confidence intervals and max-P values can be generated. This was accomplished by applying a priori normal distribution around the elasticity estimates used in the model. However, standard deviations were not available for most of the elasticity values. Therefore, this paper followed Dhoubhadel, Azzam, & Stockton (2015) by obtaining a critical t-value to estimate standard errors. Since t-values are the quotient of an estimated value by its standard deviation, by taking a critical t-value at a given confidence interval with a specified degree of freedom, the standard deviation can be extrapolated. As in the original research, this paper chose to take the t-value at *df* = 3 with a one-sided confidence interval of 0.005 in order to obtain a t-value of 5.841[23]. After calculating the standard deviations for the elasticity estimates minimum and maximum values were applied to the distributions to ensure consistent signs of the values (i.e. so that supply elasticities remains positive).

The model is solved in Microsoft Excel using the SIMETAR add-in to run 1,000 iterations the simulation (Richardson, Schumann, and Feldman, 2008). A 90% Chebyshev confidence interval is calculated at the simulated mean values for the endogenous variables along with their maximum p-values, which allows for the determination of the level at which the results are statistically significant.

4.3 Key Differences from Dhoubhadel Azzam, & Stockton and Other Notes

The first and obvious difference was the introduction of the elasticity for corn and soybean supply with respect to insurance premium subsidies. This paper took a different approach from Lusk (2015) after conferring with Jisang Yu, a PhD student at UC Davis who is researching the impact of insurance premium subsidies, and Scott Gerlt, who is responsible for the crop supply portion of the FAPRI model. Yu recommended using the own price elasticity of supply as a starting point, whereas Gerlt informed the author that the FAPRI model assumes the

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[23] This paper had originally intended to use the t-value at the confidence interval of 0.025 (3.182) to account for the fact that only one value was used for each elasticity, thereby allowing for a larger distribution of values. However, in this scenario all estimated values in the simulation were found to be insignificant, so the original t-value from Dhoubhadel, Azzam, and Stockton was used.

supply elasticity with respect to insurance premium subsidies to be 75% of the supply elasticity with respect to the net returns of each crop. Taking the value of these supply elasticities form FAPRI's database the supply elasticities for corn and soybean with respect to insurance premium subsidies was found to be about 0.16 and 0.18, respectively (FAPRI). This paper decided to take 0.7 of the own price elasticities for the two crops, which gave elasticities of .20 for corn and .18 for soybean. This will be especially important when discussing the elasticities chosen for corn and soybean at the end of this section.

The second difference was to use long-run elasticities for the parameter values. The clear difference in shocks between the two papers is that a drought has short-run impacts[24], while on the other hand, larger supply elasticities are more likely to represent the long-run implications of policy change (Lusk 2015). When long-run elasticities were not found in the literature for supply and input demand elasticities, they were calibrated based on the ratio between short-run and long-run elasticities at the level where animals were fed grains and oilseeds[25]. For example, the short-run elasticity in the literature for hog supply at farm level was 0.41 and it was 1.8 for the long-run (Lemieux & Wohlgenant, 1989). This ratio of 4.4 was then multiplied to the short-run elasticity value of the supply of hogs with respect to the price of soybean meal.

There were two motivations for following this procedure. The first was to obtain what is hoped to be realistic long-run elasticities by keeping ratio for all supply and input demand elasticities constant for the same good. The second was that some of the long-run elasticities in the literature seemed too high to be realistic. For example, in their EDM model quantifying the impact of country-of-origin labeling, Brester , Marsh, & Atwood (2004) used a short-run elasticity for poultry supply at retail level of 0.18, but the long-run elasticity was 13.1, which is about 70 times larger. It seems unrealistic that an 8% increase in the price of poultry would result in a more than doubling of poultry supply[26].

The final change to the model was introduction of cross price elasticities of supply for corn and soybean. This is not necessary since planting is likely to occur before prior to farmers having knowledge of the drought, after which it is too late to change crop allocation. However,

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[24] This is assuming actors believe the drought is idiosyncratic and not a new norm.

[25] The author applied this technique at the recommendation of the thesis adviser, Yves Surry at the Swedish University of Agricultural Sciences, in Uppsala, Sweden.

[26] Details regarding this and other calibrations made to the elasticities can be found in the Appendix-A.

agriculture policy changes have long-run implications, giving farmers time to make decisions based off policy and price changes. Therefore cross-price elasticities are important for this model, especially considering that most corn farmers already rotate with soybean.

The last point to be discussed is the selection of the long-run elasticities for soybean and corn. This paper used the long-run elasticities presented by Hendricks, Smith and Sumner (2014), which many would be likely to consider quite low (.29 for corn and .26 for soybean). In fact, their long-run elasticities were smaller than the short-run elasticities, contradicting a major tenet of microeconomics that production flexibility increases the longer the time horizon. However, the authors argue that rotational considerations for corn and soybean farmers impose restrictions on the farmer that are stronger in the long-run than in the short-run. While a farmer may choose to plant corn-on-corn in back to back years depending on price signals, doing so repeatedly will eventually reduce the productivity of the crop due to diminished nutrients in the soil and increased prevalence of pests (Ibid, p. 1). Therefore, crop rotation is more constraining on production in the long-run than in the short-run.

Regardless, this paper is aware of the potential controversy using these elasticities may have, so in Appendix-B the reader can find non-stochastic simulation results where the long-run corn and soybean elasticities provided by Harrington and Dubman (2008) from the USDA Economic Research Service. Their long-run elasticities for corn and soybean were 1.246 and 1.402, respectively. Moreover, the elasticities of premium subsidies maintained the same formula, so that they were .87 for corn and .98 for soybean. However, while there was a stronger impact on the grain and oilseed markets, the effect on the livestock markets were not divergent enough to cause any deviation from the conclusions of this paper.

Chapter 5 - Results

The results obtained were from a simultaneous 10% reduction in insurance premium subsidies for both corn and soybean. This in turn can be computed as a %2 and 1.8% shock to corn and soybean supply respectively. The results can be viewed from Tables 5.1-3, and all values are in percentages. As a reminder, the lower and upper bound values represent the 90% Chebyshev confidence intervals. This is the interval within which a least 90% of the estimated values in the 1,000 iterations fall between.

Table 5.1. Grain, Oilseed, and Ethanol Market Impact

Market	Change	Value	Standard Deviation	Lower Bound	Upper Bound	Max p-value
Corn	Quantity**[a]	-1.36	0.16	-1.87	-0.86	0.014
	Price**	3.92	0.49	2.38	5.47	0.016
Soybean	Quantity**	-2.54	0.33	-3.59	-1.50	0.017
	Price**	2.19	0.45	0.77	3.61	0.042
Soybean Meal	Quantity**	-2.02	0.29	-2.93	-1.12	0.020
	Price**	3.76	0.66	1.66	5.85	0.031
Distiller's Grain	Quantity*	0	0	0	0	0
	Price**	1.70	0.32	0.68	2.71	0.036
Ethanol	Quantity*	0	0	0	0	0
	Price**	0.08	0.02	0.02	0.13	0.049

[a] *, **, *** denote significance at 1%, 5%, and 10% levels.

Table 5.1 shows that the quantities of corn, soybean and soybean meal decreased by, 1.36% [-1.87, 0.86], -2.54% [-3.59, -1.5], and -2.02% [2.93, -1.12], while their prices increased by 3.92% [2.38, 5.47], 2.19% [0.77, 3.61], and 3.76% [1.66, 5.85] following the reduction of insurance premium subsidies. The quantity of ethanol and distiller's grain remain unchanged because of the RFS2 mandate.[27] The prices of the two products increased by 1.7% [0.68, 2.71] for DG and 0.08% [0.2, 0.13] for ethanol.

The price change for corn is relatively much greater in this paper than Lusk, whose model predicted a 4.75% increase following the elimination of the entire crop insurance program, which included a shock to corn and soybean supplies more than double the value in this paper. However, Lusk allowed for more substitutability for feed crops by livestock producers which would put less price pressure on corn following a supply shock, so the results are not directly comparable.

Overall the results reflect the expectations of the author given the framework from Chapter 1. Following a reduction in insurance premium subsidies farmers would decrease the supply of corn and soybean, which in turn would decrease the supply of soybean meal. Since feed is still demanded by livestock producers as well as corn from ethanol distiller's the

[27] The reader should keep in mind that the model did not allow for RIN trading to meet the RFS2 quotas, which would allow for a short term reduction in ethanol production.

reduction in supply results in price increases. The impact on the price of DG is likely the least because: (1) there was no change in supply instead of a reduction in available quantity, (2) the ability for livestock producers to substitute corn and soybean meal for DG is constrained by the dietary restrictions for livestock animals.

Table 5.2. Meat and Livestock Market Impact

Market	Change	Value	Standard Deviation	Lower Bound	Upper Bound	Max p-value
Beef	Retail quantity	0.01	0.02	-0.05	0.06	1.000
	Retail price	0.05	0.02	-0.01	0.11	0.168
	Processing quantity	-0.07	0.04	-0.22	0.07	0.371
	Processing price	0.14	0.05	-0.03	0.31	0.147
	Feedlot quantity*[a]	-0.22	0.07	-0.44	0.00	0.099
	Feedlot price*	0.22	0.06	0.04	0.40	0.067
	Farm quantity	-0.10	0.04	-0.23	0.03	0.186
	Farm price	-0.13	0.05	-0.29	0.04	0.167
Poultry	Retail quantity	-0.14	0.05	-0.29	0.02	0.134
	Retail price	0.51	0.17	-0.03	1.06	0.112
	Processing quantity*	-0.21	0.05	-0.36	-0.06	0.053
	Processing price*	0.35	0.15	-0.14	0.83	0.197
Pork	Retail quantity	-0.03	0.03	-0.13	0.07	0.962
	Retail price	0.08	0.04	-0.04	0.19	0.253
	Processing quantity	-0.28	0.13	-0.68	0.12	0.205
	Processing price	0.35	0.13	-0.08	0.77	0.148
	Farm quantity*	-0.98	0.27	-1.83	-0.12	0.076
	Farm price*	1.38	0.32	0.36	2.39	0.054

[a] ***, **,* denote significance at 1%, 5%, and 10% levels.

The results from Table 5-2 confirm the hypothesis of this paper, that decreasing the insurance premium subsidies for corn and soybean are unlikely to have major effects on the livestock and meat markets. For the beef market chain no quantity outside the feedlot level, for either quantity or price, changed by more than 0.1%, and none of those values were found to be statistically significant. The retail sector experienced no change at all. The only two values of statistical significance were for the feedlot level, which is logical considering it is the level directly affected by the changes in feed prices and quantities. The price and quantity of slaughter cattle changed by 0.22% [0.04, 0.4] and -0.22% [-0.44, 0.00]. Also of note is that the price and quantity of feeder cattle both decreased, following the expectations of the author.

The impact on the poultry market was slightly more than that of the beef market. The price and quantity change at the retail level was 0.51% [-0.03, 1.06] and -0.14% [-0.29, 0.02]. These values were nearly significant at the 10% level, especially the price of poultry at retail, and these price and quantity changes are also quite small. The effect on the processors, the level of poultry production directly impacted by feed prices, were statistically significant with changes in price and quantity of 0.35% [-0.14, 0.85] and -0.21% [-0.06, -0.36], which again are inconsequential with respect to addressing the externality concerns of livestock production.

The hog market was the most affected by the subsidy reduction. Once again, the only level that had statistically significant changes was at the farm level, which is directly impacted by feed prices. While none of the changes at the retail and processing level were above 0.35%, the price and quantity changes for slaughter hogs is 1.38% [0.36, 2.39] and -0.98% [-1.83, -.012]. While this demonstrates a direct linkage between insurance premium subsidies and the slaughter hogs market, it also suggests that reducing subsidies to corn and soybean would not result in substantial decreases from the externalities of hog production.

Of particular interest is that the magnitude of percentage changes in price from farm/processing to retail occurred in the opposite direction of what would be anticipated given the previous discussion of market power the in the different meat commodity chains. One would expect the percentage change in price to increase from farm to retail for beef and pork, and to decrease from processing to retail. The explanation would be that the model itself does not directly take market power into account, hence there are no price wedges imposed between different levels of the commodity chain[28]. Moreover, taking the nature of the EDM into account, having implemented a positive supply shock of the same value would have returned the same results with opposite signs. In this case the price changes would have reflected the expectations given market power in the commodity chains. This author believes this highlights the difficulty in using EDMs to analyze market power.

[28] The author would have liked to insert price wedges into the model, but was unable to due to time and resource constraints.

The lack of a major impact on the meat markets can likely be attributed to two important factors. The first is the increased flexibility in the production decisions firms face in the long-run as opposed to the short-run, which is reflected in their higher elasticity values. Specifically in this case, it means that firms are more responsive to input-price increases by substituting for cheaper inputs. The second issue is that even though feed composes a high portion of livestock production costs, especially for hog and poultry, the change in feed prices represents at the very most 2% increase in total costs. However, this result is important given that prior research has suggested that industrial livestock producers could be sensitive to even small changes in feed costs because they operate on small profit margins (Wise, 2005).

Table 5.3. Impact on Feed and Oilseed demand by Sector

Market	Change	Value	Standard Deviation	Lower Bound	Upper Bound	Max p-value
Corn	Beef	-0.83	0.90	-3.66	2.01	1.00
	Pork	-2.08	0.96	-5.11	0.95	0.21
	Poultry	-0.60	0.40	-1.88	0.67	0.45
	Ethanol*[a]	-0.03	0.01	-0.06	0.00	0.09
	Exports**	-6.37	1.00	-9.52	-3.21	0.02
Soybean Meal	Beef	-1.79	0.90	-4.64	1.05	0.25
	Pork	0.30	0.45	-1.13	1.72	1.00
	Poultry	-0.43	0.27	-1.30	0.44	0.40
	Exports**	-7.68	1.17	-11.38	-3.98	0.02
Distiller's Grain	Beef	1.58	0.61	-0.35	3.51	0.15
	Pork	3.42	1.82	-2.33	9.17	0.28
	Poultry	1.20	0.64	-0.82	3.22	0.28
	Exports**	-4.98	1.13	-8.54	-1.41	0.05
Soybean	Domestic	0.13	0.27	-0.71	0.97	1.00
	Exports**	-3.09	0.41	-4.40	-1.79	0.02

[a] *, **, *** denote significance at 1%, 5%, and 10% levels.

Table 5-3 shows the change in demand for feedstock and oilseed from each sector. While most of the values are statistically insignificant, they do give us some indication of how each sector is responding to the supply changes of feed. Exports were the most affected for all commodities, and the results were also statistically significant. The change in demand by each sector was -6.37% [-9.52, -3.21], -7.68% [-11.38, -3.98], -4.98% [-8.54, -1.41] and -3.09% [-

4.40, -1.79] for corn, soybean meal, DG, and soybean respectively. The biggest changes occur at the export level because export demand is more elastic than domestic demand. As for the livestock sector, demand for corn from all sectors decreased, with pork consumption declining the most. This is an expected response given the reduced supply of corn. In response to the decreased corn consumption all three increased in their use of DG, again with hog consumption of DG experiencing the biggest change. What is curious is that consumption of soybean meal by the hog sector increased despite the downward supply shift. The best explanation offered by this paper is that the long-run elasticity values used for hog farmers were larger than for other commodities, rather than some kind of market dynamics being at work, so in this model hog producers have more flexibility in feed choices than in the broiler and cattle sectors. As discussed previously long-run input demand elasticities were extrapolated from short-run elasticities in the literature and then multiplied by the ratio between the own price elasticity of supply at the short and long-runs. From those elasticities hog farmers had the largest ratio, so in turn the input and cross price input demand elasticities would be larger than for cattle and poultry farmers.

Chapter 6 - Discussion

This paper used a modified form of the stochastic equilibrium displacement model implemented by Dhoubhadel, Azzam, and Stockton (2015) to estimate the impact a reduction of insurance premium subsidies for corn and soybean would have on the US grain, oilseed, feed, livestock, and ethanol markets. Specifically, this model links corn, soybean meal, and distiller's grains, the coproduct of ethanol production, with the beef, poultry, and pork markets. The author also attempted to demonstrate the effect insurance premium subsidies have on the production decisions of crop farmers through a combination of decreased costs and risks.

The motivation of this research was to limit the costly externalities of industrial livestock production, especially from the environmental and human health standpoint, not to mention the fiscal burden on taxpayers. The results of the model reveal that while the subsidies have a substantial impact on the feed market itself, this shock does not deeply penetrate the meat markets. Corn and soybean meal prices increase the most due to the reduction in subsidies. The pork sector is most affected by these price changes, whereas the beef marketing chain was virtually unchanged, yet the biggest change in the meat sector was just a 1.38% increase in the farm price of hogs.

The salient limitation of this research is the lack of previous research having quantified the impact of the insurance premium subsidies on production, so a calibrated value is used. Depending on difference between the true value of the elasticities and those used in this paper, the results could have different policy implications. However, given the results from Appendix B, in which the paper used non-stochastic model with much higher own price supply elasticities, this authors finds it unlikely that different conclusions would be reached with different values for the supply elasticities with respect to premium subsidies. Furthermore it should be pointed out that this model did not include other feed crops like barley or wheat. Doing so would allow for more substitutability by livestock producers, likely dampening the effects on the meat markets even further.

Another issue worth examining deeper is the prevalence of market power in each meat commodity chain, and the role that subsidies have possibly had in producing this paradigm. Further research could look closely at how market power would alter the results obtained by this study by imposing price margins between the different stages of the commodity change and examining welfare changes.

Regardless it appears that if society desires a decrease in industrial meat production then other means must be pursued that better internalize the externalities of current systems. While eliminating insurance premium subsidies may be desirable from the taxpayer perspective, it is not a plausible solution to the problem addressed by this paper. As noted earlier, the best areas to pursue are likely modernizing the regulatory framework of meat production so that producers are more accountable for the environmental degradation, and health impacts their production systems are contributing to.

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Appendix A – Logarithmic Differential Equations of the Model

Here the reader can find the structural model from Chapter 4 in logarithmic differential form. The parameter values chosen and their sources can be found in the table in the following section. As a note to the reader, η represents demand elasticities, ε supply elasticities, and γ quantity elasticities.

Corn:

$$dlnQ_c^b - \eta_c^b dlnP_c - \gamma_c^{l,b} dlnQ_b^l - \eta_{c,sm}^b dlnP_{sm} - \eta_{c,DG}^b dlnP_{DG} = 0 \quad (1)$$

$$dlnQ_c^o - \eta_c^o dlnP_c - \gamma_c^{v,o} dlnQ_o^v - \eta_{c,sm}^o dlnP_{sm} - \eta_{c,DG}^o dlnP_{DG} = 0 \quad (2)$$

$$dlnQ_c^p - \eta_c^p dlnP_c - \gamma_c^{f,p} dlnQ_p^f - \eta_{c,sm}^p dlnP_{sm} - \eta_{c,DG}^p dlnP_{DG} = 0 \quad (3)$$

$$dlnQ_c^e - \eta_c^e dlnP_c - \gamma_c^e dlnQ_e = 0 \quad (4)$$

$$dlnQ_c^x - \eta_c^x dlnP_c = 0 \quad (5)$$

$$dlnQ_c^d - S_b^c dlnQ_c^b - S_o^c dlnQ_c^o - S_b^p dlnQ_c^p - S_b^e dlnQ_c^e - S_b^x dlnQ_c^x = 0 \quad (6)$$

$$dlnQ_c^s - \varepsilon_c dlnP_c - \varepsilon_c^{sb} dlnP_{sb} = \varepsilon_c^z dlnZ_c \quad (7)$$

Soybeans:

$$dlnQ_{sb}^{do} - \eta_{sb} dlnP_{sb} - \eta_{sb}^{sm} dlnP_{sm} = 0 \quad (8)$$

$$dlnQ_{sb}^x - \eta_{sb}^x dlnP_{sb} = 0 \quad (9)$$

$$dlnQ_{sb}^d - S_{do}^{sb} dlnQ_{sb}^{do} - S_x^{sb} dlnQ_{sb}^x = 0 \quad (10)$$

$$dlnQ_{sb}^s - \varepsilon_{sb} dlnP_{sb} - \varepsilon_{sb}^c dlnP_c = \varepsilon_{sb}^z dlnZ_{sb} \quad (11)$$

Soybean meal:

$$dlnQ_{sm}^b - \eta_{sm}^b dlnP_{sm} - \gamma_{sm}^{l,b} dlnQ_b^l - \eta_{sm,c}^b dlnP_c - \eta_{sm,DG}^b dlnP_{DG} = 0 \quad (12)$$

$$dlnQ_{sm}^o - \eta_{sm}^o dlnP_{sm} - \gamma_{sm}^{v,o} dlnQ_o^v - \eta_{sm,c}^o dlnP_c - \eta_{sm,DG}^o dlnP_{DG} = 0 \quad (13)$$

$$dlnQ_{sm}^p - \eta_{sm}^p dlnP_{sm} - \gamma_{sm}^{f,p} dlnQ_p^f - \eta_{sm,c}^p dlnP_c - \eta_{sm,DG}^p dlnP_{DG} = 0 \quad (14)$$

$$dlnQ_{sm}^x - \eta_{sm}^x dlnP_{sm} = 0 \quad (15)$$

$$dlnQ_{sm}^d - S_b^{sm} dlnQ_{sm}^b - S_o^{sm} dlnQ_{sm}^o - S_p^{sm} dlnQ_c^p - S_x^{sm} dlnQ_{sm}^x = 0 \quad (16)$$

$$dlnQ_{sm}^s - \varepsilon_{sm} dlnP_{sm} - \gamma_{sm}^{sb} dlnQ_{sb} = 0 \quad (17)$$

Distiller's Grain:

$$dlnQ_{DG}^{b} - \eta_{DG}^{b} dlnP_{DG} - \gamma_{DG}^{l,b} dlnQ_{b}^{l} - \eta_{DG,c}^{b} dlnP_{c} - \eta_{DG,sm}^{b} dlnP_{sm} = 0 \quad (18)$$
$$dlnQ_{DG}^{o} - \eta_{DG}^{o} dlnP_{DG} - \gamma_{DG}^{v,o} dlnQ_{o}^{v} - \eta_{DG,c}^{o} dlnP_{c} - \eta_{DG,sm}^{o} dlnP_{sm} = 0 \quad (19)$$
$$dlnQ_{DG}^{p} - \eta_{sm}^{p} dlnP_{DG} - \gamma_{DG}^{f,p} dlnQ_{p}^{f} - \eta_{DG,c}^{p} dlnP_{c} - \eta_{DG,sm}^{p} dlnP_{sm} = 0 \quad (20)$$
$$dlnQ_{DG}^{x} - \eta_{DG}^{x} dlnP_{DG} = 0 \quad (21)$$
$$dlnQ_{DG}^{d} - S_{b}^{DG} dlnQ_{DG}^{b} - S_{o}^{DG} dlnQ_{DG}^{o} - S_{p}^{DG} dlnQ_{c}^{p} - S_{x}^{DG} dlnQ_{DG}^{x} = 0 \quad (22)$$
$$dlnQ_{DG}^{s} - dlnQ_{c}^{e} = 0 \quad (23)$$

Ethanol:

$$dlnQ_{e}^{d} = 0 \quad (24)$$
$$dlnQ_{e}^{s} - \varepsilon_{e} dlnP_{e} - \varepsilon_{e}^{c} dlnP_{c} = 0 \quad (25)$$

Beef:

$$dlnQ_{b}^{rd} - \eta_{b}^{r} dlnP_{b}^{r} - \eta_{b,o}^{r} dlnP_{o}^{r} - \eta_{b,p}^{r} dlnP_{p}^{r} = 0 \quad (26)$$
$$dlnQ_{b}^{rs} - \varepsilon_{b}^{r} dlnP_{b}^{r} - \gamma_{b}^{r,v} dlnQ_{b}^{v} = 0 \quad (27)$$
$$dlnQ_{b}^{vd} - \eta_{b}^{v} dlnP_{b}^{v} - \gamma_{b}^{v,r} dlnQ_{b}^{r} = 0 \quad (28)$$
$$dlnQ_{b}^{vs} - \varepsilon_{b}^{v} dlnP_{b}^{v} - \gamma_{b}^{v,l} dlnQ_{b}^{l} = 0 \quad (29)$$
$$dlnQ_{b}^{ld} - \eta_{b}^{l} dlnP_{b}^{l} - \gamma_{b}^{l,v} dlnQ_{b}^{v} = 0 \quad (30)$$
$$dlnQ_{b}^{ls} - \varepsilon_{b}^{l} dlnP_{b}^{l} - \gamma_{b}^{l,f} dlnQ_{b}^{f} - \varepsilon_{b}^{c} dlnP_{c} - \varepsilon_{b}^{sm} dlnP_{sm} - \varepsilon_{b}^{DG} dlnP_{DG} = 0 \quad (31)$$
$$dlnQ_{b}^{fd} - \eta_{b}^{f} dlnP_{b}^{f} - \gamma_{b}^{f,l} dlnQ_{b}^{l} = 0 \quad (32)$$
$$dlnQ_{b}^{fs} - \varepsilon_{b}^{f} dlnP_{b}^{f} = 0 \quad (33)$$

Poultry:

$$dlnQ_{o}^{rd} - \eta_{o}^{r} dlnP_{o}^{r} - \eta_{o,b}^{r} dlnP_{b}^{r} - \eta_{o,p}^{r} dlnP_{p}^{r} = 0 \quad (34)$$
$$dlnQ_{o}^{rs} - \varepsilon_{o}^{r} dlnP_{o}^{r} - \gamma_{o}^{r,v} dlnQ_{o}^{v} = 0 \quad (35)$$
$$dlnQ_{o}^{vd} - \eta_{o}^{v} dlnP_{o}^{v} - \gamma_{o}^{v,r} dlnQ_{o}^{r} = 0 \quad (36)$$
$$dlnQ_{o}^{vs} - \varepsilon_{o}^{v} dlnP_{o}^{v} - \varepsilon_{o}^{c} dlnP_{c} - \varepsilon_{o}^{sm} dlnP_{sm} - \varepsilon_{o}^{DG} dlnP_{DG} = 0 \quad (37)$$

Pork:

$$dlnQ_{p}^{rd} - \eta_{p}^{r} dlnP_{p}^{r} - \eta_{p,b}^{r} dlnP_{p}^{r} - \eta_{p,o}^{r} dlnP_{o}^{r} = 0 \quad (38)$$
$$dlnQ_{p}^{rs} - \varepsilon_{p}^{r} dlnP_{p}^{r} - \gamma_{p}^{r,v} dlnQ_{p}^{v} = 0 \quad (39)$$
$$dlnQ_{p}^{vd} - \eta_{p}^{v} dlnP_{p}^{v} - \gamma_{p}^{v,r} dlnQ_{p}^{r} = 0 \quad (40)$$

$$dlnQ_p^{vs} - \varepsilon_p^v dlnP_p^v - \gamma_p^{v,f} dlnQ_p^f = 0 \quad (41)$$

$$dlnQ_p^{fd} - \eta_p^f dlnP_p^f - \gamma_p^{f,v} dlnQ_p^v = 0 \quad (42)$$

$$dlnQ_p^{fs} - \varepsilon_p^f dlnP_p^f - \varepsilon_p^c dlnP_c - \varepsilon_p^{sm} dlnP_{sm} - \varepsilon_p^{DG} dlnP_{DG} = 0 \quad (43)$$

Parameter Values

Here the reader can find the parameter values used in the logarithmic differential model. The long-run elasticity calibration (denoted by a, b, c, and d in the "Source" column is explained after the table.

Table A.1. Model parameter values

Parameter	Definition	Value	Source
η_c^b	Elasticity of corn demand by beef sector w.r.t price of corn	-0.66	Dhoubhdadel, 2015[29a]
η_c^o	Elasticity of corn demand by poultry sector w.r.t price of corn	-0.61	Dhoubhdadel, 2015[b]
η_c^p	Elasticity of corn demand by hog sector w.r.t price of corn	-0.30	Dhoubhdadel, 2015[c]
$\eta_{c,sm}^b$	Cross elasticity of corn demand by beef sector w.r.t price of soymeal	1.00	Dhoubhdadel, 2015[a]
$\eta_{c,sm}^o$	Cross elasticity of corn demand by poultry sector w.r.t price of soymeal	0.42	Dhoubhdadel, 2015[b]
$\eta_{c,sm}^p$	Cross elasticity of corn demand by hog sector w.r.t price of soymeal	1.05	Dhoubhdadel, 2015[c]
$\eta_{c,DG}^b$	Cross elasticity of corn demand by beef sector w.r.t price of DG	-1.07	Dhoubhdadel, 2015[a]
$\eta_{c,DG}^o$	Cross elasticity of corn demand by poultry sector w.r.t price of DG	-0.46	Dhoubhdadel, 2015[b]
$\eta_{c,DG}^p$	Cross elasticity of corn demand by hog sector w.r.t price of DG	-1.58	Dhoubhdadel, 2015[c]
$\gamma_c^{l,b}$	Elasticity of corn demand by beef sector w.r.t. quantity of cattle at feedlot level	1	Unit cost function (UCF)[30]
$\gamma_c^{v,o}$	Elasticity of corn demand by poultry sector w.r.t. quantity of poultry	1	UCF
$\gamma_c^{f,p}$	Elasticity of corn demand by pork sector w.r.t. quantity of hogs	1	UCF
η_c^e	Elasticity of corn demand by ethanol sector w.r.t price of corn	-0.02	Luchansky & Monks, 2009[31]

[29] For space consideration Dhoubhadel, Azzam, and Stockton(2015) will be referred to as Dhoubhadel, 2015.

[30] As argued by Dhoubhadel, Azzam, and Stockton, "total differentiation of a demand function derived by assuming a unit cost function and using shepherd's lemma results into expression similar to equation 19 with elasticity of demand with respect to downstream quantity equal to 1 (2015, p3).

Para-meter	Definition	Value	Source
η_c^x	Elasticity of export demand for corn	-1.64	Remier, 2012
γ_c^e	Elasticity of corn demand by ethanol sector w.r.t. quantity of ethanol	1	UCF
ε_c	Own price elasticity of corn supply	0.29	Hendricks, et al., 2014
ε_c^{sb}	Cross price elasticity of corn supply w.r.t. price of soybean	-0.22	Hendricks, et al., 2014
η_{sb}	Own price elasticity of soybean demand	-0.37	Gerlt, 2013
η_{sb}^{sm}	Cross price elasticity of soybean demand w.r.t. soymeal demand	0.25	Gerlt, 2013
η_{sb}^x	Elasticity of export demand for soybean	-1.45	Remier et al., 2012
ε_{sb}	Own price elasticity of soybean supply	0.26	Hendricks, et al., 2014
ε_{sb}^c	Cross price elasticity of soybean supply w.r.t. price of soymeal	-0.33	Hendricks, et al., 2014
η_{sm}^b	Elasticity of soymeal demand by beef sector w.r.t price of soymeal	-1.11	Dhoubhdadel, 2015[a]
η_{sm}^o	Elasticity of soymeal demand by poultry sector w.r.t price of soymeal	-0.32	Dhoubhdadel, 2015[b]
η_{sm}^p	Elasticity of soymeal demand by hog sector w.r.t price of soymeal	-0.22	Dhoubhdadel, 2015[c]
$\eta_{sm,c}^b$	Cross elasticity of soymeal demand by beef sector w.r.t price of corn	0.52	Dhoubhdadel, 2015[a]
$\eta_{sm,c}^o$	Cross elasticity of soymeal demand by poultry sector w.r.t price of corn	0.20	Dhoubhdadel, 2015[b]
$\eta_{sm,c}^p$	Cross elasticity of soymeal demand by hog sector w.r.t price of corn	0.44	Dhoubhdadel, 2015[c]
$\eta_{sm,DG}^b$	Cross elasticity of soymeal demand by beef sector w.r.t price of DG	0.31	Dhoubhdadel, 2015[a]
$\eta_{sm,DG}^o$	Cross elasticity of soymeal demand by poultry sector w.r.t price of DG	0.10	Dhoubhdadel, 2015[b]
$\eta_{sm,DG}^p$	Cross elasticity of soymeal demand by hog sector w.r.t price of DG	0.22	Dhoubhdadel, 2015[c]
$\gamma_{sm}^{l,b}$	Elasticity of soymeal demand by beef sector w.r.t. quantity of cattle at feedlot level	1	UCF
$\gamma_{sm}^{v,o}$	Elasticity of soymeal demand by poultry sector w.r.t. quantity of poultry	1	UCF
$\gamma_{sm}^{f,p}$	Elasticity of soymeal demand by pork sector w.r.t. quantity of hogs	1	UCF
η_{sm}^x	Export elasticity of soymeal	2.08	Piggot, 2001[d] (same as ratio for corn)
ε_{sm}	Own price elasticity of soymeal supply	0.14	Piggot, 2001
γ_{sm}^{sb}	Supply elasticity of soymeal w.r.t. quantity of soybean	1	Dhoubhdadel, 2015

[31] This value was found to be insignificant, but this value seems more likely than the significant value found by Luchansky and Monks of 0.13.

Para-meter	Definition	Value	Source
η_{DG}^{b}	Elasticity of DG demand by beef sector w.r.t price of DG	-2.73	Dhoubhdadel, 2015[a]
η_{DG}^{o}	Elasticity of DG demand by poultry sector w.r.t price of DG	-1.11	Dhoubhdadel, 2015[b]
η_{DG}^{p}	Elasticity of DG demand by hog sector w.r.t price of DG	-3.51	Dhoubhdadel, 2015[c]
$\eta_{DG,c}^{b}$	Cross elasticity of DG demand by beef sector w.r.t price of corn	0.83	Dhoubhdadel, 2015[a]
$\eta_{DG,c}^{o}$	Cross elasticity of DG demand by poultry sector w.r.t price of corn	0.29	Dhoubhdadel, 2015[b]
$\eta_{DG,c}^{p}$	Cross elasticity of DG demand by hog sector w.r.t price of corn	1.01	Dhoubhdadel, 2015[c]
$\eta_{DG,sm}^{b}$	Cross elasticity of DG demand by beef sector w.r.t price of soymeal	0.83	Dhoubhdadel, 2015[a]
$\eta_{DG,sm}^{o}$	Cross elasticity of DG demand by poultry sector w.r.t price of soymeal	0.56	Dhoubhdadel, 2015[b]
$\eta_{DG,sm}^{p}$	Cross elasticity of DG demand by hog sector w.r.t price of soymeal	1.67	Dhoubhdadel, 2015[c]
$\gamma_{DG}^{l,b}$	Elasticity of DG demand by beef sector w.r.t. quantity of cattle at feedlot level	1	UCF
$\gamma_{DG}^{v,o}$	Elasticity of DG demand by poultry sector w.r.t. quantity of poultry	1	UCF
$\gamma_{DG}^{f,p}$	Elasticity of DG demand by pork sector w.r.t. quantity of hogs	1	UCF
η_{DG}^{x}	Export elasticity of DG	-2.95	Dhoubhdadel, 2015[d]
η_{e}	Own price elasticity of ethanol supply	0.65	Elobeid & Tokgoz, 2008
η_{b}^{r}	Own price elasticity of beef demand at the retail level	-0.70	Brester, 1996
$\eta_{b,o}^{r}$	Cross elasticity of beef demand w.r.t. price of poultry at retail level	0.05	Brester, 1996
$\eta_{b,p}^{r}$	Cross elasticity of beef demand w.r.t. price of pork at retail level	0.19	Brester, 1996
η_{b}^{v}	Own price elasticity of beef demand at processing level	-0.57	Marsh, 1992
η_{b}^{l}	Own price elasticity of fed cattle demand at feedlot level	-0.66	Marsh, 1992
η_{b}^{f}	Own price elasticity of feeder cattle demand at farm level	-0.62	Marsh, 1992
ε_{b}^{r}	Own price elasticity of beef supply at retail level	1.25	Brester, et al., 2004[a]
ε_{b}^{v}	Own price elasticity of beef supply at processing level	0.97	Brester, et al., 2004[a]
ε_{b}^{l}	Own price elasticity of fed cattle supply at feedlot level	0.90	Buhr & Kim, 1997
ε_{b}^{c}	Elasticity of fed cattle supply w.r.t. price of corn	-0.07	Meyers et al., 1992[a]
ε_{b}^{sm}	Elasticity of fed cattle supply w.r.t. price of soymeal	-0.01	Meyers et al., 1992[a]
ε_{b}^{DG}	Elasticity of fed cattle supply w.r.t. price of DG	-0.007	Dhoubhdadel, 2015[a]
ε_{b}^{f}	Own price elasticity of feeder cattle supply at farm level	0.76	Marsh, 2003[a]
$\gamma_{b}^{r,v}$	Elasticity of retail beef quantity w.r.t. quantity at processing level	0.71	RTI International, 2007
$\gamma_{b}^{v,r}$	Elasticity of processed beef quantity w.r.t. quantity at retail level	1.03	Brester, et al., 2004

Para-meter	Definition	Value	Source
$\gamma_{b}^{v,l}$	Elasticity of processed beef quantity w.r.t. quantity at feedlot level	0.93	RTI International, 2007
$\gamma_{b}^{l,v}$	Elasticity of fed cattle quantity at feedlot level w.r.t. quantity at processing level	1.02	Brester, et al., 2004
$\gamma_{b}^{l,f}$	Elasticity of fed cattle quantity at feedlot level w.r.t. quantity at farm level	0.94	RTI International, 2007
$\gamma_{b}^{f,l}$	Elasticity of feeder cattle quantity at farm level w.r.t. quantity at feedlot level	0.78	Brester, et al., 2004
η_{o}^{r}	Own price elasticity of poultry demand at the retail level	-0.29	Brester, 1996
$\eta_{o,b}^{r}$	Cross elasticity of poultry demand w.r.t. price of beef at retail level	0.18	Brester, 1996
$\eta_{o,p}^{r}$	Cross elasticity of poultry demand w.r.t. price of pork at retail level	0.04	Brester, 1996
η_{o}^{v}	Own price elasticity of poultry demand at processing level	-0.22	Brester, et al., 2004
ε_{o}^{r}	Own price elasticity of poultry supply at retail level	0.13	Pothidee & Allen, 1999
ε_{o}^{v}	Own price elasticity of poultry supply at processing level	0.2	Brester, et al., 2004[b]
ε_{o}^{c}	Elasticity of poultry supply w.r.t. price of corn	-0.03	Heien, 1976[b]
ε_{o}^{sm}	Elasticity of poultry supply w.r.t. price of soymeal	-0.04	Meyers, et al., 1992[b]
ε_{o}^{DG}	Elasticity of poultry supply w.r.t. price of DG	-0.001	Dhoubhdadel, 2015[b]
$\gamma_{o}^{r,v}$	Elasticity of retail poultry quantity w.r.t. quantity at processing level	0.95	Dhoubhdadel, 2015
$\gamma_{o}^{v,r}$	Elasticity of processed poultry quantity w.r.t. quantity at retail level	1.01	Brester, et al., 2004
η_{p}^{r}	Own price elasticity of pork demand at the retail level	-0.79	Brester, 1996
$\eta_{p,b}^{r}$	Cross elasticity of pork demand w.r.t. price of beef at retail level	0.34	Brester, 1996
$\eta_{p,o}^{r}$	Cross elasticity of pork demand w.r.t. price of poultry at retail level	0.02	Brester, 1996
η_{p}^{v}	Own price elasticity of pork demand at processing level	-0.71	Brester, et al., 2004
η_{p}^{f}	Own price elasticity of hog demand at farm level	-0.51	Wohlgenant, 1989
ε_{p}^{r}	Own price elasticity of pork supply at retail level	3.20	Brester, et al., 2004[c]
ε_{p}^{v}	Own price elasticity of pork supply at processing level	1.94	Brester, et al., 2004[c]
ε_{p}^{f}	Own price elasticity of hog supply at farm level	1.80	Lemiuex and Wohlgenant, 1989
ε_{p}^{c}	Elasticity of hog supply w.r.t. price of corn	-0.40	Stoddart, 1991[c]
ε_{p}^{sm}	Elasticity of hog supply w.r.t. price of soymeal	-0.13	Dhoubhadel, 2015[c]
ε_{p}^{DG}	Elasticity of hog supply w.r.t. price of DG	-0.009	Dhoubhdadel, 2015[c]
$\gamma_{p}^{r,v}$	Elasticity of retail pork quantity w.r.t. quantity at processing level	0.95	Dhoubhdadel, 2015

Para-meter	Definition	Value	Source
$\gamma_p^{v,r}$	Elasticity of processed pork quantity w.r.t. quantity at retail level	1.01	Brester, et al., 2004
$\gamma_p^{v,f}$	Elasticity of processed pork quantity w.r.t. quantity at hog level	0.95	Dhoubhdadel, 2015
$\gamma_p^{f,v}$	Elasticity of hog quantity at farm level w.r.t. quantity at processing level	1.00	Brester, et al., 2004
S_b^c	Share of corn consumption by beef sector	0.11	Conley, et al., 2012
S_o^c	Share of corn consumption by poultry sector	0.13	Conley, et al., 2012
S_p^c	Share of corn consumption by pork sector	0.11	Conley, et al., 2012
S_e^c	Share of corn consumption by ethanol sector	0.35	Conley, et al., 2012
S_x^c	Share of corn consumption by export sector	0.15	Conley, et al., 2012
S_b^{sm}	Share of soymeal consumption by beef sector	0.09	United Soybean Board (USB), 2012
S_o^{sm}	Share of soymeal consumption by poultry sector	0.35	USB, 2012
S_p^{sm}	Share of soymeal consumption by pork sector	0.19	USB, 2012
S_x^{sm}	Share of soymeal consumption by export sector	0.23	USB, 2012
S_b^{DG}	Share of DG consumption by beef sector	0.56	Hoffman & Baker, 2011
S_o^{DG}	Share of DG consumption by poultry sector	0.07	Hoffman & Baker, 2011
S_p^{DG}	Share of DG consumption by pork sector	0.10	Hoffman & Baker, 2011
S_x^{DG}	Share of DG consumption by export sector	0.27	Hoffman & Baker, 2011
S_{do}^{sb}	Share of total soybean consumption in USA	0.17	USB, 2012
S_x^{sb}	Share of total soybean consumption by export sector	0.83	USB, 2012
ε_c^z	Elasticity of corn supply w.r.t. insurance premium subsidy	0.18	Author's own estimation
ε_{sb}^z	Elasticity of soybean supply w.r.t. insurance premium subsidy	0.20	Author's own estimation

The calibrated long-run elasticities denoted by superscript, a, are those relevant to the supply of beef. The short-run elasticities were taken from the literature in the table above, and then extrapolated to long-run elasticities based on the short-run/long-run elasticity ratio provided by Buhr & Kim (1997), which equates to 3.46. The same is done for the poultry sector, denoted by “b”, using the short-run/long-run elasticity ratio given by Pothidee & Allen (1990), which equals 1.44. The ratio for the pork sector was taken from Lemiuex and Wohlgenant (1989), and is valued at 4.4. Finally, the long-run export demand elasticities for soybean meal and distiller’s grain were calibrated using the short-run/long-run ratio provided by Remier, Zeng, and Gehlhar (2012).

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Appendix B – Simulation with Larger Supply Elasticity Values

In this part of the appendix the reader can find non-stochastic results for a simulation using the supply elasticities from Harrington and Dubman (2008) for corn and soybean supply (values of 1.246 and 1.401, respectively) instead of those from Hendricks, Smith and Sumner (2014) (0.29 and 0.26, respectively).

Table B.1. Results with larger supply elasticities – Feed and ethanol

Market	Change	Value
Corn	Quantity	-2.16
	Price	6.87
Soybean	Quantity	-5.04
	Price	4.23
Soybean Meal	Quantity	-4.02
	Price	7.33
Distiller's Grain	Quantity	0.00
	Price	3.11
Ethanol	Quantity	0.00
	Price	0.19

Table B.2. Results with larger supply elasticities – Feed and oilseed demand by sector

Market	Change	Value
Beef	Q* at retail	0.01
	P* at retail	0.08
	Q* at processing	-0.13
	P* at processing	0.24
	Q* at slaughter	-0.38
	P* at slaughter	0.38
	Q* at farm	-0.16
	P* at farm	-0.22
Pork	Q* at retail	-0.02
	P* at retail	0.08
	Q* at processing	-0.27
	P* at processing	0.36
	Q* at farm	-1.03
	P* at farm	1.49
Poultry	Q* at retail	-0.25
	P* at retail	0.92
	Q* at processing	-0.39
	P* at processing	0.65

Table B.3. Results with larger supply elasticities – Feed demand by sector

Market	Change	Value
Corn Demand	Beef	-0.89
	Pork	-2.46
	Poultry	-0.84
	Ethanol	-0.05
	Exports	-11.24
Soybean Meal Demand	Beef	-3.96
	Pork	1.06
	Poultry	-1.01
	Exports	-15.24
Distiller's Grain Demand	Beef	2.87
	Pork	6.84
	Poultry	2.12
	Exports	-9.21
Soybean Demand	Domestic	0.27
	Exports	-6.13

As can be seen from the tables above, even though there is a much higher impact on the feed markets in terms of quantity and prices, but there is very little change in the livestock sector. Therefore, the conclusions from the paper are not invalidated when using higher elasticity values or the long-run supply of corn and soybean.