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Three Essays on Biofuels, Drought, Livestock, and the Environment

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THREE ESSAYS ON BIOFUELS, DROUGHT, LIVESTOCK, AND THE ENVIRONMENT

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This dissertation consists of three essays. The first essay examines the impact of the 2012 drought and the biofuels mandate on the U.S. grain and livestock markets. A stochastic equilibrium displacement model is used to analyze the impact on eight commodity markets viz. beef, pork, poultry, corn, distillers' grain (DG), soybean, soymeal, and ethanol. Among the eight markets, corn and beef are found to be the most vulnerable to drought. The use of Renewable Identification Number (RIN) credits as an instrument to mitigate the impact of drought has limited effectiveness. A mandate waiver of about 23% is required to fully negate the impact of the drought on corn prices.

Using the residual supply approach, the second essay examines the oligopsony power of U.S. importers in importing sugarcane ethanol from Brazil. The residual supply elasticity of the ethanol export from Brazil to the United States is found to be highly elastic with a significant influence of the import competing countries in determining the supply of ethanol from Brazil. Nonetheless, the elasticity is positive indicating a small degree of U.S. importer market power. This implies that the U.S. importers are operating

as oligopsonist and policies that further restrict the ethanol imports would not be optimal for them.

The third essay examines the impact of livestock production on land use and associated greenhouse gas emissions (GHG). The GTAP-BIO model is used to project the growth of livestock output between 2004 and 2022 and to estimate the land use changes and associated GHG emissions. Results indicate that the increased livestock output leads to considerable increase in pasture (about 45 million hectares) and decrease in forest area (about 44 million hectares) in the world. Estimated emissions associated with this change is about 20 billion tons of carbon-dioxide equivalent (Co_2 e) during the study period or an annual average of 1.1 billion tons. A significant portion of the emissions (about 11%) can be reduced by making private household demand for livestock products more sensitive to price changes. In practice, this would require interventions that promote a range of choices of livestock products to the consumers.

To my parents,

Dr. Shiva P. Dhoubhadel and Mrs. Bidya Dhoubhadel

For teaching me the value of a good education and hard work to achieve a fulfilling life

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CHAPTER 1

INTRODUCTION

This dissertation consists of three essays. The first two essays relate to biofuels policy in the United States. U.S. biofuels policy mandates consumption of certain volumes of biofuels in order to bolster its adoption and use for transportation fuel purposes. These mandates have effects not only on the energy markets but also on the grain and livestock[1] markets. These effects are even more prominent during periods when corn production is short, such as the 2012 drought in the United States. The first essay presented in the second chapter of this dissertation examines the impact and interactions of the 2012 drought and the U.S. biofuels policy on the grain and livestock markets using a multi-market stochastic equilibrium displacement model (EDM). During the drought, there were many who felt waiving the biofuels mandate would help mitigate the impact of drought on the grain and livestock markets. The debate at that time was how much of an effect would some kind of mandate waiver have in reducing corn price in light of drought diminished corn supply. This chapter directly addresses this question by specifically examining several key questions: 1) Can blending credits given in the form of Renewable Identification Numbers (RINs) be useful in mitigating drought impacts? 2) How much of a waiver in mandate for biofuels is required to fully offset the impact of 2012 drought on corn prices? In addition to its timely content, this work also

[1] Livestock includes cattle, hogs, and poultry.

adds to the literature by demonstrating and proposing a methodology for doing statistically consistent sensitivity analysis of EDM models.

Recent emphasis of the U.S. biofuels policy has been on the advanced mandates, which require biofuels that have emissions less than 50% of the emissions compared to the traditional fuel sources. Unintentionally, this focus has created some interesting aberrations in the market. The United States is the largest producer of corn ethanol in the world, which it exports, while at the same time it imports sugarcane ethanol mainly from Brazil to fulfil the advanced mandate requirements. Since the share of the advanced mandate as a portion of the total biofuels mandate increases quite rapidly in coming years, the sugarcane ethanol import market is likely to grow. The second essay presented in the third chapter examines the strategic position of the United States in importing sugarcane ethanol from Brazil using a series of econometric models. The residual supply elasticity of the ethanol exported from Brazil to the United States is estimated to assess U.S. market power in importing ethanol from Brazil.

The global demand for protein, specifically livestock products has grown over the years and is likely continue to grow with increasing world population and increases in per capita income of developing countries. With increase in livestock production, resource allocations are likely to occur with implications for environment. Two of the many possible questions are pertinent: 1) how land use might change in various regions around the world with the increase in livestock production? 2) In relation to the land use changes, how will that alter greenhouse gas (GHG) emissions? The answers to these questions are important considering current debate regarding contribution of the livestock sector to the GHG emissions. The third essay presented in the fourth chapter uses a computable

general equilibrium model (Global Trade Analysis Project, GTAP model) to examine the impact of growth in livestock output on global land use and estimates the resulting GHG emissions from those changes. The final chapter of this dissertation, chapter 5, provides a discussion and perspective of the combined work by synthesizing the results and drawing conclusions from the three essays.

CHAPTER 2

THE IMPACT OF BIOFUELS POLICY AND DROUGHT ON THE U.S. GRAIN AND LIVESTOCK MARKETS

2.1 Introduction

The onset of the 2012 drought[2] raised concerns about the effects of biofuels policies on the livestock sector. This prompted Governors of leading cattle producing states to petition the Environmental Protection Agency (US EPA) to partially waive the mandate for 2012/13[3]. However, the EPA declined the petition. To justify this declination, the EPA (US EPA, 2012) argues that "EPA's analysis shows that it is highly unlikely that waiving the RFS volume requirements will have a significant impact on ethanol production or use in the relevant time frame that a waiver could apply (the 2012-2013 corn marketing season) and therefore little or no impact on corn, food, or fuel prices."

Irwin and Good (2012) contend that because of the cost advantage of blending ethanol in gasoline compared to ethanol substitutes and a technical constraint in ethanol blending (octane wall[4]), mere waiver in mandate will not provide enough economic incentives to blend less than 13.6 billion gallons (the blend wall[5] for 2013) of ethanol in

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[2] USDA ERS (2012[a]) estimate on 2012 corn crop production indicates that the average yield in 2012/13 market year was 122.3 bushels per acre, the lowest since 1995. On September 9, 2012, USDA ERS (2012[a]) rated 58% of pastures and ranges in the United States poor to very poor compared to 40% at the same time in 2011, and 31% on average from 2000 to 2010.

[3] It should be noted here that the request to waive the mandate may be totally uncalled for from the perspective of corn producers who are hoping to mitigate the effect of drought with higher corn prices.

[4,5] Blend wall and octane wall are discussed later in the chapter.

2012-2013 market year. Babcock (2012) and Tyner et al. (2012) present similar arguments. However, they do not completely rule out the effectiveness of the waiver in reducing ethanol consumption. Thompson et al. (2012) compare the impact of the mandate with a complete elimination of the mandate. Their results are in line with Irwin and Good's (2012) in that waiving the mandate will have a limited effect in reducing ethanol production and hence reducing the impact on the price of corn.

The question about the impact of mandates on the livestock industry during a time of potential crop shortages such as the 2012 drought still remains open. The work of Tokgoz et al. (2008) has partially addressed this question. Using a multi-commodity, multimarket econometric model, Tokgoz et al. (2008) find that a 1988-type drought and a mandate of 14.7 billion gallons increases the prices of corn, beef, pork, and poultry by 43.8%, 3.9%, 2.1%, and 2.8% respectively. However, their model does not consider a) the effect of Renewable Fuel Identification Numbers (RINs)[6] on ethanol demand, b) the effect of drought on pasture and c) the cross-elasticities of derived (producer) demand for corn, DG, and soybean meal. Inclusion of cross-elasticities accounts for the substitution and complementary relationship among corn, soybean meal, and DG in feed ration formulations. Moreover, as is typical of ethanol-livestock studies,[7] Tokgoz et al. (2008) report point estimates without reporting their statistical significance. The omission of

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[6] RINs are the credits given to blenders by the EPA for each gallon of renewable fuel blended with gasoline. If more gallons of ethanol are blended than required by the RFS mandate, the blenders can carry forward their balance RIN credits for next year and use in case they decide to blend less than mandated by RFS for that particular year.

[7] Notable examples include Elobeid et al. (2007), Hayes et al. (2009), Kruse et al. (2007), Park and Fortenbery (2007), Peters et al. (2009), Taheripour et al. (2011), and Drabik and de Gorter (2012).

statistical significance seems non-trivial considering that the parameters driving the models and impacts are stochastic.

In this chapter, the aforementioned considerations are incorporated in a more complete stochastic equilibrium displacement model (EDM) that: 1) measures the impact of the mandate on the livestock industries in the presence of a drought-induced crop and pasture shortfall, using the 2012 drought as a case study, and 2) provides confidence intervals and P-values to test alternative hypotheses about the impacts. As an additional contribution, the chapter goes a step further and considers a pertinent question that has not yet been considered in the literature: How much of the mandate needs to be waived to fully offset the impact of drought on the price of corn?[8] The answer to this question is very important in assessing the effectiveness of a mandate waiver or RIN credits as instruments for mitigating some of the impact of drought on the corn market.

Unlike an econometric model, which consists of a simultaneously estimated system of supply and demand equations requiring specific time-series data for parameter estimation and policy analysis, an EDM is a system of demand and supply equations expressed in terms of proportionate changes in the endogenous and exogenous variables. For policy analysis, any change is introduced as an exogenous shock in the solution vector of the system of equations which are then solved simultaneously. The elements of the coefficient matrix of the system of equations are all elasticity estimates or

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[8] It should be noted here that ethanol blenders will not stop blending ethanol even if the entire mandate is waived if the blending economics is favorable. The question being asked here is that what if the EPA fixes the ethanol blending to a level that it offsets the impact of drought on corn prices. This would imply that the EPA fixes a quota for ethanol blending during the drought period to reduce the corn demand for ethanol production.

consumption shares, which are obtained from the literature or other reliable sources. The resulting equilibrium displacements represent the proportionate changes in the endogenous variables resulting from the shock or policy change. Since EDM uses the elasticity estimates from literature, it allows a researcher to focus on policy applications without being concerned about estimating the parameters of the model (Wohlgenant, 2010).[9]

The rest of the chapter is organized as follows. Section 2.2 presents a graphical model illustrating the linkages among the eight commodities in the EDM model. Section 2.3 translates the graphical model into a structural model. Section 2.4 transforms the structural model into a deterministic EDM represented by a system of log-differential equations and presents the method used to make the EDM stochastic, and then lays out the framework for estimating the drought-offsetting mandate (DOM) waiver. Section 2.5 presents the results and section 2.6 provides a summary and conclusion.

2.2 Graphical representation of the EDM model

The conceptual framework underlying the basic interrelationships of the EDM is best illustrated in a graphical form. The various graphs in Figure 2.1 capture the linkages among ethanol, grain, and meat markets and illustrate the impact of drought in the absence of an RFS mandate waiver and RIN credits. Figure 2.2 is a repeat of Figure 2.1 with the inclusion of the RFS mandate waiver and RIN credits. Figure 2.3 shows the impact of drought on the disaggregated meat (beef, pork, and poultry) market through its main marketing chain components, namely farm, feedlot, processing, and retail.

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[9] Wohlgenant (2010) provides an exhaustive review of EDM.

Before delving into the demand and supply relations defining the ethanol, grain, and meat markets, this section first highlights the role of ethanol in the U.S. gasoline market. Because the RFS mandate has been in effect since 2007, blenders are obliged to blend renewable biofuels (ethanol) into gasoline. The gasoline refining industry currently blends an 84 octane gasoline product known as Reformulated Gasoline Blend-stock for Oxygenated Blending (RBOB) with ethanol (113 octane) to produce an 87 octane blended gasoline (Irwin and Good, 2012; Tyner et al., 2012). Ethanol, therefore, not only helps to fulfill the RFS mandate but also works as an octane enhancer in conventional gasoline. In the United States, typically 10% of final blended gasoline volume is ethanol.[10]

The market effects of drought and the RFS mandate

The starting point of the graphical model is Figure 2.1 panel a, which represents the market for gasoline (ethanol blended). The intersection of demand and supply schedules for gasoline determines its equilibrium price P_G and quantity (G) of gasoline. The production of G is defined by a technology where a fixed amount of gasoline is blended with ethanol or a substitute (Figure 2.1 panel b)[11]. The coefficients α and β define the minimum requirements of RBOB and ethanol/substitute blend stock discussed earlier.

[10] Higher blends such as E15, i.e. 15% ethanol blend gasoline, or E85, i.e. 85% ethanol blend, are also available but compared to E-10, the 10% ethanol blend, their share in total blended gasoline market is very small. E-10 blends accounts for more than 99% of gasoline blends (US EIA, 2012). Similarly, a small proportion of blended gasoline with less than 10% ethanol is also available.

[11] Ethanol blending technology is shown as a fixed proportion technology because typically the blending proportion is 10% of ethanol in the gasoline due to octane and blend wall. As these technical constrains are relaxed and it becomes possible to blend multiple blends without overhauling the blending infrastructures, the technology can be represented by more flexible form such as the constant elasticity of substitution (CES).

The source of the ethanol blend stock is the ethanol market represented in panel c. The ethanol supply schedule is upward sloping as usual, however the ethanol demand curve is relatively inelastic up to a certain quantity of ethanol. The inelastic demand is the result of the RFS mandate and the technical constraints in ethanol blending known as the 'blend wall' and the 'octane wall' (Irwin and Good, 2012; Tyner et al., 2012). The blend wall exists because blenders cannot blend more than 10% of the total gasoline volume marketed due to retailing and refining infrastructural constraints. Blending more than 10% of the total gasoline volume requires adding more E15 and E85 blend pumps, flex-fuel cars, and refineries which can handle a higher level of ethanol, making this an infeasible enterprise in the short run. The octane wall is related to the blending technology. Blending less than 10% of ethanol with RBOB to enhance the octane level to 87 requires changing the current blending technology which would require months to achieve. Currently, ethanol is the cheapest source of octane enhancer compared to all other alternatives (Irwin and Good, 2012)[12]. Irwin and Good (2012) point out that as long as ethanol is the cheapest alternative and the price of ethanol is below the RBOB price, blenders will continue to prefer ethanol over other alternatives for blending with gasoline. Therefore, due to the blend and octane wall, ethanol demand will continue to be inelastic up to the point where its price is less than or equal to other octane enhancers. However, ethanol is not strictly a domestic product. It can be imported and, therefore, blenders have some flexibility to substitute imported ethanol from countries such as

[12] Aromatic hydrocarbons such as Benzene, Toulene, and mixed Xylen popularly known as BTX are other octane enhancers (NREL, 2000).

Brazil especially if domestic ethanol prices become relatively higher. Availability of imported ethanol makes the demand curve relatively inelastic as opposed to being perfectly inelastic as shown in panel c. Empirical studies by Elobeid and Tokgoz (2008) and Rask (1998)[13] further support the claim that the demand for ethanol is relatively inelastic.

Panel d illustrates ethanol production technology from corn grain and panel e indicates the associated DG production. The amount of ethanol and DG produced per bushel of corn is a fixed quantity. Each bushel of corn produces approximately 2.8 gallons of ethanol (panel d) and 18 lbs. of DG (panel e), each representing approximately 1/3 the weight of a bushel of corn.

Livestock, ethanol, and exports are the major consumers[14] of domestic corn grain. Therefore, the market demand curve for corn D_C (panel g) is the horizontal summation of the derived demand for corn by the ethanol industry DD_E (panel f), livestock industry DD_M (panel h), and corn export demand DD_X (panel i). The kinked portion of corn demand, D_C (panel g) reflects the perfectly inelastic demand, DD_E for corn from ethanol sector (panel f) in short run. The inelastic corn demand from the ethanol industry reflects the fact that currently corn is the primary viable feed stock used to produce ethanol in the United States and once ethanol producers decide on the amount of ethanol to be produced they require a fixed amount of corn grain as shown in panel d. The DG market is shown

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[13] Elobeid and Tokgoz (2008) report an ethanol demand elasticity of -0.43 and Rask (1998) reports -0.37.

[14] Feed and biofuels absorb 89% of total domestic corn use (USDA ERS 2012[b]), leaving 11% for food, seed, and industrial use. Considering that the use of corn for food in the United States is not large enough and stable through time, corn for food, seed, and industrial use are not included in the analysis.

in panel k. The derived demand for DG is captured by the downward sloping schedule D_{DG}. As a by-product of ethanol, DG supply is fixed as a proportion of the quantity of corn used to produce ethanol as shown in panel e. Therefore, the supply curve of DG is drawn as a vertical line. The markets for meat and soybean/soybean meal are represented by panels l and j, respectively. For illustrative purposes, panel l considers all three meats (beef, pork, and poultry) as one product, meats (later in the algebraic version of the EDM these commodities are treated as separate products and the vertical structure of each meat market is specified).

Figure 2.3 is a representative meat supply chain linking the farm, processing, and retail markets. All demand schedules other than retail are derived demand schedules and all supply schedules other than the farm supply are derived supply schedules. Retail demand and farm supply are the primary demand and supply schedules. Underlying the vertical structure of the meat supply chain is the assumption of a fixed proportional relationship between the outputs produced at each link of the chain, which is consistent with the process of the meat fabrication.

The market impact of drought without RFS waiver and RIN credits is represented in Figures 2.1 and 2.3 by arrows that show shifts from the solid demand and supply schedules to their dashed counterparts. The arrows indicate the expected direction of the impact.[15] The respective supply schedules of the corn market (panel g) and the soybean market (panel j) shift left, indicating a rise in corn prices (panel f) to ethanol producers,

[15] It is "expected" because of the added effects of cross-price elasticities of the three meats at retail, and the cross-elasticities of livestock producers' derived demand of the three feed inputs (corn, DG, and soybean meal).

livestock producers (panel h), and export price (panel i). The rise in the price of corn shifts ethanol supply (panel c) and meat supply (panel l) to the left, exacerbating further the initial effect of the drought on the meat supply. Demand for DG; a feed substitute for corn in rations, increases causing a price increase in DG market (panel k). The effect of drought on the meat marketing chain is illustrated in Figure 2.3 by the leftward shift in meat supply at the farm level due to poor pasture. The reduced supply at the farm level is transmitted to the feedlot level and further reduces the supply at this level by the increased corn prices. The shift is then transmitted downstream to the processing and retail segments of the chain, resulting in an overall increase in the price of meats.

Figure 2.2 and related panels trace the market effect of drought with a RFS waiver and use of RINs. First note that it was projected that at the end of 2012, about 1.89 billion gallons of RIN credits would be available to be used for 2013 (Paulson, 2012)[16]. If these RIN credits are used, they shift the blenders' demand curve for ethanol. For example, the 2013 RFS mandate is 13.8 billion gallons of renewable fuel blending. If used fully, the 1.89 billion gallons of RIN credits will reduce the demand for ethanol to about 12 billion gallons (panel c). Therefore, the RIN credits provide some cushioning mechanism by shifting ethanol demand leftwards from D_E to D'_E (panel c). The leftward shift of ethanol demand translates into a leftward shift in the derived demand for corn by the ethanol industry (from DD_E to DD'_E in panel f).

[16] There is a controversy surrounding carryover RIN from 2012. For details see Paulson (2013). Since Paulson's (2012) estimate is a conservative estimate of carryover RIN from 2012, it is used for this analysis.

Irwin and Good (2012) contend that for the RFS waiver to be effective in reducing current ethanol demand the price of gasoline, i.e. RBOB should drop below the price of ethanol to the extent that it triggers substitution of an alternative octane enhancer for ethanol. The authors argue that in order to drop RBOB price well below ethanol price, the crude oil price has to drop substantially. They see very little possibility of this happening considering crude oil price trends before 2012/2013. They also find it unlikely that corn prices will rise so high that ethanol prices will exceed the RBOB price. Tyner et al. (2012) also make similar arguments but indicate that there may be some flexibility in octane enhancer substitution. Therefore, given the current economic incentives of blenders to use ethanol, it is believed that even if the EPA relaxes the RFS mandate, ethanol demand will not move significantly to the left. The EPA's lack of action makes it appear that they concur with these arguments when they denied a RFS waiver for the year 2012.

Given the potential ineffectiveness of the RFS mandate, the effect of RINs in the presence of drought is illustrated in Figure 2.2. Note that the dashed schedules in the affected markets represent shifts in their respective supply or demand schedules due to drought. The difference between Figures 2.1 and 2.2 is that while the shifts in Figure 2.1 are represented by unidirectional arrows, the shifts in Figure 2.2 are represented by arrows going in opposite directions, indicating the potential mitigating effect of the RIN credits.

2.3 The structural model

The structural model consists of several sub-models, each corresponding to a specific market. In addition to the meat market, which is segmented into three submarkets, beef, pork, and poultry, the model also includes ethanol and the grain markets consisting of corn, soybeans/soybean meal, and DG. Retail meat demands include both grocery and food away from home outlets which are the primary demands. Demands along the supply chain are derived (conditional) demands from adjacent segments downstream. Primary supply is at the farm level and flows to the downstream levels and is derived from upstream levels. Equality between buying and selling price is assumed.[17] Also, the model assumes a fixed proportion relationship between the nonmaterial inputs (labor, packaging, etc…) and the raw material inputs livestock, feed ingredients for both livestock and ethanol. Supplies of non-material inputs are assumed to be perfectly elastic. Substitution is allowed among corn, soybean meal, and DG in livestock feeding. Prices and quantities are denoted by P and Q, respectively. Only those exogenous shifters such as rainfall and mandate variables which are of particular interest to this work are considered. All other shifters are assumed constant and hence suppressed in the model. The specific definitions of the variables in the structural models are listed in Table 2.1.

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[17] This may seem unrealistic since processors may possess some market power. However, as long as the degree of market power is unaffected by drought through its effect on capacity utilization, assuming market power away will not affect the results because the wedge between prices will remain constant when the various market equilibria are displaced by drought.

2.3.1 Meat markets

Beef

Following RTI (2007) the beef marketing chain is represented by eight equations which represent four links to sub-markets within the supply chain, each defined by its own demand and supply. The four links within the beef supply chain are retail (equations 1-2), processing (equations 3-4), feedlot (equations 5-6), and feeder cattle (equations 7-8). The general forms of the equations are specified as follows[18]:

Retail:

1) Beef primary demand: $Q_b^{rd} = f_{1b}\left(P_b^r, P_p^r, P_k^r\right)$

2) Beef derived supply: $Q_b^{rs} = f_{2b}\,(P_b^r, Q_b^w)$

Processing:

3) Beef derived demand: $Q_b^{wd} = f_{3b}\,(P_b^w, Q_b^r)$

4) Beef derived supply: $Q_b^{ws} = f_{4b}\,(P_b^w, Q_b^s,)$

Feedlot:

5) Slaughter fed cattle derived demand: $Q_b^{sd} = f_{5b}\,(P_b^s, Q_b^w)$

6) Slaughter fed cattle derived supply: $Q_b^{ss} = f_{6b}\left(P_b^s, Q_b^f, P_{co}, P_{sym}, P_{DG}\right)$

Feeder cattle:

7) Feeder cattle derived demand: $Q_b^{fd} = f_{7b}\left(P_b^f, Q_b^s\right)$

[18] Note that material input quantities rather than material input prices are used at adjacent levels of the vertical market as arguments in the derived demand and derived supply functions. In the case of derived demands, having downstream material input quantities as arguments rather than material input prices is appropriate (see Brester et. al. 2004 and RTI, 2007 for similar specifications). In the case of derived supply, it would be more appropriate to model supply as a function of upstream material-input prices. However, following RTI (2007) quantities instead of prices are used because the RTI study provides estimates of the elasticity of quantity transmission, which is used to empirically implement the model.

8) Feeder cattle primary supply: $Q_b^{fs} = f_{8b}(P_b^f, W_g)$

Pork

The structure of the pork marketing chain is similar to that of beef except that it is more vertically integrated with the use of production and marketing contracts (Wise and Trist, 2010). Demand and supply relationships are specified at retail (equations 9- 10), processing (equations 11-12), and farm (equations13-14).

Retail:

9) Pork primary demand: $Q_p^{rd} = f_{1p}\left(P_p^r, P_b^r, P_k^r\right)$

10) Pork derived supply: $Q_p^{rs} = f_{2p}\left(P_p^r, Q_p^w\right)$

Processing:

11) Pork derived demand: $Q_p^{wd} = f_{3p}\left(P_p^w, Q_p^r\right)$

12) Pork derived supply: $Q_p^{ws} = f_{4p}\left(P_p^w, Q_p^f\right)$

Farm:

13) Derived demand for slaughter hogs: $Q_p^{fd} = f_{5p}(P_p^f, Q_p^w)$

14) Primary supply of slaughter hogs[19]: $Q_p^{fs} = f_{6p}(P_p^f, P_{co}, P_{sym}, P_{DG})$

[19] The supply function can be derived assuming revenue of a representative hog producer is a weighted average of revenue from the spot market and revenue from production or marketing contracts, where the weights are the proportion of finished hogs sold on the spot market and the proportion of finished hogs sold through contracts. For simplicity of the model, the markets are not segmented here.

Poultry

The poultry supply chain is fully integrated from processing to the farm level (Weng, 2012), therefore, only retail (equation15-16) and processing (equations 17-18) demand and supply are included in the model.

Retail:

15) Poultry primary demand: $Q_k^{rd} = f_{1k}\left(P_k^r, P_b^r, P_p^r\right)$

16) Poultry derived supply: $Q_k^{rs} = f_{2k}\,(P_k^r, Q_k^w)$

Processing**:**

17) Poultry derived demand: $Q_k^{wd} = f_{3k}\,(P_k^w, Q_k^r)$

18) Poultry primary supply: $Q_k^{ws} = f_{4k}\left(P_k^w, P_{co}, P_{sym}, P_{DG}\right)$

2.3.2 Grain markets

Corn

The structural model of the corn marketing chain consists of derived demands for corn by cattle, hog, poultry, and ethanol producers and corn export demand (equations 19-23). The horizontal sum of the demands is given by equation 24. Corn supply is captured by equation 25.

19) Derived demand of corn from cattle: $Q_{co}^b = f_{1co}\left(P_{co}, Q_b^s, P_{sym}, P_{DG}\right)$

20) Derived demand of corn from hog: $Q_{co}^p = f_{2co}\left(P_{co}, Q_p^f, P_{sym}, P_{DG}\right)$

21) Derived demand of corn from poultry: $Q_{co}^k = f_{3co}\left(P_{co}, Q_k^w, P_{sym}, P_{DG}\right)$

22) Derived demand of corn from ethanol: $Q_{co}^e = f_{4co}\left(P_{co}, Q_e\right)$

23) Corn export demand: $Q_{co}^{x} = f_{5co}(P_{co}$ [20]$)$

24) Total corn demand: $Q_{co}^{d} = Q_{co}^{b} + Q_{co}^{p} + Q_{co}^{k} + Q_{co}^{e} + Q_{co}^{x}$

25) Corn supply: $Q_{co}^{s} = f_{6co}(P_{co}, R)$

Soybean and soybean meal[21]

The soybean meal marketing chain has total demand (equation 30) which is the sum of derived demands by cattle (equation 26), hog (equation 27), and poultry producers (equation 28), and soybean meal export demand (equation 29). Soybean meal supply is represented in equation 31. Domestic and export demands for soybean are represented in equations 32 and 33. Total demand and supply of soybeans is represented in equations 34-35 respectively.

Soybean meal:

26) Derived demand of soybean meal from cattle: $Q_{sym}^{b} =$

$f_{1sym}\left(P_{co}, Q_{b}^{s}, P_{sym}, P_{DG}\right)$

27) Derived demand of soybean meal from hog: $Q_{sym}^{p} = f_{2sym}\left(P_{co}, Q_{p}^{f}, P_{sym}, P_{DG}\right)$

28) Derived demand of soybean meal from poultry: $Q_{sym}^{k} =$

$f_{3sym}\left(P_{co}, Q_{k}^{w}, P_{sym}, P_{DG}\right)$

[20] In general, export demand is the function of world prices. However, for simplicity it is assumed that domestic corn price is equal to the world price. This assumption seems reasonable considering that the U.S is a dominant exporter of corn in the world.

[21] Soybean meal and soybean oil are the joint products produced by using soybean as the main input for production. Therefore, the supply of these joint products is highly dependent on supply of soybean. In this analysis, only soybean meal is considered as it has direct implications for livestock production cost. Soybean oil and biodiesel, which is produced in United States by processing soybean oil is ignored in this analysis as biodiesel production represents a small portion of U.S. biofuels production.

29) Soybean meal export demand: $Q_{sym}^{x} = f_{4sym}\left(P_{sym}\right)$

30) Total soybean meal demand: $Q_{sym}^{d} = Q_{sym}^{b} + Q_{sym}^{p} + Q_{sym}^{k} + Q_{sym}^{x}$

31) Soybean meal supply: $Q_{sym}^{s} = f_{5sym}\left(P_{sym}, Q_{sy}\right)$

Soybeans:

32) Soybean domestic demand: $Q_{sy}^{d} = f_{1sy}(P_{sy}, P_{sym})$

33) Soybean export demand: $Q_{sy}^{x} = f_{2sy}\left(P_{sy}\right)$

34) Total soybean demand: $Q_{sy} = Q_{sy}^{d} + Q_{sy}^{x}$

35) Soybean supply: $Q_{sy} = f_{3sy}(P_{sy}, R)$

2.3.3 Distillers' grain market

The derived demand for DG (equation 40) is the sum of the derived demands for DG from the cattle (equation 36), pork (equation 37), poultry (equation 38), and exports (equation 39). Primary supply of DG (equation 41) is specified as a fixed proportion of corn used for ethanol production.

36) Derived demand of DG from cattle: $Q_{DG}^{b} = f_{1DG}\left(P_{co}, Q_{b}^{s}, P_{sym}, P_{DG}\right)$

37) Derived demand of DG from hog: $Q_{DG}^{p} = f_{2DG}\left(P_{co}, Q_{p}^{f}, P_{sym}, P_{DG}\right)$

38) Derived demand of DG from poultry: $Q_{DG}^{k} = f_{3DG}(P_{co}, Q_{k}^{w}, P_{sym}, P_{DG})$

39) DG export demand: $Q_{DG}^{x} = f_{3DG}(P_{DG})$

40) Total DG demand: $Q_{DG}^{d} = Q_{DG}^{b} + Q_{DG}^{h} + Q_{DG}^{k} + Q_{DG}^{x}$

41) DG supply: $Q_{DG}^{s} = 0.18\ Q_{co}^{e}$

2.3.4 Ethanol market

Ethanol demand by gasoline blenders is represented by equation 42. The primary supply of ethanol by producers is captured in equation 43.

42) Derived demand of ethanol from the blenders: $Q_e^d = f_{1e}(P_e, M)$

43) Ethanol supply: $Q_e^s = f_{2e}(P_e, P_{co})$

2.4 The equilibrium displacement model

Total differentiation of the structural equations (equations 1 through 43) and their expression in log differential form provides a system of 43 log differential equations (Appendix 2.A). The log differential form of each of the 43 equations represents percentage changes, with the endogenous (exogenous) variables on the left (right) hand side of the equality sign. With the exception of the three exogenous shocks of interest: *dlnR* (in equations 25 and 35), representing the proportionate change in rainfall/drought; *dlnWg* (in equation 8) the proportionate change in pasture yield, and *dlnM* (in equation 42) the proportionate change in ethanol blended due to the RFS mandate waiver and/or use of RIN credits, the log differentials of the remaining exogenous variables are set equal to zero.

Following the convention of representing a system of equation as **AX = b** and denoting the vector of percentage changes in the endogenous variables as $\mathbf{X}_{(43 \times 1)}$, the vector of elasticity-weighted percentage changes in exogenous variables as $\mathbf{b}_{(43 \times 1)}$, and the coefficient matrix by $\mathbf{A}_{(43 \times 43)}$, the system is represented in matrix form as:

44) $\mathbf{A}_{(43 \times 43)} . \mathbf{X}_{(43 \times 1)} = \mathbf{b}_{(43 \times 1)}$, and the solution of the system as:

45) $\mathbf{X}_{(43 \times 1)} = \mathbf{A}^{-1}\mathbf{b}$.

The elements of the coefficient matrix **A** represent either elasticity estimates or quantity shares. Most of these estimates are obtained from the literature but a few are estimated by the author. Their respective definitions and sources are presented in the Table 2.2.

2.4.1 Stochastic model

Davis and Espinoza (1998) highlight the usefulness of a stochastic framework compared to using single point deterministic estimates or a simple sensitivity analysis with a limited number of adjustments. They contend that the deterministic framework does not provide a way for determining the statistical merit of the estimated percentage changes in the endogenous variables. Conversely, the stochastic framework provides a distribution of points around an estimate which provides such a framework. They also indicate that unlike a typical sensitivity analysis where point estimates are selected at the discretion of the researcher; the stochastic framework estimates are randomly drawn from a distribution avoiding biases introduced by the researcher. This analysis adopts the Davis and Espinoza (1998) framework which is referred here as a stochastic equilibrium distribution model (SEDM) instead of a standard deterministic EDM. While Davis and Espinoza (1998) show the superiority of using SEDM method, they provide little guidance for selecting the proper distribution to be simulated. One of the contributions of this analysis is that basic statistical principles are used to develop a method of constructing the unknown distributions of the estimates.

The elasticity estimates comprising the coefficient matrix **A** are gathered from the literature. As econometric estimates represent a single realization in a distribution of estimates, the parent distribution from which they are taken may theoretically be used to

draw additional estimates. Unfortunately, many of the elasticity estimates obtained from literature do not report information about these parent distributions. Moreover, multiple estimates of a single elasticity are available from various sources which use varying estimation methods which may or may not have compatible assumptions about their individual distributions. Therefore, a choice must be made about what is a reasonable method for selecting appropriate sensitivity values. Multiple elasticity estimates are available from various sources and could be considered a sample of observations (of elasticity estimates). Given this information, the Central Limit Theorem suggests that the sampling distribution of the sample mean approach a normal distribution (Casella and Berger, 2002). In practice, a normal distribution is approximated by the t-distribution for small samples such as the sample of elasticity estimates obtained from literature. Oftentimes, these samples are four or less implying small degrees of freedom (df). The calculated value for a t-statistic is the relevant elasticity value divided by its standard deviation. In this work, t-value is obtained from the t-table for df = 3 and a one-tailed level of significance of 0.005, which is calculated as 5.841. Then using this t-value and the elasticity estimates from literature, standard deviation (σ) of the elasticity estimates are extrapolated. The estimated σ is then used to stochastically simulate the distribution of elasticity estimates around true mean of the estimates. Purposely a large confidence level (i.e. a level of significance of 0.005) is used to reflect a high degree of confidence in the elasticity estimates from the literature. The lower the confidence level, the larger is the σ value. Larger σ values allow for wider variation in the stochastically drawn elasticities. The idea is to have parsimony, enough variation to test sensitivity but not so

much that stochastically drawn elasticities are far away from those reported in the literature. Given that the estimates were estimated properly (i.e. no violation of any modeling assumptions), this method provides a statistically relevant method of establishing ranges for the sensitivity parameters.

Now that we have the σ values of the estimates, the next step is to select a type of distribution for simulating the estimates. While the Central Limit Theorem suggests that the sampling distribution of the elasticity estimates is likely to be normally distributed, we do not know the true mean of this distribution. This implies that any of the elasticity estimates from the literature can equal a true mean. Given the fact that we do not know the true mean, we assign equal probability of selection to each of the alternative elasticity estimates when they are simulated. Use of uniform distribution for simulation fulfills this objective. Uniform distribution assures that each observation of elasticity within a specified range is as equally likely as the true mean and is used in the simulation process. Single standard deviation of the estimates are used as upper and lower limits of the uniform distribution making it a conservative simulation. Moreover, the demand elasticities are restricted to be negative and supply elasticities to be positive.

Independence among the elasticity estimates is assumed, which at first may seem unreasonable. Again consider the estimates and process that created them. Presumably the estimates were created in a model that has little or no misspecification error, indicating that the estimates themselves have been purged of any interdependencies among the variables in the model. This assumption allows each elasticity estimate to be randomly drawn without considering its effect on any other elasticity. If this were not the case, a variance covariance matrix would be required. Since the estimates are collected

from a wide variety of sources, information needed to create the variance-covariance structure is neither available, nor feasible. In such a circumstance, guessing at the variance covariance structure and incorporating it into the model would cause additional bias (Davis and Espinoza, 1998).

To summarize, the t-distribution defines the area with a specific degree of confidence where the true mean is likely to lie and the uniform distribution provides a pool of equally likely candidates of true means. The process of generating elasticity estimates using this process fulfills three objectives: 1) it makes them stochastic within a very close neighborhood of the original estimates from literature, 2) it uses a random selection based on central tendency, 3) it provides a method to determine statistical significance.

The resulting posterior distributions of the endogenous variables are simulated 1000 times using a MS-Excel add-on simulation software SIMETAR 2011 (Richardson, et al., 2008). The Latin Hypercube simulation procedure is the one applied in SIMETAR. Based on the simulation, using Chebychev inequality a 90% confidence interval is constructed around the simulated means of the endogenous variables and their associated maximum P-values are calculated (Davis and Espinoza, 1998). Construction of the confidence intervals and associated maximum P-values provides information on the statistical significance of the simulated mean values making it possible to determine at what level the final results of the model become statistically significant.

2.4.2 Drought offsetting mandate (DOM) waiver

DOM waiver is defined as the reduction in the RFS mandate necessary to offset the effects of drought such that the price of corn would remain unchanged. To do this, let us start with the reduced form of the equilibrium price of corn, P_{co} and set it as a function of the mandate and drought variables.

46) $P_{co} = f(M, R)$

where *M* (the mandate) and *R* (rainfall/drought) are exogenous variables whose proportional changes drive the equilibrium displacement of all the other endogenous variables. Total differentiation of equation 46 yields equation 47.

47) $dlnP_{co} = \varepsilon_{P_{co,M}} dln\, M + \varepsilon_{P_{co,R}}\, dlnR$

where $\varepsilon_{P_{co,R}} = \left(\frac{dP}{dR}\right)\left(\frac{R}{P}\right)$ is the elasticity of corn price with respect to a change in rainfall and $\varepsilon_{P_{co,M}} = \left(\frac{dP}{dM}\right)\left(\frac{M}{P}\right)$ is the elasticity of corn price with respect to a change in the mandate. Setting $dlnP_{co} = 0$ and solving for the drought offsetting mandate results in equation 48.

48) $\frac{dlnM}{dlnR} = -\frac{\varepsilon_{P_{co,R}}}{\varepsilon_{P_{co,M}}}$ for $dlnP_{co} = 0$

The equation gives the percentage change in the ethanol mandate required to offset the effect on corn price of a 1% change in rainfall. To compute equation 48, the elasticity in the numerator (denominator) is obtained by solving the EDM for the equilibrium price of corn assuming a 1% change in rainfall, *R* (mandate, *M*) and no change in mandate, *M* (rainfall , *R*).

2.5 Results

Using the 11 year average rainfall (average of cumulative rainfall between April and August) data published by National Climatic Data Center for the corn-belt area as the baseline, the proportion of deficit rainfall in 2012 compared to the baseline average was estimated. The rainfall in the corn-belt area during 2012 was about 32% less than the baseline. The percentage decrease in rainfall is weighted by its elasticity values and then used as the shock to the exogenous variable *R*. Using the elasticity relationship between rainfall and pasture yield outlined in Wiles et al. (2011), the percentage decline in pasture productivity associated with a 32% decrease in rainfall is estimated at 46.4%. The estimated decline in pasture is then weighted by its elasticity and used as the shock to the exogenous variable *Wg*.

The multi-market impacts of a 32% drop in rainfall are analyzed in conjunction with the effect of the RFS mandate. Because the EPA did not waive the RFS mandate target for 2012, the only flexibility ethanol blenders have in blending ethanol is the use of RIN credits. However, note that the exogenous variable *M* represents both RFS mandate waiver and RIN credit use by blenders and either/both potentially shift ethanol demand. In this case, *M* represents RIN credits only. Paulson (2012) reported that about 1.89 billion gallons of RIN credits were available to be used towards fulfilling the RFS mandate deficit at the end of 2012. These credits could have fulfilled about 13.9% of the 13.6 billion gallon required by the RFS mandate for 2012-2013 period, allowing blenders to use less ethanol if they chose to.

In this analysis two scenarios are considered; drought impacts with and without the use of all the available RIN credits.

2.5.1 Scenario 1: Multimarket impact of drought without the use of RIN credits

Table 2.3 shows the impact on the meat sector. In general, the magnitude of the impact on equilibrium prices and quantities is higher for beef than pork and poultry. A 32% drop in rainfall leads to 4.9% [1.3, 8.4],[22] 1.1% [0.4, 1.8], and 2.1% [0.8, 3.5] increase in the retail prices of beef, pork, and poultry. Although retail prices for all meats show an increase, their respective retail quantities do not - beef consumption drops by -3.1% [-5.4, -0.7] but pork and poultry consumption remain unchanged. The larger impact of drought on beef is driven by two factors: 1) drought affects the availability of pasture for cattle and 2) drought impacts the production of corn and soybean which are the major sources of feed in finished beef production. Unlike beef production, pork and poultry are affected only through the impact on feed costs.

Along the meat marketing chain, the largest price impact is observed at the processor level in the beef and pork marketing chains where price increases by 6.3% [1.9, 10.8] and 1.2% [0.4, 1.9]. In terms of output impact, the largest drop in quantity is at the farm level with -10.4% [-11.6, -9.3] and -0.5% [-0.9, -0.1] decline for beef and pork. In the case of poultry, the largest price impact is observed at the retail level and there are no significant quantity changes at all levels. These results indicate a differential impact of drought on all three meat marketing chains. The differential impact along the marketing chain is largely driven by the own- and cross-elasticities of demand at the retail level, and substitution among the feed grains at the farm level.

[22] Values in the brackets are the 90% confidence intervals.

Results in Table 2.4 show that without the use of RIN credits, drought has the largest impact on corn with 8.8% [7.1, 10.6] increase in price and a -2.9% [-3.4, -2.4] decline in quantity. The impact is smaller in the case of soybean and soybean meal with 5.1% [3.6, 6.6] and 7.4% [5.9, 9.0] increase in the price and a -1.9% [-2.2, -1.6] and -5.5% [-6.0, -4.9] decline in quantity. For DG there is no significant change in price and quantity. Note that grain and feed markets are the ones directly affected by drought; the magnitude of the impact on these markets is generally higher compared to meat markets. The drought impacts are lessened as one moves through the production chain from grain and feed to meat. The higher corn prices due to drought induces a 1.8% [0.9, 2.7] increase in the ethanol price and there is no decline in ethanol consumption as no RIN credits are used.

Drought without the use of RIN credits decreases corn export demand by -9.8% [-12.1, -7.4] and corn demand for cattle feed by -8.9% [-12.3, -5.4]. There is no significant reduction in corn demanded by pork and poultry for feed. For soybeans, both domestic and export demand are reduced by -10.4% [-12.2, -8.7] and -1.5% [-2.4, -0.5] respectively. The reduction in domestic soybean demand is driven by a -9.6% [-13.5, -5.7] and -4.6% [-5.9, -3.2] decline in soybean meal demand from the cattle feeding sector and export demand. Unlike corn and soybean meal, where demand from pork and poultry remain unchanged, DG demand from these sectors increases by 5.3% [3.3, 7.3] and 5.6% [3.6, 7.6]. However, DG demands for cattle feeding decreases by -3.1% [-5.8, -0.5] and export demand remains unchanged. These results are consistent with the fact that the equilibrium quantities of pork and poultry at the upstream levels are not impacted by drought in a major way, leaving feed demand by the two sectors unaffected. The

reduced feed demand from the cattle sector is to be expected considering the impacts of drought on calf production which leads to some cow/calf liquidation. All of the above results emphasize the dual impact of drought on beef through both pasture and feed grains, while pork and poultry are relatively spared from drought impact.

2.5.2 Scenario 2: Multimarket impact of drought with the use of RIN credits

There is a little difference in the impact of drought with and without the use of RIN credits at almost all levels of the meat marketing chain (Table 2.3). Whenever a difference exists, it does not exceed 0.5 percentage points. This indicates that using RIN credits does not translate into significantly smaller impacts on meat markets.

In contrast, as shown in Table 2.4, in the case of grain, feed and ethanol markets, there is a larger effect when RIN credits are used. Use of RIN credits results in lower prices in all cases, most noticeably for corn and ethanol, compared to no RIN use. With RIN credits, the price of corn and ethanol decreases by 5.58 and 14.36 percentage points compared to no RIN use. Since use of RIN credits decreases ethanol consumption by -8.5% [-10.0, -7.0], there is a discernable decrease in the equilibrium quantities of corn and DG by 1.39 and 1.54 percentage points compared to no RIN use. As expected, RIN credits soften ethanol demand from blenders, translating into less demand for corn and, hence, less production of DG.

As one would expect, use of RIN credits helps to sustain corn demand from the meat sectors. With the use of RIN credits, there is a slightly smaller decrease in demand for corn from beef and slight increase in corn demand from pork and poultry sectors compared to the no RIN credits scenario. However, use of RIN credits has no

discernable impact on demand for soybean meal from all meat sectors. Although RIN use does not result in a significant change in DG price, there is less demand for DG from all the meat sectors. This is also the result of substitution of corn for DG. The use of RINs also dampens the negative impact on export demand for corn and soybean meal (Table 2.4).

2.5.3 Estimate on DOM waiver

Table 2.5 presents the simulation results on the level of mandate waiver required to fully offset the impact of the 32% decrease in rainfall on the equilibrium corn price. Results indicate that to fully negate the impact of a 32% decrease in rainfall on the corn price, an approximately -23% [-30.2, -15.2] of mandate waiver (i.e. 13.6 to 10.47 billion gallons for 2012/2013) is required. This policy change translates into about a -13.63% [-15.9, -11.3] decrease in ethanol consumption. On average, a 1% decrease in rainfall leads to about 0.26% increase in corn price, and a 1% decrease in the mandate results in a 0.38% decrease in corn price.[23] This translates into the following: to fully offset the effect of a 1% decrease in rainfall, the mandate should be decreased by 0.68%. Given the environmental objectives of the RFS mandate, it may not be feasible for the EPA to fully offset the impact of a drought as severe as the one in 2012. This would require a mandate waiver of 3.12 billion gallons (from 13.6 to 10.47 billion gallons). However, the results do indicate that a mandate waiver or use of RIN credits can be an

[23] These intermediate calculations are not shown in Table 2.5. Also it should be noted that small decrease in rainfall would have no effect on corn prices unless a certain threshold level of drought is attained. The relationship specified here assumes that the threshold level of drought has been attained.

effective tool for mitigating the impact of drought on the corn market when there is a severe drought as in 2012.

2.6 Summary and conclusions

To estimate the combined effect of biofuels policy and drought, a stochastic EDM model is developed. This model links the beef, pork, poultry, corn, soybean, soymeal, DG, and ethanol markets. Results suggest that U.S. biofuels policy has a considerable indirect influence on grain, feed, and meat markets. That influence is exacerbated by drought, especially for beef through drought's effect on feed grains and pasture.

Results also suggest that the grain and feed markets are the primary recipients of the supply shock from drought which are then relayed to the meat markets. Corn prices respond the most to drought with the highest increase among all commodities considered. Corn feed demand from the livestock sector is the most affected compared to soybean meal and DG demand. Among meats, beef is the most affected by drought as it affects supply of feed as well as pasture.

As RIN credits fulfill some of the RFS mandate, they provide some relief from the effect of drought by helping to lessen the adverse impact on grain markets, especially the corn market. However, the impact of RIN is limited and is not fully transmitted to the meat markets, particularly beef.

The lower proportionate level of waiver required (about 0.68 times the decrease in level of rainfall) to induce a status quo corn price indicates that such a waiver or RIN credits can be a feasible option to mitigate the impact of drought on the corn market. However, it should be underlined that the diminished impact of corn price changes does

not result in significant relief for meat markets. This may partially explain why the EPA did not grant a mandate waiver for 2012.

The results presented here should be taken more as indicative rather than definitive since the drought impacts reported are significant over a range of values. Moreover, the confidence interval and associated P-values are not generated directly from the observational data. Statistical significance in this case may not be directly comparable with the statistical significance from observational data (Davis and Espinoza, 1998). Despite those shortcomings, the model is very useful in general application and in predicting the direction and the magnitude of the range of drought impacts. At the very least the stochastic nature of the model provides relevant information on the robustness of the results. As with many partial equilibrium models there is the *Ceteris Paribus* assumption with respect to external shocks not considered in this analysis. For example, it is assumed that the export demand for meats are unchanged after the drought. Last but not the least, the model has pedagogical value in that it can be used and/or improved upon by others for research, extension, and classroom teaching purposes.

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Table 2.1 : Variable definitions

Variables	Definitions
Q_b^r	Quantity of beef at the retail level
Q_b^w	Quantity of beef at the processing level
Q_b^s	Quantity of slaughter cattle at the feedlot level
Q_b^f	Quantity of feeder cattle at the farm level
Q_p^r	Quantity of pork at the retail level
Q_p^w	Quantity of pork at the processing level
Q_p^f	Quantity of hog at the farm level
Q_k^r	Quantity of poultry at the retail level
Q_k^w	Quantity of poultry at the processing level
Q_{co}^b	Quantity of corn for cattle producers
Q_{co}^p	Quantity of corn for hog producers
Q_{co}^k	Quantity of corn for poultry producers
Q_{co}^e	Quantity of corn for ethanol producers
Q_{co}^x	Quantity of corn export
Q_{co}	Quantity of total corn
Q_{sym}^b	Quantity of soybean meal for cattle producers
Q_{sym}^p	Quantity of soybean meal for hog producers
Q_{sym}^k	Quantity of soybean meal for poultry producers
Q_{sym}^x	Quantity of soybean meal export
Q_{sym}	Quantity of total soybean meal
Q_{sy}^x	Quantity of soybean export
Q_{sy}^d	Quantity of domestic soybean
Q_{sy}	Quantity of total soybean
Q_{DG}^b	Quantity of DG for cattle producers
Q_{DG}^p	Quantity of DG for hog producers
Q_{DG}^k	Quantity of DG for poultry producers
Q_{DG}^x	Quantity of DG export
Q_{DG}	Quantity of total DG demand
Q_e	Quantity of ethanol demand
P_b^r	Price of beef at the retail level
P_b^w	Price of beef at the processing level
P_b^s	Price of slaughter cattle at the feedlot level
P_b^f	Price of feeder cattle at the farm level
P_p^r	Price of pork at the retail level
P_p^w	Price of pork at the processing level
P_p^f	Price of hog at the farm level
P_k^r	Price of poultry at the retail level
P_k^w	Price of poultry at the processing level
P_{co}	Price of corn
P_{sy}	Price of soybean
P_{sym}	Price of soybean meal
P_{DG}	Price of DG
P_e	Price of ethanol
R	Rainfall/drought
M	Quantity of ethanol demand changes from mandate or RIN credits
W_g	Pasture yield

Table 2.2 : Parameter estimates

Parameters	Definitions	Estimated Values	Source
η_b^r	Own price elasticity of beef demand at the retail level	-0.70	Brester, 1996
η_b^w	Own price elasticity of beef demand at the processing level	-0.57	Marsh,1992
η_b^s	Own price elasticity of slaughter cattle demand at the feedlot level	-0.66	Marsh,1992
η_b^f	Own price elasticity of feeder cattle demand at the farm level	-0.62	Marsh,1992
η_{bp}^r	Cross elasticity of beef demand with respect to price of pork at the retail level	0.19	Brester, 1996
η_{bk}^r	Cross elasticity of beef demand with respect to price of poultry at the retail level	0.05	Brester, 1996
η_p^r	Own price elasticity of pork demand at the retail level	-0.79	Brester, 1996
η_p^w	Own price elasticity of pork demand at the processing level	-0.71	Brester et al., 2004
η_p^f	Own price elasticity of hog demand at the farm level	-0.51	Wohlgenant, 1989
η_{pb}^r	Cross elasticity of pork demand with respect to price of beef at the retail level	0.34	Brester, 1996
η_{pk}^r	Cross elasticity of pork demand with respect to price of poultry at the retail level	0.02	Brester, 1996
η_k^r	Own price elasticity of poultry demand at the retail level	-0.29	Brester, 1996
η_k^w	Own price elasticity of poultry demand at the processing level	-0.22	Brester et al., 2004
η_{kb}^r	Cross elasticity of poultry demand with respect to price of beef at the retail level	0.18	Brester, 1996
η_{kp}^r	Cross elasticity of poultry demand with respect to price of pork at the retail level	0.04	Brester, 1996
η_e	Own price elasticity of ethanol demand	-0.43	Elobied and Tokgoz, 2008
η_{co}^b	Elasticity of corn demand by beef sector with respect price of corn	-0.19	Authors' estimation[24]
$\eta_{co,sym}^b$	Cross elasticity of corn demand by beef sector with respect price of soymeal	0.29	Authors' estimation
$\eta_{co,DG}^b$	Cross elasticity of corn demand by beef sector with respect price of DG	-0.31	Authors' estimation
η_{co}^p	Elasticity of corn demand by hog sector with respect price of corn	-0.14	Authors' estimation
$\eta_{co,sym}^p$	Cross elasticity of corn demand by hog sector with respect price of soymeal	0.24	Authors' estimation
$\eta_{co,DG}^p$	Cross elasticity of corn demand by hog sector with respect price of DG	-0.36	Authors' estimation

[24] Based on the structural models, the estimates were obtained by following double log differential forms with appropriate corrections for serial correlation.

Parameters	Definitions	Estimated Values	Source
η_{co}^{k}	Elasticity of corn demand by poultry sector with respect price of corn	-0.21	Authors' estimation
$\eta_{co,sym}^{k}$	Cross elasticity of corn demand by poultry sector with respect price of soymeal	0.29	Authors' estimation
$\eta_{co,DG}^{k}$	Cross elasticity of corn demand by poultry sector with respect price of DG	-0.32	Authors' estimation
η_{co}^{e}	Elasticity of corn demand by ethanol sector with respect price of corn	0	Fixed proportion relation[25]
η_{sym}^{b}	Elasticity of soymeal demand by beef sector with respect price of soymeal	-0.32	Authors' estimation
$\eta_{sym,co}^{b}$	Cross elasticity of soymeal demand by beef sector with respect price of corn	0.15	Authors' estimation
$\eta_{sym,DG}^{b}$	Cross elasticity of soymeal demand by beef sector with respect price of DG	0.09	Authors' estimation
η_{sym}^{p}	Elasticity of soymeal demand by hog sector with respect price of soymeal	-0.05	Authors' estimation
$\eta_{sym,co}^{p}$	Cross elasticity of soymeal demand by hog sector with respect price of corn	0.1	Authors' estimation
$\eta_{sym,DG}^{p}$	Cross elasticity of soymeal demand by hog sector with respect price of DG	0.05	Authors' estimation
η_{sym}^{k}	Elasticity of soymeal demand by poultry sector with respect price of soymeal	-0.22	Authors' estimation
$\eta_{sym,co}^{k}$	Cross elasticity of soymeal demand by poultry sector with respect price of corn	0.14	Authors' estimation
$\eta_{sym,DG}^{k}$	Cross elasticity of soymeal demand by poultry sector with respect price of DG	0.07	Authors' estimation
η_{sy}	Own price elasticity of soybean demand	-0.37	Gerlt, 2013
$\eta_{sy,sym}$	Cross price elasticity of soybean demand with respect to soymeal demand	0.25	Gerlt, 2013
η_{DG}^{b}	Elasticity of DG demand by beef sector with respect price of DG	-0.79	Authors' estimation
$\eta_{DG,co}^{b}$	Cross elasticity of DG demand by beef sector with respect price of corn	0.4	Authors' estimation
$\eta_{DG,sym}^{b}$	Cross elasticity of DG demand by beef sector with respect price of soymeal	0.24	Authors' estimation
η_{DG}^{p}	Elasticity of DG demand by hog sector with respect price of DG	-0.8	Authors' estimation
$\eta_{DG,co}^{p}$	Cross elasticity of DG demand by hog sector with respect price of corn	0.38	Authors' estimation
$\eta_{DG,sym}^{p}$	Cross elasticity of DG demand by hog sector with respect price of soymeal	0.23	Authors' estimation
η_{DG}^{k}	Elasticity of DG demand by poultry sector with respect price of DG	-0.77	Authors' estimation
$\eta_{DG,co}^{k}$	Cross elasticity of DG demand by poultry sector with respect price of corn	0.39	Authors' estimation
$\eta_{DG,sym}^{k}$	Cross elasticity of DG demand by poultry sector with respect price of soymeal	0.2	Authors' estimation

[25] Because of the fixed proportion relation between corn and ethanol, the decision on volume of ethanol production determines the quantity of corn demanded. This implies that corn demand for ethanol does not respond to corn price and is inelastic as shown in Fig 2.1, panel f.

Parameters	Definitions	Estimated Values	Source
η_{co}^{x}	Corn export demand elasticity	-1.11	Remier et al. 2012
η_{sym}^{x}	Soybean meal export demand elasticity	-1.41	Piggot and Wohlgenant, 2001
η_{sy}^{x}	Soybean export demand elasticity	-0.90	Remier et al. 2012
η_{DG}^{x}	DG export demand elasticity	2	Expert opinion
η_{e}^{m}	Ethanol demand elasticity with respect to mandate	1	See footnote 21 in the main text
ε_{b}^{r}	Own price elasticity of beef supply at the retail level	0.36	Brester et al., 2004
ε_{b}^{w}	Own price elasticity of beef supply at the processing level	0.28	Brester et al., 2004
ε_{b}^{s}	Own price elasticity of slaughter cattle supply at the feedlot level	0.26	Marsh, 1994
ε_{b}^{f}	Own price elasticity of feeder cattle supply at the farm level	0.22	Marsh, 2003
ε_{p}^{r}	Own price elasticity of pork supply at the retail level	0.73	Brester et al., 2004
ε_{p}^{w}	Own price elasticity of pork supply at the processing level	0.44	Brester et al., 2004
ε_{p}^{f}	Own price elasticity of slaughter hog supply at the farm level	0.41	Lemieux and Wohlgenant, 1989
ε_{k}^{r}	Own price elasticity of poultry supply at the retail level	0.18	Brester et al., 2004
ε_{k}^{w}	Own price elasticity of poultry supply at the processing level	0.14	Brester et al., 2004
ε_{co}^{b}	Elasticity of slaughter cattle supply with respect to price of corn	-0.02	Meyers et al. 1992
ε_{sym}^{b}	Elasticity of slaughter cattle supply with respect to price of soymeal	-0.003	Meyers et al. 1992
ε_{DG}^{b}	Elasticity of slaughter cattle supply with respect to price of DG	-0.002	Expert opinion
ε_{co}^{p}	Elasticity of hog supply with respect to price of corn	-0.09	Stoddart, 1991
ε_{sym}^{p}	Elasticity of hog supply with respect to price of soymeal	-0.03	Expert opinion
ε_{DG}^{p}	Elasticity of hog supply with respect to price of DG	-0.002	Expert opinion
ε_{co}^{k}	Elasticity of poultry supply with respect to price of corn	-0.02	Heien, 1976
ε_{sym}^{k}	Elasticity of poultry supply with respect to price of soymeal	-0.03	Meyers et al. 1992
ε_{DG}^{k}	Elasticity of poultry supply with respect to price of DG	-0.001	Expert opinion
ε_{co}	Own price elasticity of corn supply	0.25	Bhattacharya et al., 2009
ε_{sym}	Own price elasticity of soymeal supply	0.14	Piggott et al., 2001
ε_{sy}	Own price elasticity of soybean supply	0.25	Gerlt, S., 2013
ε_{DG}	Own price elasticity of DG supply	0	Fixed proportion relation[26]
ε_{e}	Own price elasticity of ethanol supply	0.65	Elobeid and Tokgoz, 2008

[26] Result of the fixed proportion relation between ethanol and its by-product DG

Parameters	Definitions	Estimated Values	Source
$\varepsilon_{e,co}$	Elasticity of ethanol supply with respect to price of corn	0.13	Luchansky and Monks, 2009
ε_{b}^{g}	Elasticity of feeder cattle supply with respect to pasture yield	0.25	Expert opinion
ε_{co}^{k}	Corn supply elasticity with respect to rainfall	0.16	Authors' estimation using Westcott and Jewison 2013
ε_{co}^{k}	Soybean supply elasticity with respect to rainfall	0.23	Authors' estimation using Westcott and Jewison 2013
τ_{b}^{rw}	Elasticity of beef quantity at the retail level with respect to quantity at the processing level	0.71	RTI, 2007
τ_{b}^{wr}	Elasticity of beef quantity at the processing level with respect to quantity at the retail level	1.03	Brester et al., 2004
τ_{b}^{ws}	Elasticity of beef quantity at the processing level with respect to quantity at the feedlot level	0.93	RTI, 2007
τ_{b}^{sw}	Elasticity of slaughter beef quantity at the feedlot level with respect to beef quantity at the processing level	1.02	Brester et al., 2004
τ_{b}^{sf}	Elasticity of slaughter quantity at the feedlot level with respect to feeder cattle quantity at the farm level	0.94	RTI, 2007
τ_{b}^{fs}	Elasticity of feeder quantity at the farm level with respect to slaughter quantity at the feedlot level	0.78	Brester et al., 2004
τ_{p}^{rw}	Elasticity of pork quantity at the retail level with respect to quantity at the processing level	0.95	Expert opinion
τ_{p}^{wr}	Elasticity of pork quantity at the processing level with respect to quantity at the retail level	1.01	Brester et al., 2004
τ_{p}^{wf}	Elasticity of pork quantity at the processing level with respect to hog quantity at the farm level	0.95	Expert opinion
τ_{p}^{fw}	Elasticity of hog quantity at the farm level with respect to quantity at the processing level	1.00	Brester et al., 2004
τ_{k}^{rw}	Elasticity of poultry quantity at the retail level with respect to quantity at the processing level	0.95	Expert opinion
τ_{k}^{wr}	Elasticity of poultry quantity at the processing level with respect to quantity at the retail level	0.98	Brester et al., 2004
$\tau^{co,s}$	Elasticity of corn demand by beef sector with respect to quantity of slaughter cattle	1	Unit cost function (UCF)[27]
$\tau^{co,p}$	Elasticity of corn demand by pork sector with respect quantity of hog	1	UCF
$\tau^{co,k}$	Elasticity of corn demand by poultry sector with respect to quantity of poultry	1	UCF
$\tau^{co,e}$	Elasticity of corn demand by ethanol sector with respect to quantity of ethanol	1	UCF
S_{b}^{co}	Share of total corn utilization by beef sector	0.11	Conley et al., 2012
S_{p}^{co}	Share of total corn utilization by hog sector	0.11	Conley et al., 2012
S_{k}^{co}	Share of total corn utilization by poultry sector	0.13	Conley et al., 2012
S_{e}^{co}	Share of total corn utilization by ethanol sector	0.35	Conley et al., 2012

[27] 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.

Parameters	Definitions	Estimated Values	Source
S_x^{co}	Share of total corn utilization for net corn export	0.15	Conley et al., 2012
$\tau^{sym,s}$	Elasticity of soymeal demand by beef sector with respect to quantity of slaughter cattle	1	UCF
$\tau^{sym,p}$	Elasticity of soymeal demand by pork sector with respect quantity of hog	1	UCF
$\tau^{sym,k}$	Elasticity of soymeal demand by poultry sector with respect to quantity of poultry	1	UCF
S_b^{sym}	Share of total soymeal utilization by beef	0.09	USB, 2012
S_p^{sym}	Share of total soymeal utilization by hog sector	0.19	USB, 2012
S_k^{sym}	Share of total soymeal utilization by poultry sector	0.35	USB, 2012
S_x^{sym}	Share of total soymeal utilization for net soymeal export	0.23	USB, 2012
$\tau^{DG,s}$	Elasticity of DG demand by beef sector with respect to quantity of slaughter cattle	1	UCF
$\tau^{DG,p}$	Elasticity of DG demand by pork sector with respect quantity of hog	1	UCF
$\tau^{DG,k}$	Elasticity of DG demand by poultry sector with respect to quantity of poultry	1	UCF
S_b^{DG}	Share of total DG utilization by beef sector	0.56	Hoffman and Baker, 2011
S_p^{DG}	Share of total DG utilization by hog sector	0.10	Hoffman and Baker, 2011
S_k^{DG}	Share of total DG utilization by poultry sector	0.07	Hoffman and Baker, 2011

Table 2.3: Meat market impact of 32% decrease in rainfall[28]

Markets	Proportionate Change in	Without the use of RIN credits					With the use of RIN credits				
				90% CI					90% CI		
		Mean	Std. Dev	Lower	Upper	Max p-value	Mean	Std. Dev	Lower	Upper	Max p-value
		1	2	3	4	5	6	7	8	9	10
Beef	Retail Price	0.049	0.011	0.013	0.084	0.053	0.047	0.011	0.012	0.082	0.054
	Retail Qty	-0.031	0.007	-0.054	-0.007	0.059	-0.030	0.007	-0.054	-0.007	0.059
	Processor Price	0.063	0.014	0.019	0.108	0.050	0.062	0.014	0.018	0.107	0.050
	Processor Qty	-0.068	0.013	-0.109	-0.026	0.038	-0.067	0.013	-0.108	-0.025	0.038
	Slaughter Price	0.034	0.015	-0.015	0.082	0.207	0.033	0.015	-0.015	0.081	0.209
	Slaughter Qty	-0.091	0.012	-0.130	-0.053	0.017	-0.090	0.012	-0.128	-0.052	0.018
	Farm Price	0.053	0.016	0.002	0.105	0.092	0.055	0.016	0.004	0.105	0.087
	Farm Qty	-0.104	0.004	-0.116	-0.093	0.001	-0.104	0.004	-0.116	-0.092	0.001
Pork	Retail Price	0.011	0.002	0.004	0.018	0.040	0.009	0.002	0.002	0.016	0.055
	Retail Qty	0.008	0.003	-0.001	0.018	0.133	0.009	0.003	0.000	0.019	0.093
	Processor Price	0.012	0.002	0.004	0.019	0.039	0.009	0.002	0.002	0.016	0.058
	Processor Qty	0.000	0.002	-0.006	0.007	1.000	0.003	0.002	-0.003	0.009	0.356
	Farm Price	0.011	0.002	0.003	0.018	0.051	0.008	0.002	0.001	0.015	0.073
	Farm Qty	-0.005	0.001	-0.009	-0.001	0.065	-0.001	0.001	-0.004	0.002	1.000
Poultry	Retail Price	0.021	0.004	0.008	0.035	0.039	0.019	0.004	0.006	0.032	0.048
	Retail Qty	0.003	0.001	-0.001	0.007	0.166	0.003	0.001	0.000	0.007	0.117
	Processor Price	0.017	0.004	0.006	0.029	0.047	0.015	0.004	0.003	0.027	0.059
	Processor Qty	-0.001	0.001	-0.003	0.001	0.551	0.000	0.001	-0.002	0.002	1.000

[28] The values in this table and subsequent tables are in terms of proportionate change which needs to be multiplied by 100 to get the percentage change

Table 2.4: Grain, feed, and ethanol market impact of 32% decrease in rainfall

Markets	Proportionate Change in	Without the use of RIN credits					With the use of RIN credits				
				90% CI					90% CI		
		Mean	Std. Dev	Lower	Upper	Max p-value	Mean	Std. Dev	Lower	Upper	Max p-value
		1	2	3	4	5	6	7	8	9	10
Corn	Price	0.088	0.005	0.071	0.106	0.004	0.033	0.004	0.021	0.045	0.014
	Qty	-0.029	0.002	-0.034	-0.024	0.003	-0.043	0.001	-0.046	-0.040	0.001
Soybean	Price	0.051	0.005	0.036	0.066	0.008	0.044	0.004	0.031	0.057	0.009
	Qty	-0.019	0.001	-0.022	-0.016	0.002	-0.020	0.001	-0.023	-0.018	0.002
Soybean meal	Price	0.074	0.005	0.059	0.090	0.004	0.074	0.005	0.058	0.089	0.004
	Qty	-0.055	0.002	-0.061	-0.049	0.001	-0.055	0.002	-0.061	-0.050	0.001
DG	Price	-0.016	0.007	-0.039	0.008	0.220	-0.016	0.007	-0.039	0.006	0.183
	Qty	0.000	0.000	0.000	0.000	0.036	-0.015	0.001	-0.018	-0.013	0.003
Ethanol	Price	0.018	0.003	0.009	0.027	0.025	-0.126	0.009	-0.154	-0.098	0.005
	Qty	0.000	0.000	0.000	0.000	0.036	-0.085	0.004	-0.100	-0.071	0.003
Corn demand	Beef sector	-0.089	0.011	-0.123	-0.054	0.015	-0.078	0.011	-0.112	-0.045	0.018
	Pork sector	0.000	0.004	-0.011	0.012	1.000	0.011	0.003	0.001	0.021	0.081
	Poultry sector	0.000	0.004	-0.011	0.011	1.000	0.011	0.003	0.003	0.020	0.058
	Ethanol sector	0.000	0.000	0.000	0.000	0.036	-0.085	0.004	-0.100	-0.071	0.003
	Export	-0.098	0.007	-0.121	-0.074	0.006	-0.036	0.004	-0.050	-0.022	0.016
Soybean demand	Domestic	-0.104	0.006	-0.122	-0.087	0.003	-0.103	0.005	-0.120	-0.086	0.003
	Export	-0.015	0.003	-0.024	-0.005	0.041	-0.016	0.003	-0.025	-0.007	0.032
Soybean meal demand	Beef sector	-0.096	0.012	-0.135	-0.057	0.017	-0.101	0.012	-0.139	-0.062	0.014
	Pork sector	0.000	0.001	-0.004	0.005	1.000	-0.001	0.001	-0.004	0.003	1.000
	Poultry sector	-0.001	0.002	-0.006	0.005	1.000	-0.006	0.001	-0.010	-0.002	0.043
	Export	-0.046	0.004	-0.059	-0.032	0.009	-0.039	0.004	-0.051	-0.027	0.009
DG demand	Beef sector	-0.031	0.008	-0.058	-0.005	0.071	-0.054	0.008	-0.079	-0.028	0.023
	Pork sector	0.053	0.006	0.033	0.073	0.014	0.035	0.006	0.017	0.052	0.026
	Poultry sector	0.056	0.006	0.036	0.076	0.012	0.034	0.005	0.018	0.051	0.024
	Export	0.031	0.014	-0.015	0.077	0.216	0.033	0.014	-0.011	0.076	0.180

Table 2.5: Level of mandate waiver required to fully offset the impact of 32% decrease in rainfall on the equilibrium corn price

Proportionate Change in	Stochastic Mean	Std. Dev	90% CI		Max p-value
			Lower	Upper	
Mandate	-0.227	0.024	-0.302	-0.152	0.011
Ethanol Quantity	-0.136	0.007	-0.159	-0.113	0.003

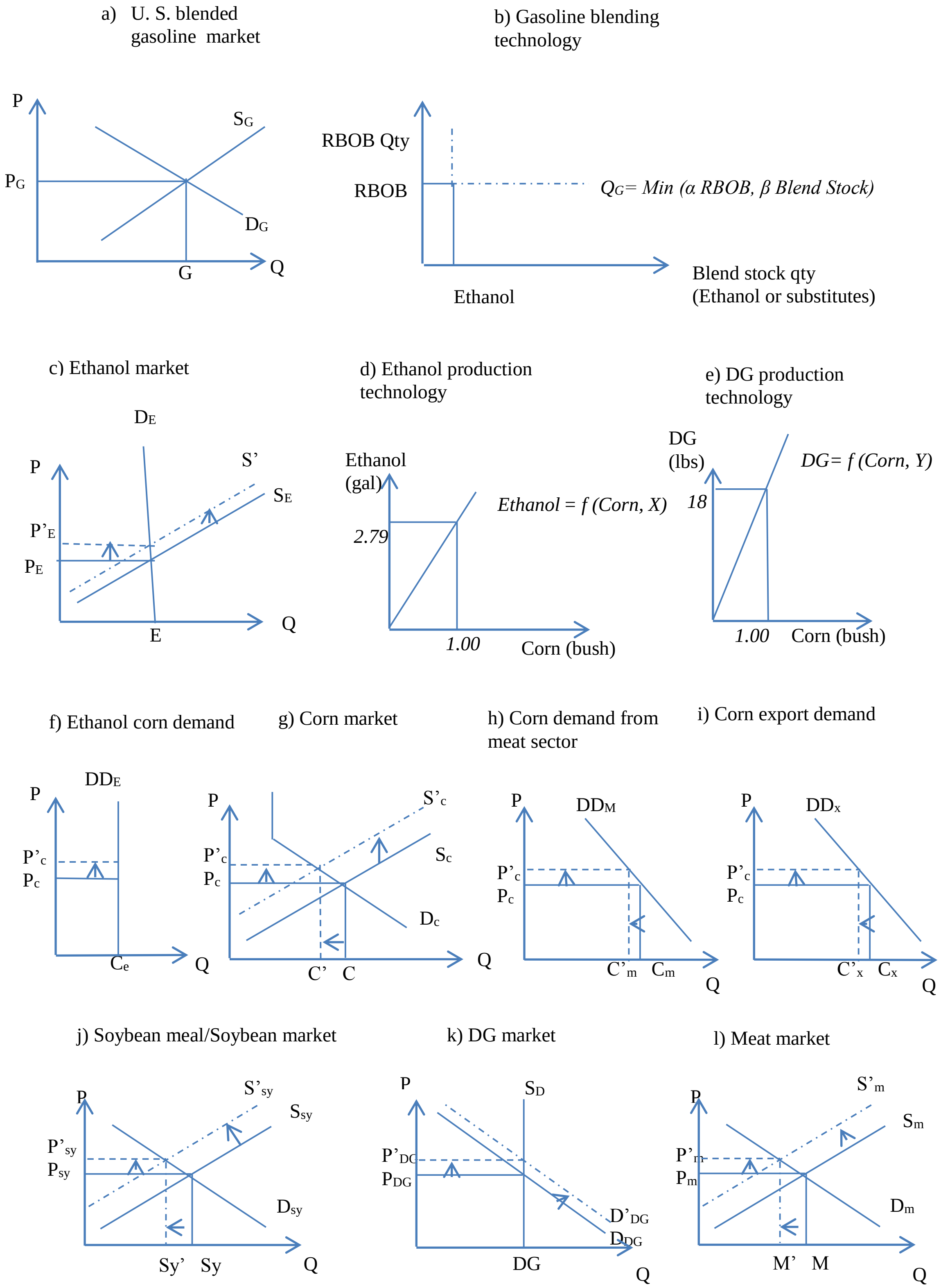

Figure 2.1: Market effects of drought without the RFS waiver and the RIN credits

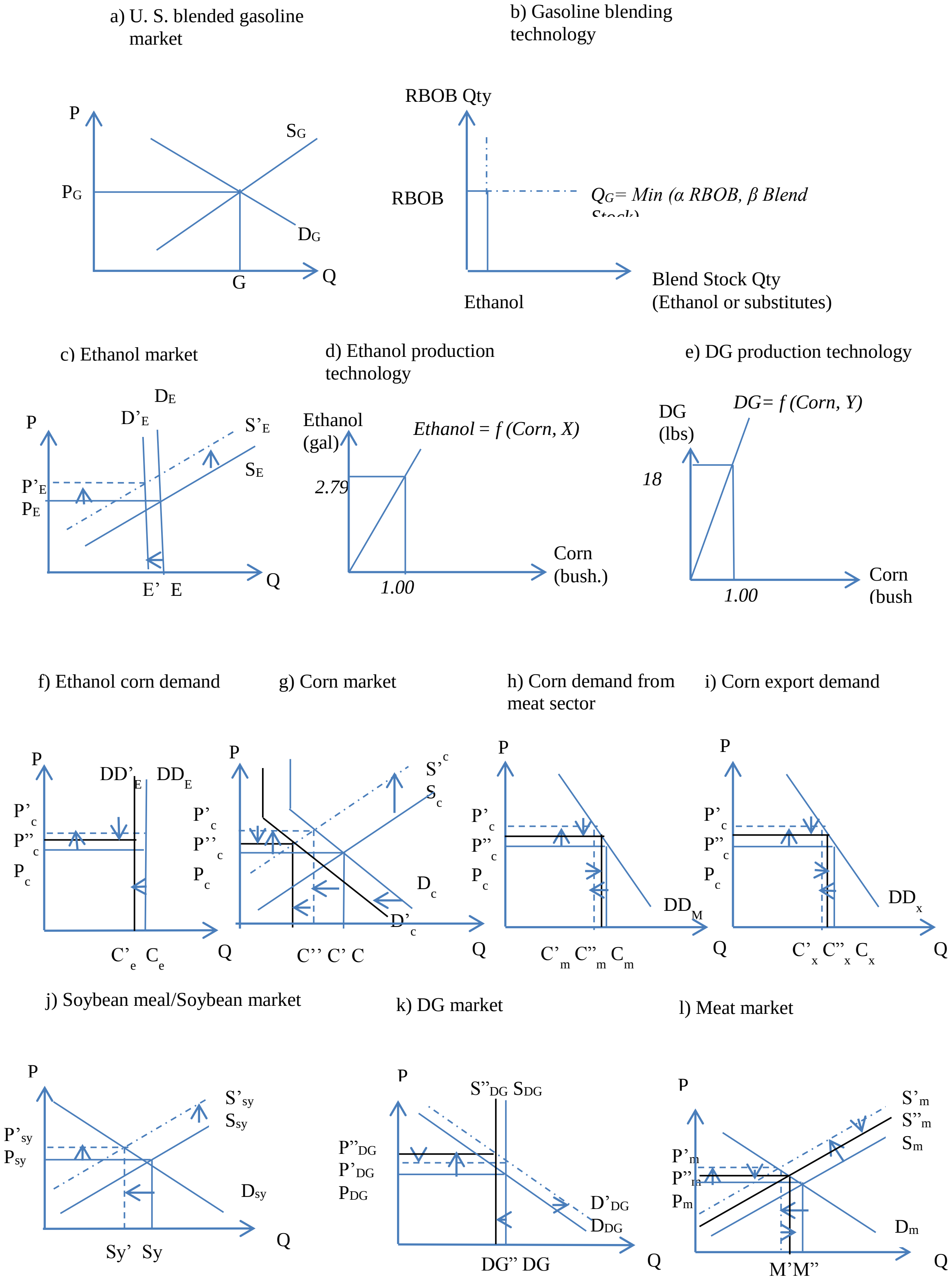

Figure 2.2 : Market effects of drought with the RFS waiver and the RIN credits

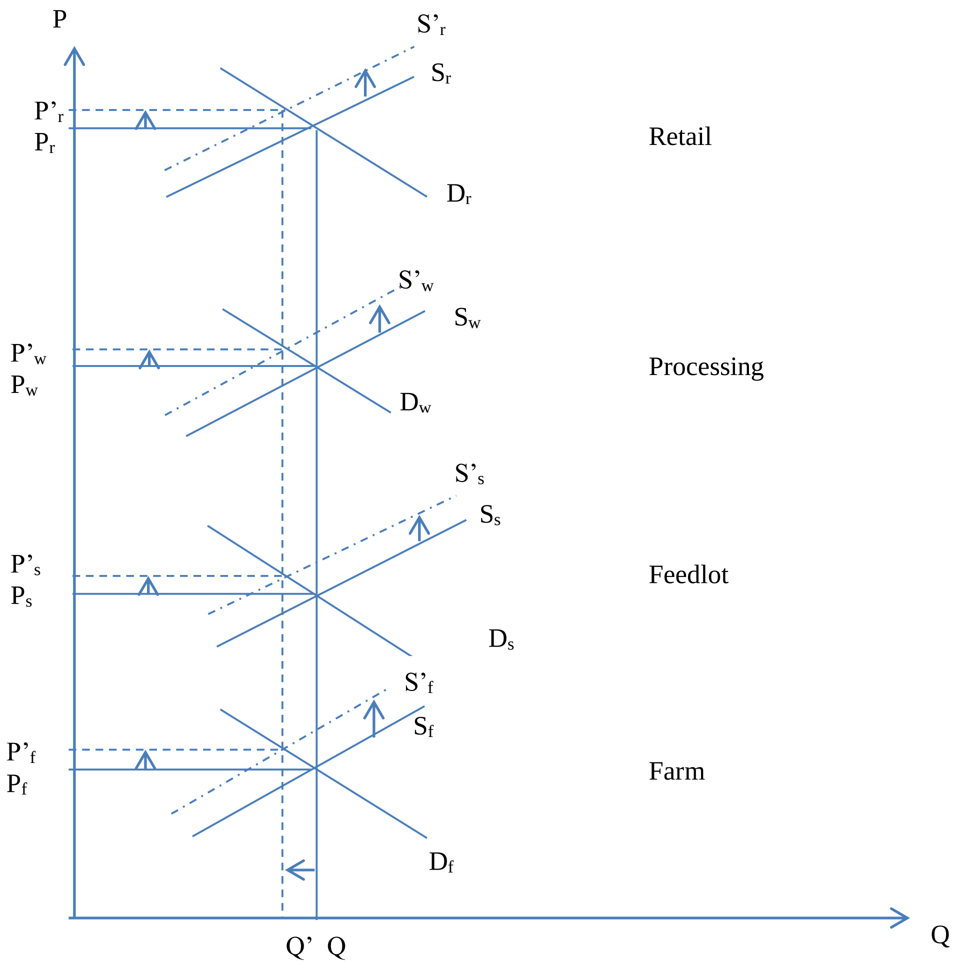

Figure 2.3 : Market effects of drought on the meat marketing chain

APPENDIX 2.A: LOG DIFFERENTIAL EQUATIONS OF THE STRUCTURAL MODELS

Beef market:

1. $dlnQ_b^{rd} - \eta_b^r dlnP_b^r - \eta_{bp}^r dlnP_p^r - \eta_{bk}^r dlnP_k^r = 0$

2. $dlnQ_b^{rs} - \varepsilon_b^r dlnP_b^r - \tau_b^{rw} dlnQ_b^w = 0$

3. $dlnQ_b^{wd} - \eta_b^w dlnP_b^w - \tau_b^{wr} dlnQ_b^r = 0$

4. $dlnQ_b^{ws} - \varepsilon_b^w dlnP_b^w - \tau_b^{ws} dlnQ_b^s = 0$

5. $dlnQ_b^{sd} - \eta_b^s dlnP_b^s - \tau_b^{sw} dlnQ_b^w = 0$

6. $dlnQ_b^{ss} - \varepsilon_b^s dlnP_b^s - \tau_b^{sf} dlnQ_b^f - \varepsilon_{co}^b dlnP_{co} - \varepsilon_{sym}^b dlnP_{sym} - \varepsilon_{DG}^b dlnP_{DG} = 0$

7. $dlnQ_b^{fd} - \eta_b^f dlnP_b^f - \tau_b^{fs} dlnQ_b^s = 0$

8. $dlnQ_b^{fs} - \varepsilon_b^f dlnP_b^f = \varepsilon_b^g dlnW_g$[29, 30]

Pork market:

9. $dlnQ_p^{rd} - \eta_p^r dlnP_p^r - \eta_{pb}^r dlnP_b^r - \eta_{pk}^r dlnP_k^r = 0$

10. $dlnQ_p^{rs} - \varepsilon_p^r dlnP_p^r - \tau_p^{rw} dlnQ_p^w = 0$

11. $dlnQ_p^{wd} - \eta_p^w dlnP_p^w - \tau_p^{wr} dlnQ_p^r = 0$

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[29] The elasticity of cattle supply with respect to pasture yield (*Wg)* is not available in the literature. Consultation with a range specialist revealed that during drought the general tendency is to overgraze pasture to maintain production. This implies that the elasticity of cattle supply with respect to pasture yield is inelastic. The non-responsiveness of cattle supply is also supported by the fact that pasture is not the only source of feed during drought, hay from previous years or corn stalks can be also used to supplement the pasture supply making the response to pasture decline relatively inelastic. Because there is no estimate in the literature, ε_b^g = 0.25 is used.

[30] To find the relationship between pasture yield and rainfall, the regression estimates from Wiles et al. (2011) are rescaled and converted into elasticity at mean estimates using the information provided in the article. The elasticity estimate used is the average of the estimate for North Dakota, Montana, and Wyoming provided in Wiles et al. (2011).

12. $dlnQ_p^{ws} - \varepsilon_p^w dlnP_p^w - \tau_p^{wf} dlnQ_p^f = 0$

13. $dlnQ_p^{fd} - \eta_p^f dlnP_p^f - \tau_p^{fw} dlnQ_p^w = 0$

14. $dlnQ_p^{fs} - \varepsilon_p^f dlnP_p^f - \varepsilon_{pco}^f dlnP_{co} - \varepsilon_{psym}^f dlnP_{sym} - \varepsilon_{pDG}^f dlnP_{DG} = 0$

Poultry market:

15. $dlnQ_k^{rd} - \eta_k^r dlnP_k^r - \eta_{kb}^r dlnP_b^r - \eta_{kp}^r dlnP_p^r = 0$

16. $dlnQ_k^{rs} - \varepsilon_k^r dlnP_k^r - \tau_k^{rw} dlnQ_k^w = 0$

17. $dlnQ_k^{wd} - \eta_k^w dlnP_k^w - \tau_k^{wr} dlnQ_k^r = 0$

18. $dlnQ_k^{ws} - \varepsilon_k^w dlnP_k^w - \varepsilon_{pco}^w dlnP_{co} - \varepsilon_{psym}^w dlnP_{sym} - \varepsilon_{pDG}^w dlnP_{DG} = 0$

Corn market:

19. $dlnQ_{co}^b - \eta_{co}^b dlnP_{co} - \tau^{co,s} dlnQ_b^s - \eta_{co,sym}^b dlnP_{sym} - \eta_{co,DG}^b dlnP_{DG} = 0$

20. $dlnQ_{co}^p - \eta_{co}^p dlnP_{co} - \tau^{co,p} dlnQ_p^f - \eta_{co,sym}^p dlnP_{sym} - \eta_{co,DG}^p dlnP_{DG} = 0$

21. $dlnQ_{co}^k - \eta_{co}^k dlnP_{co} - \tau^{co,k} dlnQ_k^w - \eta_{co,sym}^k dlnP_{sym} - \eta_{co,DG}^k dlnP_{DG} = 0$

22. $dlnQ_{co}^e - \eta_{co}^e dlnP_{co} - \tau^{co,e} dlnQ_e = 0$

23. $dlnQ_{co}^x - \eta_{co}^x dlnP_{co} = 0$

24. $dlnQ_{co}^d - S_b^{co} dlnQ_{co}^b - S_p^{co} dlnQ_{co}^p - S_k^{co} dlnQ_{co}^k - S_e^{co} dlnQ_{co}^e - S_x^{co} dlnQ_{co}^x = 0$

25. $dlnQ_{co}^s - \varepsilon_{co} dlnP_{co} = \varepsilon_{co}^R dlnR$[31]

Soybean and soybean meal market:

26. $dlnQ_{sym}^b - \eta_{sym}^b dlnP_{sym} - \tau^{sym,s} dlnQ_b^s - \eta_{sym,co}^b dlnP_{co} - \eta_{sym,DG}^b dlnP_{DG} = 0$

27. $dlnQ_{sym}^p - \eta_{sym}^p dlnP_{sym} - \tau^{sym,p} dlnQ_p^f - \eta_{sym,co}^p dlnP_{co} - \eta_{DG,sym}^p dlnP_{DG} = 0$

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[31] $\varepsilon_{co}^R = 0.16$. The elasticities of corn and soybean with respect to rainfall are calculated using precipitation slope coefficients from Westcott and Jewison (2013).

28. $dlnQ_{sym}^{k} - \eta_{sym}^{k} dlnP_{sym} - \tau^{sym,k} dlnQ_{k}^{w} - \eta_{sym,co}^{k} dlnP_{co} - \eta_{sym,DG}^{k} dlnP_{DG} = 0$

29. $dlnQ_{sym}^{x} - \eta_{sym}^{x} dlnP_{sym} = 0$

30. $dlnQ_{sym}^{d} - S_{b}^{sym} dlnQ_{sym}^{b} - S_{p}^{sym} dlnQ_{sym}^{p} - S_{k}^{sym} dlnQ_{sym}^{k} - S_{x}^{sym} dlnQ_{sym}^{x} = 0$

31. $dlnQ_{sym}^{s} - \varepsilon_{sym} dlnP_{sym} - \tau_{sym}^{b} dlnQ_{sy} = 0$

32. $dlnQ_{sy}^{d} - \eta_{sy} dlnP_{sy} - \eta_{sy,sym}^{sy} dlnP_{sym} = 0$

33. $dlnQ_{sy}^{x} - \eta_{sy}^{x} dlnP_{sy} = 0$

34. $dlnQ_{sy} - S_{d}^{sy} dlnQ_{sy}^{d} - S_{x}^{sy} dlnQ_{sy}^{x} = 0$

35. $dlnQ_{sy}^{s} - \varepsilon_{sy} dlnP_{sy} = \varepsilon_{sy}^{R} dln\, R$[32]

Distillers' grain market:

36. $dlnQ_{DG}^{b} - \eta_{DG}^{b} dlnP_{DG} - \tau^{DG,s} dlnQ_{b}^{s} - \eta_{DG,co}^{b} dlnP_{co} - \eta_{DG,sym}^{b} dlnP_{sym} = 0$

37. $dlnQ_{DG}^{p} - \eta_{DG}^{p} dlnP_{DG} - \tau^{DG,h} dlnQ_{p}^{f} - \eta_{DG,co}^{p} dlnP_{co} - \eta_{DG,sym}^{p} dlnP_{sym} = 0$

38. $dlnQ_{DG}^{k} - \eta_{DG}^{k} dlnP_{DG} - \tau^{DG,k} dlnQ_{k}^{w} - \eta_{DG,co}^{k} dlnP_{co} - \eta_{DG,sym}^{k} dlnP_{sym} = 0$

39. $dlnQ_{DG}^{x} - \eta_{DG}^{x} dlnP_{DG} = 0$

40. $dlnQ_{DG}^{d} - S_{b}^{DG} dlnQ_{DG}^{b} - S_{p}^{DG} dlnQ_{DG}^{h} - S_{k}^{DG} dlnQ_{DG}^{k} - S_{x}^{DG} dlnQ_{DG}^{x} = 0$

41. $dlnQ_{DG}^{s} - 0.18\, dlnQ_{co}^{e} = 0$

Ethanol market:

42. $dlnQ_{e}^{d} - \eta_{e} dlnP_{e} = \eta_{e}^{m} dlnM$[33]

43. $dlnQ_{e}^{s} - \varepsilon_{e} dlnP_{e} - \varepsilon_{e,co} dlnP_{co} = 0$

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[32] ε_{sy}^{R} = 0.23 (Wescott and Jewison, 2013).

[33] $\eta_{e}^{m} = 1$. The assumption here is that the level of ethanol consumption is equal to the level of the mandate when the mandate does not exceed the blend wall, and any change in the mandate shifts the ethanol demand curve by the amount of mandate change. This means that the proportionate change in ethanol consumption is equal to the proportionate change in the mandate.

DOES THE UNITED STATES HAVE MARKET POWER IN IMPORTING ETHANOL FROM BRAZIL?

3.1 Introduction

The Renewable Fuels Standards (RFS2) as enacted under the Energy Independence and Security Act 2007 (EISA) consists of two parts: a renewable fuel mandate and an advanced biofuel mandate. The mandates require consumption of a certain volume of conventional (corn ethanol) and advanced biofuels such as cellulosic ethanol, biodiesel, and sugarcane ethanol for each year. The conventional corn-based ethanol produced in the United States only fulfills the requirements of the renewable mandate. The advanced mandate requires only those biofuels which reduce 50% or more of greenhouse gases (GHGs) (US EIA, 2012). The advanced mandate increases in coming years. In 2013, it required that 2.75 billion gallons of advanced biofuels be produced to fulfill the mandate requirement which is scheduled to increase to 21 billion gallons by 2022 (US EPA, 2010). Moreover, its share in the total mandate is also increasing. By 2022, the advanced biofuels portion is expected to be about 58% of the total RFS2 mandate compared to about 17% in 2013.

Progress in the production of advanced biofuels in the United States has not been as envisaged. The mandate for biomass-based diesel for 2012 was one billion gallons with actual production estimated at 969 million gallons (US EIA, 2013). The mandate for cellulosic ethanol in 2012 was 500 million gallons. However, due to inadequate production, the U.S. Environmental Protection Agency (US EPA) revised the target to 10.45 million gallons. Even this target was not achieved as the U.S. Energy Information

Agency (US EIA, 2012) estimated production of cellulosic ethanol for 2012 was 0.5 million gallons only. Given the limited production of cellulosic ethanol, it is unlikely that the 16 billion gallons of cellulosic ethanol targeted to advanced biofuels by 2022 will be fulfilled.

Lowering the target amount of advanced biofuels required does not seem viable for the EPA, given the high proportion of the overall RFS2 target it represents. Since corn-based ethanol is explicitly prohibited from being considered as an advanced biofuel (US EIA, 2012), two options seem likely. The first is to increase the quantities of sugarcane-based ethanol through imports, a classified advanced biofuel (US EIA, 2012). The second option would be to increase the production of biodiesel in excess of its own mandate and use that excess to make up for the lack of other advanced biofuels such as cellulosic ethanol. Given the current economics and the state of biodiesel production in the US, the import of sugarcane ethanol produced in Brazil is favored even with a $1/gallon tax credit for biodiesel (Irwin and Good, 2013). This is further reinforced by the fact that blenders already import ethanol from Brazil.[34, 35]

The strategic position of the United States in importing sugarcane ethanol from Brazil remains unexplored. As shown by Helpman and Krugman (1989), trade policy

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[34] The assumption here is that the 'blend wall', which is a technical constraint in ethanol blending that does not allow blenders to blend more than 10% of the total gasoline volume of ethanol, will be circumvented in coming years.

[35] Realizing the strategic importance of Brazilian ethanol in fulfilling the advanced mandate, there have been calls to remove the advanced biofuel mandate by the domestic ethanol industry, probably to evade competition from Brazilian ethanol (WSJ January 30, 2013). This is quite unlike in the past when domestic industries considered mandates as a policy instrument for protecting the U.S. ethanol industry. This highlights the strategic importance of Brazilian ethanol for fulfilling the RFS mandates.

instruments such as a tariff, a subsidy, or a quota may improve or worsen the welfare of the trading partners depending on the structure of the international market in question. For example, when a country is a dominant importer and its importing firms are too small to exercise buyer power, the country can behave as a monopsonistic firm and buy the imported goods cheaper by restricting imports with an optimal tariff (Vousden, 1990). Alternatively, if importers do have buyer power, then unrestricted imports will be the optimal trade policy. Despite the implications of market structure for trade policy, most of the past analyses of U.S. trade policy toward ethanol imports have not considered the strategic position of the United States in the international ethanol market[36].

Formal studies on U.S.–Brazil sugarcane ethanol trade structure are sparse. To date this work has been focused on the U.S. ethanol tax and tariff policies. Notable contributions include Elobeid and Tokgoz (2008), de Gorter and Just (2008), de Gorter et al. (2009), Devadoss and Kuffel (2010), Yano et al. (2010), Lee and Sumner (2010), and Lasco and Khanna (2010). So far, studies of U.S. market power in the international ethanol market are not available.

This chapter is directed toward the initial steps to remedy this defect. The approach taken for this study is based on Baker and Breshnahan (1988) and Goldberg and Knetter (1999) who estimate the (inverse) residual demand elasticity to measure oligopoly power. For this study, the (inverse) residual supply is estimated to gauge the presence of oligopsony power. Unlike conventional supply elasticities of ethanol imports from Brazil

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[36] Devadoss and Kuffel (2010), Lee and Sumner (2010), and de Gorter et al. (2009) are some notable examples of the studies that do not consider the U.S. strategic position in biofuels trade. However, Lasco and Khanna (2010), include a U.S. market power scenario in analyzing US–Brazil ethanol trade.

such as those available from Elobeid and Tokgoz (2008), de Gorter and Just (2008), and Lee and Sumner (2010), the residual supply elasticities provide insight into market power by including the strategic interdependence among import-competing countries, including the United States, the European Union, and other significant trade partners.

The next section provides some background information about Brazilian sugarcane ethanol exports and a brief description of biofuels policies of major ethanol importing countries. Section 3.3 presents a theoretical base used to frame the empirical model, which is described in section 3.4. Section 3.5 details the data sources. Section 3.6 presents the results, and the final section of the chapter summarizes and concludes with a trade policy implication of the results.

3.2 The Brazilian sugarcane ethanol trade

The United States and Brazil are major producers, consumers, and traders of fuel ethanol accounting for 87% of the world's production in 2011 (ISO, 2012). The United States leads Brazil in the production and export of this fuel. Brazilian ethanol is primarily distilled from sugarcane and is regarded as environmentally friendly compared to the primarily corn-based U.S. product. Brazilian sugarcane ethanol exports increased sharply in 2001 and peaked near 1.35 billion gallons in 2008 (ISO, 2012). Exports then dropped during the 2009-2011 period due to a smaller sugarcane crop as a result of crop failure in Brazil, but recovered in 2012, reaching 818 million gallons (UNICA, 2013).

The United States is the largest importer of Brazilian sugarcane ethanol, which accounted for 66% of total Brazilian exports in 2012 and 28% of the total between 2001 and 2012 (Table 3.1). This relationship is likely to continue given the increasing amounts

of advanced biofuels mandated in the United States. Other major Brazilian ethanol importers include the European Union (EU) (mainly the Netherlands and Sweden), the Caribbean Basin Initiative (CBI) countries (mainly Jamaica, El Salvador, and Costa Rica), Japan, South Korea, Nigeria, Mexico, and India. These countries including the United States, accounted for about 95% of Brazilian ethanol exports in 2012 (MDICE, 2013).

As the third largest producer and consumer of ethanol in the world, the European Union (EU) plays a key role in global ethanol trade (ISO, 2012). Ethanol consumption in the EU began to increase during the mid-2000s as member countries instituted blending mandates similar to the United States (ISO, 2012). The EU's share of Brazil's ethanol exports between 2001and 2012 was about 20% with the Netherlands accounting for nearly 100% of the EU imports in 2012 (Table 3.1). The Renewable Energy Directive (RED) 2009, a part of the EU Energy and Climate Change Package, mandates member countries to obtain 10% of their transportation fuel from renewable sources (ISO, 2012). Under the RED, biofuels that can be counted toward fulfilment of the mandates have to reduce GHG emissions by 50% compared to conventional fossil fuels by 2017 (ISO, 2012). However, recently citing the indirect land use change impacts of biofuels, the European Commission proposed to reduce the 10% mandate of biofuels to maximum 5% in 2020 and fulfill the remaining mandate requirements from second generation biofuels such as lingo-cellulosic ethanol and ethanol made from waste and residual materials. If the proposal is implemented, it will require second generation biofuels to increase from the current level of 1.2 million tons to 4 million tons (ISO, 2012). The current state of production of second generation biofuels in EU and the rest of the world, make the

fulfilment of this target unlikely (ISO, 2012). These facts create considerable uncertainty surrounding the future demand for ethanol including that produced by Brazil.

During the period of 2001-2012, the three major CBI countries; Jamaica, El Salvador, and Costa Rica accounted for 15% of the total Brazilian ethanol exports. This share remained constant at 15% in 2012 (Table 3.1). Jamaica purchased about 8% of the exports during this period (MDICE, 2013) with El Salvador and Costa Rica accounting for 4% and 3% respectively. The Caribbean Basin Economic Recovery Act of 1989 (CBERA) allows the CBI countries duty-free access to U.S. ethanol market within the quota limit of 7% of total U.S. consumption. These countries take advantage of that act and use some of their imported hydrous ethanol (ethanol with about 4-7% water) from Brazil to reprocess into anhydrous ethanol (99% ethanol) and export it to the United States (Farinelli et al., 2009)[37]. The remaining ethanol is used domestically and fulfills their needs and mandates[38]. This duty-free access to the U.S. market gave these countries a competitive edge in exporting ethanol to the United States which had a tariff on ethanol imports. This advantage was eliminated at the end of 2011 when the tariff was suspended (ISO, 2012).

Japan and South Korea are the two major East Asian countries importing ethanol from Brazil accounting for about 9% and 8% respectively of the total Brazilian ethanol exports during the 2001-2012 period (Table 3.1). In 2012, Japan and South Korea

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[37] A small portion of U.S. ethanol import is still an anhydrous ethanol imported from countries other than Brazil (Hill, 2013).

[38] Jamaica has 10% ethanol gasoline blend mandate since 2009. Costa Rica started 10% ethanol blending in gasoline from 2013. Currently El Salvador does not have any mandate on ethanol blending (ISO, 2012).

imported a smaller percentage of the total at 4% and 5% (Table 3.1). Japan's current fuel ethanol blend limit is 3% with a proposed target of 10% biofuel blends by 2030 (Farinelli et al., 2009). Combined with the recent joint ventures between Japanese and Brazilian firms to produce more ethanol, raising the blend limit makes it likely that Japanese ethanol imports from Brazil will increase (ISO, 2012). South Korean biofuels policies have been concentrated toward development of its biodiesel industry since two thirds of the country's transportation sector runs on diesel (Masiero, 2008). However, the remaining third of the transportation sector uses ethanol which is blended with gasoline, is primarily imported from Brazil (Masiero, 2008). Due to the climate and limited land area in these countries, they are not likely to produce ethanol from food or feed crops (Masiero, 2008). This means that renewable fuels are likely continued to be imported from countries such as Brazil.

India, Nigeria, and Mexico also import ethanol from Brazil. Between 2001 and 2012 India, Nigeria and Mexico imported about 5%, 3%, and 2% of Brazil's total exports respectively (Table 3.1). However in recent years, especially after 2010, imports by India and Mexico have been almost non-existent with Nigerian imports declining to about 2% of Brazil's exports in 2012. As the domestic supply of ethanol is only sufficient to produce a 2% blend in India, target to blend 5% ethanol in transportation fuels has not been fully successful as of 2012 (ISO, 2012). Similarly Nigeria's plan of reaching a 10% ethanol blend has been unsuccessful. Domestic production is being bolstered by a plan to establish 14 biofuels plants that use sweet sorghum as the feed stock (ISO, 2012). The Mexican government introduced biofuels law to establish its biofuels production and

commercialization program in 2008. The program has not been successful due to the high price of sugarcane and the higher cost of ethanol production (ISO, 2012).

3.3 Theoretical framework

As mentioned earlier, Goldberg and Knetter's (1999) framework is used to estimate U.S. market power in importing sugarcane ethanol from Brazil. This methodology is modified to estimate market power exerted by an importing country (buyer) on the exporting country (seller). In the original work, market power is captured by the estimation of the (inverse) residual demand elasticity. In this work, the (inverse) residual supply elasticity is estimated as a measure of importer (buyer) market power. The residual demand for a specific product facing an exporting country is the difference between total demand by all importers and export supply by all rival exporting countries. Alternatively, the residual supply for a product imported by a particular country is the difference between the total supply by all exporting countries minus the import demand by all rival importing countries. In the context of estimating buyer power of U.S. importers in the sugarcane ethanol market, residual supply is the difference between Brazilian sugarcane ethanol supply and the demand by all countries that import Brazilian ethanol other than the United States.

A graphical representation of Brazilian sugarcane ethanol residual supply to the United States is shown in Figure 3.1. The schedules S_B and D_{row} respectively represent excess supply of sugarcane ethanol by Brazil and import demand for the Brazilian ethanol by all countries other than the United States. The United States is the largest importer of Brazilian ethanol and the rest of the importers are the fringe countries

competing with the United States in importing Brazilian ethanol. The residual supply of ethanol to the United States in the right panel is given by the horizontal difference between S_B and D_{row} in the left panel. Therefore, the residual supply schedule U.S. importers face is a function of changes in excess supply of ethanol from Brazil and the demand from importers in other competing countries. If the residual supply schedule is horizontal, i.e. a perfectly competitive market, the price of Brazilian ethanol is completely determined by the other importers' demand. U.S. ethanol importers would not be able to induce any price changes based on the amount they import. Conversely, an upward sloping residual supply schedule would indicate some degree of market power as measured by the residual supply elasticity.[39] As the residual supply is influenced by Brazilian excess supply and competing demand from other countries, the variables representing exogenous shocks to Brazilian excess supply and other importing countries' import demand provide the necessary information to map out the residual supply schedule faced by the U.S. importers.

Brazilian domestic sugarcane ethanol supply is derived from the profit-maximization problem of Brazilian ethanol producers represented in equation (1):

$$(1) \qquad \pi_B = w^B Q_e^B + \boldsymbol{\omega Q_{bp}} - C_e(w_v, Q_e^B) - \boldsymbol{F_e}$$

where π_B is profit from domestic ethanol production and sales, w^B and Q_e^B are the price and quantity of sugarcane ethanol sold, $\boldsymbol{\omega}$ and $\boldsymbol{Q_{bp}}$ are the price and quantity vectors of ethanol by-products sold, C_e is the variable cost function. Costs are dependent on the

[39] Brazil being the largest exporter of sugarcane ethanol in the world, it is possible that it can exert considerable market power in the world ethanol market and a more appropriate market structure in this context would be a bilateral oligopoly.

price of variable inputs w_v, and the quantity of ethanol produced Q_e^B. Fixed costs are denoted by $\boldsymbol{F_e}$. Maximization of (1) with respect to Q_e^B yields the Brazilian domestic ethanol supply function (2):

(2) $Q_e^B = f(w^B, \boldsymbol{\omega}, w_v)$

The horizontal difference between the domestic supply of sugarcane ethanol in Brazil and its domestic demand yields the country's excess ethanol supply for export (3):

(3) $Q_e^{ex} = f(w^B, \boldsymbol{W}, \boldsymbol{Z})$

where $\boldsymbol{W}$ is the vector of domestic ethanol supply shifters and $\boldsymbol{Z}$ is the vector of domestic demand shifters.

Brazilian sugarcane ethanol is exported to *n* countries around the world, including the United States. The import price (in Brazilian currency, the real) facing U.S. importers is denoted as $w^{US}$and the quantity of imports as Q_e^{US}. The other *n*-1 importing countries face import prices $w^2, \dots, w^n$(in real). The respective inverse supply functions are written as (4) and (5)[40].

(4) $w^{US} = S^{US}(Q_e^{US}, w^2 \dots \dots \dots \dots \dots \dots w^n, \boldsymbol{W}, \boldsymbol{Z})$

(5) $w^k = S^k(Q_e^k, w^j, w^{US}, \boldsymbol{W}, \boldsymbol{Z})$ where k indexes other importers and *j* = 1,…….., *n*-2 and $j \neq k$.

Individual importers in these countries (including the United States and other importing countries) are assumed to face the same prices, costs and similar industry-wide technology so when they maximize their individual profits, the quantity of ethanol

[40] It should be noted here that these relationships are specified as an inverse of the typical quantity dependent relationships associated with supply functions. This inverse supply specification is in line with Baker and Bresnahan (1988) and Goldberg and Knetter's (1999) specification of inverse demand functions.

demanded represents their individual derived demand which when aggregated becomes the country's demand for Brazilian ethanol. Profits of an individual U.S. importer, *i* are given by (6):

(6) $$Max_{q_e^i}\, \pi^{\,i} = P^{US}\, q_f^i\left(q_e^i, \boldsymbol{q_v^i}\right) - e\, w^{US} q_e^i - \boldsymbol{w_v^{us} q_v^i} - F^i$$

where $q_f^i\left(q_e^i, \boldsymbol{q_v^i}\right)$ is the individual importer's production function of blended gasoline, with q_e^i the quantity of imported sugarcane ethanol and $\boldsymbol{q_v^i}$ the vector of other variable inputs. P^{US}, is the price of blended gasoline in dollars, with *e* the exchange rate of dollars to Brazilian reals, $\boldsymbol{w_v^{us}}$ the vector of variable input costs, and F^i the fixed costs.

The first order condition with respect to the import quantities of the above profit-maximization problem equates the value of the marginal product (VMP) of the import to the marginal expenditure (ME) on the import. However, in this case ME is denoted as the perceived ME (PME), since importers are responding to their belief about the effect of rival importers' purchase on import price (Goldberg and Knetter, 1999). Solving for the import price from the first order condition gives equation (7):

(7) $$w^{US} = e.VMP^i(eP^{US}, w_v^{us}, q_e^i) - q_e^i S_1^{US}\left(1 + \sum_{j\neq i} \frac{\partial q_e^j}{\partial q_e^i}\right)\left(1 + \sum_{j\neq i} \frac{\partial w^{US}}{\partial w^k}\frac{\partial w^k}{\partial w^{US}}\right)$$

The slope of the U.S. residual supply curve is denoted by S_1^{US}. By letting θ^i represent the first parenthetical term following S_1^{US}, (the strategic interdependence among the U.S. importers); and λ^{US} represent the second parenthetical term (the strategic interdependence among the U.S. importers and the importers from other competing countries), equation (7) is rewritten as (8).

(8) $$w^{US} = e.VMP^i(eP^{US}, w_v^{US}, q_e^i) - q_e^i S_1^{US} \theta^i \lambda^{US}$$

The industry analogue of (8) is obtained by summing the weighted average of individual U.S. importers, where the weights are the import shares s^i[41]. The summation yields equation (9):

(9) $\sum_i s^i w^{US} = e.\sum_i s^i VMP^i\left(eP^{US}, w_v^{US}, q_e^i\right) - \sum_i s_i q_e^i S_1^{US} \theta^i \lambda^{US}$

Since $\sum_i s^i = 1$, it follows that $\sum_i s^i VMP^i(eP^{US}, w_v^{US}, q_e^i) = VMP^{US}$ substituting $q_e^i = s_i.Q_e^{US}$ in (9) yields (10):

(10) $w^{US} = e.VMP^{US}(eP^{US}, w_v^{US}, Q_e^{US}) - Q_e^{US} S_1^{US} \theta^{US} \lambda^{US}$ where $\theta^{US} = \sum_i s_i^2 \ \theta^i$

Analogous to (6) and (7), profits and first-order conditions of individual importers of other countries are given by (11) and (12):

(11) $Max_{q_e^j} \pi^j = eP^k q_f^j\left(q_e^j, q_v^j\right) - w^k q_e^j - e\, w_v^j q_v^j - F^j$

(12) $w^k = e.VMP^k(eP^k, w_v^k, Q_e^k) - Q_e^k S_1^k \theta^k \lambda^k$ where *k = 1,……., n-1*

Simultaneously solving the system of *2(n-1)* equations defined by (5) and (12), results in the set of inverse import supply functions, one for each ethanol importer other than U.S. importers. These functions are further simplified to a function of ethanol supply and demand shifters in Brazil ($\boldsymbol{W}, \boldsymbol{Z}$); ethanol import demand shifters from competing countries, eP^k and ew_v^k (prices of gasoline and other input costs), U.S. imports Q_e^{US}, and Ω the parameter representing strategic interdependence among ethanol importers in the import competing countries including the United States.

(13) $w^k = s^k(Q_e^{US}, \boldsymbol{W}, \boldsymbol{Z}, eP^k, ew_v^k, \Omega)$

[41] Goldberg and Knetter (1999) provide justification of this form of aggregation at an industry level.

Equation (13) is a partially reduced form of the inverse supply functions of the *n-1* competing countries. The dependence of the functions given by (13) on the U.S. imports arises because only the rival import supply functions are solved for in (13). The reduced form is partial since U.S. imports, $Q_e^{US}$are endogenous.

Substituting these *n-1* inverse supply equations from (13) into equation (4) yields inverse residual supply for the U.S. importers, which is now a function of U.S. imports, shifters of Brazilian ethanol supply and demand, and shifters of ethanol import demands of ethanol importers other than U.S. importers, as presented in (14) and (15):

$$(14)\ w^{US} = S^{Res.US}(Q_e^{US}, w^2(Q_e^{US}\boldsymbol{W}, \boldsymbol{Z}, eP^2, ew_v^2, \Omega)\ \dots\dots w^n(Q_e^{US}\boldsymbol{W}, \boldsymbol{Z}, eP^n, ew_v^n, \Omega)\ , \boldsymbol{W}, \boldsymbol{Z})$$

$$(15)\ w^{US} = S^{Res.US}(Q_e^{US}, \boldsymbol{W}, \boldsymbol{Z}, eP^k, ew_v^k, \Omega)$$

The (inverse) supply function in (15) takes into account the strategic interdependence among importers by including the conduct parameter Ω, and hence represents the (inverse) residual supply faced by U.S. importers in importing ethanol from Brazil.

Since both w^{US} and Q_e^{US} are endogenous in (15), estimation of (inverse) residual supply requires using an appropriate methodology to account for the simultaneous nature of these variables. The quantity of ethanol imports to the United States (Q_e^{US}) is identified by shifters of U.S. import demand for Brazilian ethanol. The demand shifters (P^{US} and w_v^{US}) in equation (10) are associated only with U.S. import demand, while the demand shifters in equation (15) ($eP^k$and ew_v^k) shift only competing country's import demands, making the (inverse) residual supply equation identified when equations (10) and (15) are estimated simultaneously.

Typically oligopsony power for the i^{th} importer is measured by the relative markdown as shown in equation 16:

$$(16)\quad \frac{VMP^{i} - w^{i}}{w^{i}} = \frac{\lambda^{i}}{\varepsilon^{i}}$$

where λ^{i} is the conjectural elasticity with values ranging from 0 (perfect competition) to 1 for (monopsony), and ε^{i} is the elasticity of input supply.

Asche et al. (2009) posit that since oligopsonists operate as monopsonists on their own residual supply, the elasticity of residual supply has a direct correspondence to the relative markdown. However, because the residual supply elasticity itself is dependent on the buyers' conjectures, the conjectured residual supply may differ from actual residual supply and there may not be a direct correspondence with the relative markdown. In the case of oligopoly, Baker and Bresnahan (1988) show that the elasticity of residual demand can represent a relative markup if the conjectured residual demand coincides with the actual residual demand. They show that in cases such as a Stackelberg leader, a dominant firm model, a competitive market, and a monopoly, the residual demand elasticity is identical to the relative markup. Oligopsony being the mirror image case of oligopoly, a similar argument is made here for oligopsony power. Therefore, given the dominance of the United States as a buyer of Brazilian ethanol, the elasticity of residual supply is expected to reflect market power if the conjectured residual supply coincides with the actual residual supply. Independent of its exact correspondence with the relative mark down, the slope of residual supply in itself provides evidence that the United States has some degree of market power as a buyer.

The residual supply elasticity (ε^{US}) of U.S. ethanol imports from Brazil is found by taking the reciprocal of the inverse residual supply elasticity (μ^{US}), which is derived by differentiating equation (15) with respect to Q_e^{US}. The functional form here is specified as a double logarithmic, yielding equation (17):

$$(17)\quad 1/\varepsilon^{US} = \mu^{US} = \frac{\partial \ln S^{Res.US}}{\partial \ln Q_e^{US}} + \sum_j \left(\frac{\partial \ln S^{Res.US}}{\partial \ln w^k}\right)\left(\frac{\partial \ln w^k}{\partial \ln Q_e^{US}}\right)$$

where *j* and *k* = 1,…….., n-1.

The first component on the right of the equal sign in equation (17) measures the direct effect of U.S. ethanol imports on its inverse residual supply. The next component takes into account the effect of its competitor's reactions on its imports. The first term in the parenthesis of the second component captures the shift in U.S. residual supply due to changes in the import prices of competitors and is expected to be negative (Asche et al., 2009). The second term in parenthesis captures the effect of U.S. imports on the prices paid for ethanol imports by competing importers, and is expected to be positive (Asche et al., 2009). Given these relationships, as the intensity of competition among ethanol importers increases, the magnitude of the second component in equation (17) increases, resulting in a decrease in magnitude of inverse residual supply elasticity, $\mu^{US}$and correspondingly increase in the elasticity of residual supply to the United States, ε^{US} (Asche et al., 2009).

3.4 Empirical specification

The econometric model used to estimate U.S. (inverse) residual supply (equation 15) is given in equation 18:

(18) $lnw_t^{US} = \alpha + \mu^{US}\, lnQ_{et}^{US} + \tau_w ln\, \boldsymbol{W_t} + \tau_z ln\boldsymbol{V}_t + \epsilon_t$

where w_t^{US} is the monthly U.S. import price of Brazilian ethanol in dollars/gallons; Q_{et}^{US} is the monthly quantity of U.S. ethanol imports in gallons; $\boldsymbol{W}_t$ is the vector of supply shifters of Brazilian ethanol; $\boldsymbol{V_t}$ is the vector of ethanol demand shifters in Brazil and competing importing countries. The parameter μ^{US} represents the inverse of residual supply elasticity of ethanol imports facing the United States, and τ_w and τ_z are the parameters associated with Brazilian excess supply shifters, and demand shifters in Brazil and competing countries.

The EU, Japan, South Korea, Jamaica, and Nigeria are identified as the relevant competing importers. Mexico and India are omitted considering the small volumes of Brazilian ethanol imported in recent years. As the Jamaican share in Brazilian ethanol exports is more than the combined share of El Salvador and Costa Rica, Jamaica is taken as representative of the CBI countries.

Due to the endogeneity of Q_{et}^{US}, two-stage least squares is used to estimate equation (15) with U.S. import demand shifters acting as an instrument for Q_{et}^{US}. The variables included as the demand shifters are U.S. retail gasoline price, the exchange rate of dollars to the real, and the monthly U.S. corn price[42].

Brazil operates many dual plants which switch between ethanol production and sugar production depending on whichever is most profitable. This fact makes the sugar/ethanol price in Brazil an important determinant of ethanol supply. Unfortunately, monthly data on Brazilian sugar prices are not available. World sugar prices are used as

[42] As corn is a major feed stock for ethanol production in the United States, corn prices influence domestic ethanol supply and, thus, import demand for ethanol.

a proxy since Brazil is the largest single producer and exporter of sugar in the world (Haley, 2013). The variables representing ethanol demand shifters in Brazil are represented by the monthly aggregate sales/registration of pure ethanol/flex fuel vehicles in that country. Brazilian ethanol exports to the United States exhibit a seasonal pattern that starts to rise in May/June, reaches a maximum during the month of August and declines thereafter. To capture this seasonal pattern, seasonal control variables are added to the model.

The shifters of ethanol demand of the *n-1* competing importers include exchange rates between the real and the respective currencies, and the price of gasoline. In cases where the monthly price of gasoline is not available for all countries within a group, a representative country within the group is used as a proxy. For example, the EU is represented by the Netherlands, the largest EU importer. In cases where the importing countries are not part of a group and have no monthly gasoline prices, world crude oil price are substituted.

The version of equation (18) used for estimation is as follows:

$$(19)\ lnw_t^{US} = \alpha + \mu^{US}\, lnQ_{et}^{US} + \sum_i \beta_{1i} ln\, D_{it} + \sum_j \beta_{2j} ln\, e_{Brt}^{j} + \beta_3 ln\, P_{gt}^{Ned} + \beta_4 ln\, P_{ot}^{w} + \beta_5 ln\, P_{st}^{W} + \beta_6 Brv + \epsilon_{1t}$$

Where D_{it} are dummy or indicator variables that capture the seasonal effects; e_{Brt}^{j}, exchange rates among the ethanol importing countries j with the Brazilian real; P_{gt}^{Ned}, retail price of gasoline in the Netherlands; P_{ot}^{w}, world crude oil price; P_{st}^{W}, world sugar price, and Brv, monthly number of pure alcohol or flex fuel vehicles sold/registered in Brazil. The endogenous variable Q_{et}^{US} is instrumented by P_{gt}^{US}, U.S. monthly retail price

of gasoline; e_{Brt}^{US}, exchange rate between Brazil and the United States, and P_{ct}^{US}, U.S. average monthly corn price.

The a priori expectations for the impacts of the independent variables on the U.S. import price, w_t^{US} are as follows: the inverse residual supply elasticity, μ^{US} is expected to be positive. Parameters β_{2j} which show the effect of changes in the exchange rates are expected to be negative; as the currency of an importing country depreciates, it is expected that its imports fall resulting in an outward shift of the supply to the United States and fall in the import price. Gasoline and world crude oil price coefficients β_3 and β_4 may be either positive or negative depending on the relationship between gasoline and ethanol consumption in the importing countries[43]. If ethanol and gasoline are substitutes in all countries, as gasoline and world crude oil prices increase all countries including the United States will increase demand for ethanol imports, increasing import price for all. However, if ethanol and gasoline are complements (as in the case of a fixed ethanol blending proportion, with no substitution possibility) for all of the competing countries prices will fall. More likely however, some substitution and complementarity will occur making the outcome ambiguous. An increase in the world sugar price, β_5 or the number of registered Brazilian flex fuel vehicles, β_6 is expected to positively impact the U.S. import price by reducing Brazilian ethanol excess supply.

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[43] If the recommended blending proportion for ethanol-gasoline has been attained, i.e. 'blend wall' is binding then we see a complementary relation in ethanol and gasoline consumption. However, if blend wall is not binding, substitution relationship will be operational.

3.5 Data sources

Monthly data for the period between 2002 and 2013 are obtained from various sources. U.S. ethanol import volumes from Brazil and corresponding FOB value (free on board at the exporter's port of shipment) in dollars are obtained from the foreign trade data base of Brazilian Ministry of Development, Industry, and Foreign Trade (Alice Web2 data base). The FOB values are converted into FOB unit prices by dividing them by corresponding import volumes. The FOB data corresponds to the standard international commodity classification HS 2207: un-denatured ethyl alcohol of at least 80% strength and denatured ethyl alcohol of any strength. Ethanol imported from Brazil is primarily un-denatured ethyl alcohol which is denatured upon arrival in the United States. Since the majority of these imports are converted into denatured ethanol and used for fuel (Farinelli et al., 2009 and MDICE, 2013), aggregated data (i.e. data for HS 2207 classification) are used. Monthly U.S. and Netherland gasoline retail price data for regular gasoline are obtained from the Energy Information Agency (US EIA) website. Monthly U.S. corn prices are accessed from the USDA National Agricultural Statistic Services (NASS) data base. Monthly data on the world crude oil prices come from the World Bank data base. Monthly world sugar price matches those reported in the USDA Economic Research Service (ERS) 'sugar and sweeteners year book' data base. The monthly sales of Brazilian alcohol/flex fuel vehicle are compiled from information provided by the Brazilian Automotive Industry Association, ANFAVEA website (http://www.anfavea.com.br/carta.html).

Monthly exchange rates of the real with the dollar, euro, yen, and won are extracted from those reported by the U.S. Federal Reserve website. Monthly exchange rates between the real and the naira come from the Central Bank of Nigeria website. Similarly monthly exchange rates between the real and Jamaican dollars are obtained from the Bank of Jamaica website.

3.6 Results

Six different models or specifications of equation (19) are estimated using two-stage least squares method. Coefficient estimates and accompanying statistical analysis for these six models are presented in Table 3.2. In the first stage of estimation, U.S. imports are instrumented by the U.S. monthly gasoline price and corn price. The monthly gasoline price reflects ethanol demand condition in the United States while corn prices influence domestic supply[44].

Model 1 and 2 are identical except for the seasonal control variables, model 1 has monthly controls and model 2 uses quarterly control variables. As anticipated, the inverse residual supply elasticity estimates are positive and statistically significant for both models (0.084 and 0.074, respectively). The corresponding reciprocal elasticities are 11.904 and 13.33 respectively, indicating a highly elastic residual supply curve. The seasonal control variables for both models indicate limited seasonal influence – the month of August and the third quarter statistically differ from their respective bases, January and the first quarter.

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[44] The results from the over-identification test and the validity of instrument test to justify the appropriateness of these instruments are presented later in this section.

Unfortunately these two outcomes are less than ideal due to possible multi-collinearity, and first order auto correlation concerns. The correlation matrix among the six exchange rates presented in Table 3.3 confirms that they are highly correlated and the residuals of these two models are positively correlated as indicated by their respective Durbin-Watson (DW) statistics (1.19 and 1.20) which fall well below the lower bound 5% level of significance. Moreover, these models have a high level of correlation among the instruments and their error terms, as indicated by the highly significant F-values of the over-identification test (Table1). While the signs on the residual supply elasticities and coefficient estimates of other variables are generally consistent with the expectation, these concerns warrant exploring alternative model specifications.

To address the collinearity issue, the exchange rate variables are transformed into their 'principal components'. The 'principal components' transformation is a statistical technique used to capture patterns in a data set of multiple variables by the use of Eigen-values and Eigen-vectors of the correlation matrix of the variables in the original data (Smith, 2002 and Jolliffe, 2002). Table 3.4 presents the Eigen-values from the transformation of the six exchange rate variables. Because the first three Eigen-values explain close to 98% of the variation in the raw data (Table 3.4), exchange rate variables in models 1 and 2 are replaced by their first three principal components. This replacement transforms model 1 to 3 and model 2 to 4. The inverse residual supply elasticity estimates from the transformed models (0.235 from model 3 and 0.239 from model 4) are larger in magnitude and their level of significance increased to the 95% confidence level. The implied residual supply elasticities are 4.25 and 4.18, respectively about one third of their previous estimates, but still highly elastic. Use of the principal

components helped mitigate some of the multi-collinearity and the first order autocorrelation concerns. The newly estimated DW statistics of models 3 and 4 (1.58 and 1.66) are closer to 2 but still within the inconclusive range. All the parameter estimates associated with the principal components are significant (Table 3.2).

Just as it is in model 1 and 2, seasonality is significantly present only in August for model 3 and the third quarter for model 4. Both model 3 and 4 have the same base periods as model 1 and 2. The signs on parameter estimates for gasoline price and world crude oil price remain unchanged but the magnitudes of these coefficients increased and are of greater statistical significance. Compared to the first two models, the second two indicate competing countries play a larger role in influencing the residual supply of Brazilian ethanol to the United States. Brazilian domestic excess supply shifters, world sugar price and pure ethanol or flex fuel vehicle registrations are not statistically significant indicating they have little effect on residual ethanol supply to the United States.

Knowing the high correlation among the variables presented in Table 3.3, a possible gain from adding three additional variables to the principal components may improve the estimates. These variables include gasoline price in the Netherlands, world crude oil price, and world sugar price. Model 5 added the fossil fuel prices, both gasoline price in the Netherlands and world crude oil price as additional variables into the principal component array. Model 6 added world sugar price as an additional variable to the principal components of model 5. Eigen-values and the proportion of variation captured by them are presented in Tables 3.5 and 3.6 respectively for models 5 and 6.

With seasonal variation in the data adequately captured by the quarters, only quarters are used as the seasonal control variables for the two new models.

The statistically significant inverse residual supply elasticity estimates from models 5 and 6 are 0.140 and 0.138 with corresponding reciprocal residual supply elasticities of 7.14 and 7.25 respectively. These estimates are about midway between the estimates from the first and second pairs of models. The additional variables in the principal components do not significantly further mitigate the collinearity concerns. The DW statistics (1.466 for model 5 and 1.473 for model 6) fall below the 5% level of significance indicating possible positive first order correlation among the residuals. The magnitude of the estimated coefficients for all variables in the models 5 and 6 are slightly smaller than those of models 3 and 4. All the principal component coefficient estimates are significant, but the coefficients on supply shifters (world sugar price and Brazilian vehicle sales in model 5 and Brazilian vehicle sales in model 6) are not, making models 5 and 6 results similar to models 3 and 4 with respect to shifts in ethanol import demand in competing countries and shifts in Brazilian ethanol excess supply.

Because the multi-collineartity concern is minimized by including principal components of exchange rates only, the DW statistic for model 4 is closer to 2, and that model adequately captures the seasonality makes it the preferred model. The validity of the instruments in explaining U.S. imports is tested for model 4. This test is done by regressing U.S. ethanol imports on all of the exogenous variables including U.S. gasoline and corn prices. The maximum likelihood estimation results in Table 3.7 indicate that the two instruments are jointly significant in explaining the endogenous variable. Moreover, the over-identification test statistics presented at the bottom of Table 3.2 for model 4 also

indicate that these instruments are not correlated with the error terms of the model. Therefore, the instruments used for the model are considered valid.

The model 4 findings show that the residual supply elasticity of ethanol supply from Brazil is highly elastic, indicating a small degree of market power for U.S. importers in importing ethanol from Brazil. The residual supply shows a positive seasonal increase during the third quarter. More importantly, the effect of import demand from competing countries in determining residual supply to the United States is evident by the fact that exchange rate effects captured by principal components, gasoline price in the Netherlands, and the world crude oil price are highly significant. Conversely, the excess supply shifters in Brazil are found to have no significant influence on the residual supply.

3.7 Summary and conclusion

The requirement in the United States to blend higher volumes of advanced biofuels with gasoline and the shortfall in domestic production to fulfill this requirement mean that imports of ethanol from Brazil will likely take on an even more vital role. The strategic position of U.S. importers as the buyers of Brazilian ethanol is analyzed based on the residual supply elasticity of ethanol imports from Brazil. The residual supply elasticity is found to be highly elastic: a small percentage change in price results in much larger percentage change in quantity supplied, as much as 4.18 times. This elasticity is consistent with an upward sloping supply curve indicating a small degree of U.S. importer market power.

Using arguments proposed in the new trade theory (Helpman and Krugman, 1989), a dominant ethanol importing country such as the United States can gain by restricting ethanol imports from its trade partner, Brazil, by imposing an optimal tariff when individual importers do not recognize their market power. The reasoning is that under free trade, where import demand intersects residual supply, the marginal cost of an extra unit of ethanol imported by the United States from Brazil exceeds the value of that unit. An optimal tariff would restrict imports to a level where the marginal cost and the value of the unit are equal. The empirical evidence from this work suggests that U.S. importers are already exercising some degree of market power and imports of ethanol are occurring at the oligopsony equilibrium. Therefore from the U.S. perspective, an additional restriction using a tariff may not be welfare improving[45].

While this work provides valuable information to those interested in ethanol imports, it is not exhaustive since it does not account for the possibility of bilateral oligopoly, which is possible since Brazil is the world's dominant exporter of sugarcane ethanol and the United States its dominant importer. A fruitful avenue of future research would be to extend the empirical analysis to a residual supply/demand model that distinguishes between alternative oligopoly solutions: U.S. dominance, Brazilian dominance or some other structure in between.

[45] However, it should be noted that the optimal imports would be different if all U.S. importers collude and act as a single firm.

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Table 3.1: Share of the Brazilian ethanol importing countries in the total Brazilian ethanol export

Brazilian ethanol importing countries	Share in total Brazilian ethanol in 2012 (%)	Share in total Brazilian ethanol export between 2001and 2012 (%)
United States	66	28
European Union	3	20
CBI countries (Jamaica, El Salvador, and Costa Rica)	15 (Jamaica:8, El Salvador:4, and Costa Rica:3)	15 (Jamaica: 8, El Salvador :4, and Costa Rica:3)
Japan	4	9
Korea	5	8
India	-	5
Mexico	-	2
Nigeria	2	3

Source: MDICE, 2013

Table 3.2: Alternative model specifications and the parameter estimates

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	-12.610***	-12.328***	0.584	0.887	-0.794	-1.061
	(3.737)[+]	(3.609)	(1.253)	(1.309)	(1.005)	(0.954)
Log (U.S. imports)	0.084*	0.074*	0.235**	0.239**	0.140***	0.138**
	(0.046)	(0.043)	(0.099)	(0.104)	(0.050)	(0.055)
February	-0.018		0.027			
	(0.100)		(0.169)			
March	-0.003		0.185			
	(0.106)		(0.193)			
April	-0.096		0.356			
	(0.115)		(0.215)			
May	-0.018		0.160			
	(0.105)		(0.183)			
June	-0.090		0.023			
	(0.103)		(0.171)			
July	-0.162		-0.108			
	(0.106)		(0.173)			
August	-0.245***		-0.369*			
	(0.116)		(0.195)			
September	-0.095		-0.505			
	(0.101)		(0.169)			
October	-0.047		-0.111			
	(0.103)		(0.172)			
November	-0.065		-0.132*			
	(0.103)		(0.172)			
December	0.107		0.187			
	(0.105)		(0.182)			
Quarter 2		-0.0009		0.105	0.046	0.053
		(0.059)		(0.108)	(0.081)	(0.081)
Quarter 3		-0.145**		-0.233*	-0.177**	-0.172*
		(0.069)		(0.120)	(0.089)	(0.089)
Quarter 4		0.012		-0.086	0.018	0.027
		(0.063)		(0.113)	(0.082)	(0.080)
Log (Euro/Real)	-0.982**	-1.014**				
	(0.455)	(0.429)				
Log (Yen/Real)	0.042	0.080**				
	(0.335)	(0.313)				
Log (Won/Real)	0.094	0.046				
	(0.369)	(0.351)				
Log (Jamaican $/Real)	0.352	0.372				
	(0.439)	(0.423)				
Log (Naira/Real)	1.987***	1.967***				
	(0.647)	(0.637)				
Principal Component 1			0.456***	0.468***	0.136***	0.149***
			(0.167)	(0.174)	(0.038)	(0.031)
Principal Component 2			-0.447***	-0.453***	-0.102**	-0.115***
			(0.159)	(0.165)	(0.045)	(0.032)
Principal Component 3			-0.601**	-0.628**	-0.162**	0.137*
			(0.285)	(0.295)	(0.082)	(0.074)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Log (Netherlands gasoline price)	-0.639 (0.846)	-0.440 (0.774)	-4.414** (1.699)	-4.247** (1.700)		
Log (World crude oil price)	0.508** (0.253)	0.446* (0.240)	1.028** (0.404)	0.922** (0.405)		
Log (World sugar price)	-0.212 (0.241)	-0.178 (0.232)	-0.683 (0.467)	-0.682 (0.482)	0.150 (0.204)	
Log (Number of Brazilian vehicles)	-0.015 (0.052)	-0.021 (0.050)	-0.072 (0.086)	-0.088 (0.090)	-0.059 (0.063)	-0.056 (0.062)
DW Statistics	1.191	1.205	1.586	1.661	1.466	1.475
Number of observation	130	130	130	130	130	130
R^2	0.816	0.810	0.605	0.570	0.670	0.671
Over-identification test F-value	3.54**	3.95**	0.37	0.33	0.02	0.28

******* Statistically significant at ≤ 0.01 level of significance
****** Statistically significant at > 0.01 and ≤ 0.05 level of significance
***** Statistically significant at > 0.05 and ≤ 0.10 level of significance
[+] Values in the parenthesis are standard error of the estimates

Table 3.3: Correlation among the exchange rates, world crude oil, and world sugar price variables

Pearson Correlation Coefficients, N = 138

	$/Re	Euro/ Re	Yen/ Re	Won/ Re	Jam $/Re	Naira/ Re	Netherlands gas price	World oil price	World sugar Price
$/Re	1.000	0.968	0.680	0.869	0.919	0.910	0.840	0.858	0.769
Euro/Re	0.968	1.000	0.646	0.809	0.900	0.869	0.892	0.870	0.712
Yen/ Re	0.680	0.646	1.000	0.401	0.398	0.367	0.431	0.444	0.161
Won/Re	0.869	0.809	0.401	1.000	0.897	0.882	0.656	0.694	0.792
Jam $/Re	0.919	0.900	0.398	0.897	1.000	0.972	0.869	0.868	0.883
Naira/Re	0.910	0.869	0.367	0.882	0.972	1.000	0.824	0.837	0.912
Netherlands gas price	0.840	0.892	0.431	0.656	0.869	0.824	1.000	0.960	0.707
World oil price	0.858	0.870	0.444	0.694	0.868	0.837	0.960	1.000	0.743
World sugar Price	0.769	0.712	0.161	0.792	0.883	0.912	0.707	0.743	1.000

Table 3.4: Eigen values of the correlation matrix from the six exchange rate variables

	Eigenvalue	Proportion	Cumulative
1	5.042	0.840	0.840
2	0.692	0.115	0.955
3	0.180	0.030	0.985
4	0.051	0.008	0.994
5	0.025	0.004	0.998
6	0.008	0.001	1.000

Table 3.5: Eigen values of the correlation matrix from the six exchange rate variables, the Netherlands gasoline price, and the world crude oil price

	Eigenvalue	Proportion	Cumulative
1	6.625	0.828	0.828
2	0.747	0.093	0.922
3	0.471	0.059	0.980
4	0.063	0.008	0.988
5	0.052	0.007	0.995
6	0.025	0.003	0.998
7	0.011	0.001	0.999
8	0.005	0.001	1.000

Table 3.6: Eigen values of the correlation matrix from the six exchange rate variables, the Netherlands gasoline price, the world crude oil, and the world sugar price

	Eigenvalue	Proportion	Cumulative
1	7.369	0.819	0.819
2	0.854	0.095	0.914
3	0.494	0.055	0.969
4	0.151	0.017	0.985
5	0.058	0.007	0.992
6	0.034	0.004	0.996
7	0.025	0.003	0.998
8	0.009	0.001	1.000
9	0.005	0.001	1.000

Table 3.7: Maximum livelihood estimates for testing the validity of instruments

Variables	Estimates
Intercept	2.3171
	(7.368)+
Log U.S. gasoline price	1.354
	(2.693)
Log Corn price	1.816**
	(0.787)
Quarter 2	-0.323
	(0.391)
Quarter 3	-0.300
	(0.405)
Quarter 4	0.204
	(0.375)
Principal Component 1	-1.512***
	(0.277)
Principal Component 2	1.765***
	(0.343)
Principal Component 3	1.825***
	(0.690)
Log (Netherlands gasoline price)	8.301**
	(3.599)
Log (World crude oil price)	-1.660
	(2.066)
Log (World sugar price)	3.930***
	(1.048)
Log (Number of Brazilian vehicles)	0.687**
	(0.311)
AR1	-0.286**
	(0.095)
Number of observation	130
R^2	0.43
F-value for joint significance of first two variables in the model	2.96*

******* Statistically significant at ≤ 0.01 level of significance
****** Statistically significant at > 0.01 and ≤ 0.05level of significance
***** Statistically significant at > 0.05 and ≤ 0.10level of significance
+ Values in the parenthesis are standard error of the estimates

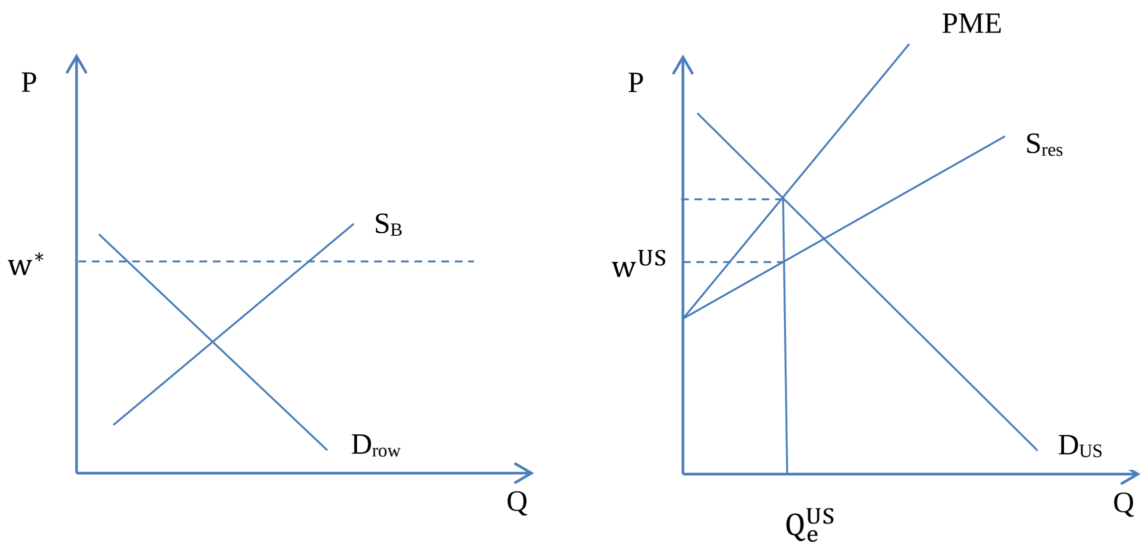

Figure 3.1: Graphical representation of residual supply of ethanol from Brazil to the United States

CHAPTER 4

LIVESTOCK DEMAND, GLOBAL LAND USE, AND INDUCED GREENHOUSE GAS EMISSIONS

4.1 Introduction

The global demand for livestock products has grown over the years and will likely continue to grow due to increasing income and population. The global production of meat increased from an estimated 26.66 kg per capita in 1970 to 42.02 kg in 2012 (FAOSTAT, 2014). Looking ahead, with expected increase in global population and purchasing power, demand for livestock products is expected to grow at a fairly substantial rate with FAO (2011) projecting for 2050 a 73% increase over the 2010 levels.

While the total production of all meats has historically grown, the growth patterns of the various types of meat differ. For instance, per capita production of ruminant meats has declined about 1.3 kg between 1970 and 2012, while during the same time period the demand for pork and poultry meats has increased by 5.9 and 10.7 kg per capita respectively (Taheripour et al. 2013). Although the per capita output of ruminant meats is declining, the total consumption is expected to increase as the FAO (2011) projects demands for poultry, ovine (lamb/mutton), bovine (beef/buffalo meat), and porcine (pork) meats will increase by 225%, 178%, 158%, and 137% by 2050 compared to 2010 consumption. These projections indicate that poultry is expected to grow faster than the other meat sources followed by ruminant meats, with pork expected to make the smallest gain.

Increasing livestock production has implications for natural resource use and environment. In particular, this work focuses on the changes in land use as a result of increased livestock

production and associated production of greenhouse gases (GHG) with the land use change. Notably, each species of livestock has a different effect on land use and environment. The production differences among the various livestock species vary in land use patterns and amount of GHG produced. For example, poultry requires less space and feeds higher in protein and energy than do cattle. Gerbens-Leenes and Nonhebel (2002) estimate that beef requires an area of 20.9 m^2 per year per kg of meat while pork and poultry only require 8.9 and 7.3 m^2 per year per kg of product respectively. This difference in land requirements is the result of varying nutritional requirements, growth rates, and production methods. These factors contribute to the feed conversion ratio, which measures the amount of feed per kg of meat produced. Bender (1997) estimates the feed conversion rate for beef to be about 7 kg of feed per kg of beef, which is higher than 6.5 and 2.7 kg of feed per kg of pork and poultry meat. The quantity as well as the quality of the feed varies among the different species. Increased ruminant production would trigger expansion of both pasture and cropland while increased non-ruminant production would mostly be limited to crop land increases[46]. Moreover, land use changes differ depending on the production systems used (i.e. feedlot beef versus grass fed beef). This is well illustrated in the difference between North and South America where South America is predominantly a pasture based system and North America a mixed system of pasture and intensive feeding (Opio et al., 2013). Expansion of beef production in South America would have a much different effect on land use and GHG production than an expansion in North America. Typically when forest land is converted into pasture or cropland to accommodate increased livestock production, it results in higher GHG emissions and reduced biodiversity (Blake and Nicholson, 2004) due to land clearing and reduced long term carbon sequestration.

[46] Cropland expansion will be contingent on the productivity of land. If productivity of land increases with the intensive use of inputs (technology, capital, and labor) cropland expansion will be limited.

Given the complexity and extent of land use changes due to livestock production expansion, it follows that a careful study of how the future changes in global livestock production and consumption may alter land use and associated GHG emissions is required. Despite the magnitude of the potential impacts of the production changes on the environment, the literature relating to livestock-induced land use changes is sparse. The available literature generally focuses on estimating land requirements for various livestock production systems at the country level (e.g. Gerbens-Leenes and Nonhebel, 2002; Elferink and Nonhebel, 2007) or estimating emission changes which emanate from causes other than land use changes due to livestock production (e.g. Hertel et al. 2010, Tyner et al. 2010, and Keeney and Hertel 2008).

Further, the emissions associated with land use changes are also not fully accounted in the available estimates of total emissions from livestock sector. While Steinfeld et al. (2006) and Goodland and Anhang (2009) estimate about 2.4 to 2.6 billion tons Co_2 e (CO_2 equivalent) emissions per year as a result of land use change due to livestock production, these reports, however, do not provide a detailed explanation of the methods used to obtain these estimates and appear to be more of "a back-of-the-envelope" type of calculations. Herro et al. (2011) criticize Goodland and Anhang (2009) for not presenting the detailed methodology of estimation and emphasizing the negative impacts of livestock on environment. A recent FAO report authored by Gerber et al. (2013) estimates about 7.1 billion tons of CO_2 e emissions annually from the livestock sector and attributes feed production and enteric fermentation as the major sources of the emissions from livestock sector, accounting for respectively 45% and 39% of the total emissions from the sector. The FAO report attribute about 0.65 billion tons Co_2 e per year to the land use changes due to livestock production[47]. However, this estimate fails to fully account the

[47] As reported by Gerber et al. (2013), land use emission of 0.6 billion tons Co_2 e is calculated as 9.2% of the total emission of 7.1 billion tons Co_2 e per year from the livestock sector.

emissions from land use changes associated with livestock production as the report mainly accounts for land use changes due to expansion of soybean crops in Latin America and the Caribbean regions. Given that the report does not account for land use changes in all regions of the world and for all crops, it is likely that it under estimates the emissions from land use changes due to livestock production at the global level. Moreover, the emission estimates are based on the reference years 1996-2006, which needs to be updated to account for the livestock production after 2006. Given this gap in the literature, this analysis, therefore, focuses on land use change due to increase in livestock production in all regions of the world and the associated GHG emissions from such change.

This chapter has a threefold objective: (1) Provide a baseline projection for regional livestock output growth for 2022 at the global scale; (2) Use the baseline projection estimates of livestock output to estimate the expected global land use changes by region; and (3) Estimate the GHG emissions associated with those changes. Considering the global scale of this work and the number of interactions among many economic sectors and regions, a computable general equilibrium (CGE) model, GTAP (Global Trade Analysis Project)[48] is applied.

Section 4.2 of this chapter introduces and briefly outlines the model. Section 4.3 describes the simulation procedures used to estimate the growth of livestock output and the associated data sources. Section 4.4 presents the model estimates of livestock output growth by 2022 and its impact on global land use and associated GHG emissions. The final section serves as the chapter summary and provides conclusions.

[48] The GTAP model is developed by the researchers at Purdue University and is widely used all over the world.

4.2 The model

The model for this work is based on a modified version of the standard GTAP model called the GTAP-BIO.

4.2.1 The standard GTAP model

GTAP is a multi-sector, multi-region CGE model. The model is fully described and discussed with underlying assumptions and equations in the book "Global Trade Analysis" (Hertel ed., 1997)[49]. A summary of the salient features of the model based on the description of Brokmeier (2001) and Birur (2010) is provided below.

Figure 4.1 provides a basic illustration of the model. The "regional household"[50], which represents a country or a region composed of many countries collects income generated by all sources[51] and allocates it among representative private, government, and the saving demands. The regional household is assumed to have a Cobb-Douglas (CD) utility function[52]. Therefore, changes in the regional income is equi-proportionally exhausted over private, government, and saving demands (Figure 4.2).

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[49] The use of particular assumptions and functional forms in the GTAP model seems to be motivated by the objective of estimating minimum number of parameters for the model without compromising much on reflecting the reality. For example the separability and Armington assumptions help to considerably reduce the number of parameter estimation. Despite its merits, these assumptions have come under criticism for being too restrictive (Hertel ed., 1997). However, given that typically applied general equilibrium models involve estimation of a large number of parameters, simplification in the form of some 'reasonable' assumptions is expected. Hertel ed. (1997) defends the Armington assumption for the GTAP model, "Although we agree that more flexible functional forms are preferable, this critique could apply just as well to every other behavior relationship in the model. The question is: can it be estimated/calibrated and operationalized in the context of a disaggregated global model? At this point the answer is "no", although progress has been made in the context of one region models."

[50] Some of the technical terms such as the "regional households" are used here verbatim from the GTAP model specific terminologies.

[51] The regional household income sources are mainly production, consumption, and income taxes as shown in the Figure 4.1.

[52] The CD functional form implies that the share of private, government, and saving expenditure remains constant with increase in the income of regional households.

The private household has a non-homothetic utility function known as a Constant Difference of Elasticity (CDE)[53] function, which implies that income elasticities differ across goods. The government expenditure is governed by a Cobb Douglas utility function resulting in constant expenditure shares of government purchases. The private households, the firms, and the government pay taxes (net of any subsidies) to the regional household. The regional saving is completely exhausted in the investment goods.

Each firm (producer) maximizes its profits in a competitive market using a nested[54] Constant Elasticity of Substitution (CES)[55] production function as shown in Figure 4.3. The model also assumes a CES substitution among primary inputs including land, labor, and capital and fixed proportion relations among intermediate inputs. The firm makes payment to the regional household for using its endowment resources (land, labor, and capital) in the production process and receives payments from the private households, government, and other firms in the economy for selling their output to these agents (Figure 4.1). Among the primary factors of production, the land endowment is assumed to be imperfectly mobile with labor and capital as being perfectly mobile within each region but imperfectly mobile across all regions.

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[53] The choice of CDE functional form for the private household demand in the GTAP model seems to be motivated by the fact that the budget share of necessities tends to decrease and that of luxury goods tends to increase with increase in income. The non-homothetic functions such as the CDE allows budget shares to vary with change in income, which is not possible for the homothetic functions. The name "Constant Difference" is derived from the fact that the difference in Allen partial elasticities derived from the CDE functional form remains constant, i.e. $\sigma_{ij} - \sigma_{ik} = \text{constant}$.

[54] The nested production structure assumes that the production nests are weakly separable implying that a profit maximizing firm selects the optimal mix of inputs in a nest independent of input prices in other nests.

[55] The use of CES production function in the GTAP model also seems to be motivated by the fact that it allows reduction in parameter estimates to one per production nest/branch and at the same time it is 'quite general' in nature (Hertel ed., 1997). Hertel ed. (1997) states that "Within the primary factor branch of the production tree, substitution possibilities are also restricted to one parameter. This CES assumption is quite general in those sectors that employ two inputs: capital and labor. However, in agriculture, where a third input, land enters the production function, we are forced to assume that all pairwise elasticities of substitution are equal. This is surely not true, but we do not have enough information to calibrate a more general specification at this point."

As shown in Figure 4.1, in an open economy, the firms sell their outputs and buy inputs both domestically and internationally. GTAP uses the Armington assumption with respect to traded goods, meaning that the imports are differentiated by country of origin. The imported goods are kept in a separate nest in the production process (Figure 4.3). The firms first decide on the countries from which to import and then decide on the optimal mix of domestic and imported inputs based on the prices of imports and the domestically produced inputs (Figure 4.3). Additionally, the private households and the government also import some of their consumption goods from the rest of the world (ROW) with analogous separability and Armington assumptions as in the case of the firms (Figure 4.2). Each regional household generates additional revenues in the form of import and export taxes due to the trade with the ROW (Figure 4.1).

In a multi-region version of the GTAP model, all regional savings are deposited in a "Global Bank" as global savings and hence all the savings and investments are aggregated at the global level with a common global price for the savings. The general equilibrium nature of the model is imposed by applying Walras Law that in equilibrium all markets clear (i.e. aggregate demand equals aggregate supply in all input and output markets, imports equal exports in the international market), all firms earn zero economic profits, and all consumers operate on their budget constraints, and global investments equal global savings. The equality of global investments and global savings in the final equilibrium provides the accounting check on the general equilibrium status of the model.

4.2.2 The GTAP-BIO model

This modified version of the standard GTAP model was originally used to estimate the impact of increased biofuels production on global land use and associated GHG emissions (Tyner et al., 2010 and Taheripour and Tyner, 2013). The latest version of GTAP-BIO has been

modified to explicitly model the livestock sector, including feed demand which not only includes conventional feed sources but also distillers' grains, a dry by-product (DDGS) of corn ethanol production primarily used as a livestock feed ingredient. The model also accounts for competition among other crops, livestock, and the biofuels sector in the land market. This section highlights only those modifications to the standard GTAP model that are pertinent to the objectives of this study.

Figure 4.4 illustrates the land supply module in the GTAP-BIO model. This module determines the supply of land[56] for forest, crop, and pasture production purposes in 18 Agro-Ecological Zones (AEZs) around the world. The elasticity of transformation, ETL1 determines the transformation of land for forest, crops and pasture, while ETL2 governs allocation of crop land among different crops. ETL3 is the elasticity of transformation of pasture land for meat and milk production.

Besides modeling the land use, this version of the model explicitly models feed demand for livestock. A representative nested feed demand structure used in the model is shown in Figure 4.5. The DDGS and coarse grain are kept in the energy feed nest while soybean and soybean meal composite and oilseeds and oilseed meals composite constitute the protein feed nest. The energy and protein feeds make the energy-protein composite feed. This composite feed along with other sources of feed such as intermediate processed livestock products, crops, and other processed feed make up the final feed composite used for feeding livestock. Details on the elasticity values used at each nest in the feed demand tree are provided by Taheripour et al. (2011).

[56] Only those lands are considered which can be used for forest, crop cultivation or pasture purposes. Land used for human habitation or unused land are not included.

4.3 The GTAP-BIO simulation procedure and data sources

In order to examine the impact of increased livestock output on global land use and resulting GHG emissions three experiments are applied using the modified GTAP-BIO model and GTAP database version 7, which corresponds to the reference year 2004.

1. Experiment 1: An experiment is carried out by using the forecasted changes (Table 4.2) in GDP, population, capital, and skilled and unskilled labor between the years 2004 (baseline) and 2022 as exogenous shocks to the GTAP-BIO model for all GTAP regions (Table 4.1). The land use changes obtained from this experiment can be attributed to changes in demand for all goods and services in the regional economies including changes in livestock production.
2. Experiment 2 is used in combination with experiment 1 to determine the effect that private household demand has on land use. To isolate this, livestock demand is held constant for the private households while the other forecasted changes, GDP, population, capital, and skilled and unskilled labor are made. The difference in land use between this experiment and experiment 1 can be attributed to the effect of the private households alone on land use. The details of these experiments are found in Appendix 4.A.
3. Experiment 3: This experiment is similar to the second experiment; it not only fixes the private household's demand but also the intermediate demands (intermediate demand includes demands for livestock products by industries as an input in production process) for livestock products. The difference between the results of the first and this experiment amounts to the induced land use changes as a result of change in the sum of household and intermediate demands for livestock products.

Two additional steps are added: 1) The resulting land use changes are coupled with emissions factors developed by Plevin et al. (2014)[57] to calculate induced land use emissions due to changes in livestock outputs for the time period of (2004-2022). 2) A series of simulations with changes in the substitution parameter of the model are solved to test the sensitivity of the results.

4.3.1 Data sources for the exogenous shocks in the model

The projected data for GDP, population, and capital (Table 4.2) mainly come from CEPII baseline database version 2.1 (Foure' et. al, 2012). The projected changes in skilled and unskilled labor between the years 2004 to 2022 (Table 4.2) are from the baseline projection database prepared by Chappuis and Walmsley (2011) for the GTAP model. Both the CEPII and Chappuis and Walmsley (2011) information are presented originally as country level data and therefore are aggregated into the 19 GTAP regions. The percentage change in each of the five variables between 2004 and 2022 is calculated and then used as a shock in these variables in the model thus simulating projected growth in livestock output and associated land use change.

[57] Plevin et al. (2014) has developed a comprehensive model, "the AEZ_EF v47", specifically designed to estimate GHG emissions associated with land use changes. The model considers various sources and sinks of GHG emission such as the above and below-ground live biomass, dead organic matter, soil organic matter, harvested wood products, non-Co_2 emissions (e.g. CH_4 and N_2O), and foregone sequestration in estimating the induced land use emissions (Plevin et al. 2014). Moreover, the model is designed to fit well with the GTAP-BIO model such that the regions and AEZs in the AEZ_EF v47 model exactly matches with the 19 regions and 18 AEZs in the GTAP model. This facilitates direct use of the land use change results from the GTAP model simulations into the AEZ_EF v47 model. The detailed methodology and the assumptions used in estimating the emissions from land use change are provided by Plevin et al. (2014).

4.4 Results

4.4.1 Change in livestock output[58]

Table 4.3 presents the GTAP-BIO simulation results on growth in global livestock outputs as a consequence of the projected regional changes in the five factors (GDP, population, capital, and skilled and unskilled labor) between the years 2004 (baseline year) and 2022 (Table 4.2). As expected the largest percentage increase is observed for non-ruminant production (111%) followed by ruminant (84%) and milk production (64%) (Table 4.3).

Table 4.4 shows the projected increases in livestock output for each of the 19 regions. Among these regions, China-Hong Kong (CHIHKG) and INDIA are the regions with the greatest increases in livestock output. CHIHKG has more than a 200% increase in all categories with INDIA not far behind with nearly a 200% increase. This increase is mainly driven by the large simultaneous increase in GDP and capital (Table 4.2). Among livestock output categories, CHIHKG has the highest growth for ruminants but INDIA has the largest increase in non-ruminants. The rest of South Asia (R_S_Asia), other East Europe and the rest of the former Soviet Union excluding Russia (Other_CEE_CIS), Middle-Eastern and North Africa (MEAS_NAfr), and Sub-Saharan Africa (S_S_AFR) are the other regions with relatively high growth in livestock outputs.

The demand for livestock output comes mainly from two sources[59]: household demand and intermediate input demand by firms that use it to produce another product. Table 4.5 shows the

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[58] The GTAP-BIO results (except for the land use change) are presented in the proportionate change form, hence the results on livestock output changes are in percentage change rather than the absolute change.

[59] Livestock output demand from the government is also another source. Given that the share of government's demand in the total demand for the livestock output is negligible, this category of demand is not considered in the analysis.

projected increase in regional household demands for the livestock outputs. INDIA, CHIHKG, and S_S_AFR are the regions with the largest increase in demand (Table 4.5). The household demand for livestock production are larger in percentage terms for INDIA and S_S_AFR than that of CHIHKG; excluding non-ruminants for which CHIHKG has a higher percentage increase than S_S_AFR but lower than INDIA. These increases are mainly driven by large population growth in INDIA and S_S_AFR (Table 4.2). Other regions which are projected to have large percentage increases in demand are MEAS_NAfr, R_S_Asia, Malaysia and Indonesia (Mala_Indo), and Oth_CEE_CIS (Table 4.5).

Livestock output is not only used by the private households but is also used as an input in many industries. For example, raw milk, meat and eggs are used as ingredients in other value added products such as baked and processed foods. Table 4.6 shows the projected growth in the processed food industry demand for livestock outputs[60]. Similar to the household demand, growth in output demanded by the processed food industry is also highest in INDIA and CHIHKG regions, followed by Oth_CEE_CIS, MEAS_NAfr, and S_S_AFR.

4.4.2 Land use impact

Tables 4.7 through 4.9 show the impacts of livestock output growth on land use by private household, intermediate industry, and their combined demand effects. The columns associated with "A" in the tables are the results associated with Experiment 1 and represent the total change in land use by land use types i.e. forest, crops, and pasture land. These columns are repeated on all three tables, 4.7, 4.8, and 4.9. The columns listed under "B" in the Table 4.7, columns under

[60] Since processed food industry is one of the largest consumer of livestock output, only the projected demand from this industry is presented in Table 4.6. Results for other industries are omitted here for space considerations. Further in the table, the projected growth in demand for milk, ruminants, and non-ruminants are equal for a region which is an implication of the fixed proportion assumption in the model whereby the percentage increase in inputs used for production is equal to the percentage increase in output.

"D" in the Table 4.8, and columns under "F" in the Table 4.9 report respectively the changes in land use while holding household demand constant (experiment 2), holding intermediate industrial demand constant, and lastly holding the combined demand (private household plus intermediate) constant (experiment 3) at the baseline level. The "C", "E", and "G" columns in the tables isolate the predicted net land use change induced by the growth 1) in household demand for livestock output, 2) in intermediate industrial livestock demand, and 3) in the combined demand for the 2004-2022 periods.

As is evident in columns listed under "C", "E", and "G" of the tables, pasture area always expands, while forest land is always reduced as a result of increases in livestock demands. In Table 4.9, the final result of the overall change in crop land has a mixed outcome. In some regions cropland is reduced, while in others such as Canada (CAN), CHIHKG and Mala_Indo crop land increased. Globally there is a net increase in pasture of about 44.5 billion hectares, with a decrease in crop land and forest of 1.1 billion and 43.3 billion hectares respectively. Contrastingly with the increase in demand from private households only, Table 4.7 indicates that crop land increases globally, which is evident in six of the regions in order of decreasing magnitude, CHIHKG, Mal_Indo, rest of South East Asia (R_SE_Asia), CAN, INDIA, and EU27. The expansion in pasture area is most notable in the regions with purely pasture based livestock production systems such as S_S_AFR, BRAZIL, South and Other Americas (S_o_Amer), and R_S_Asia (Table 4.7). In particular, the pasture expansion is largest in S_S_AFR with an increase of about 8.5 million hectares in pasture land and decreases of about 8 and 0.5 million hectares in forest and crop land cover. The expansion of pasture is small in the advanced economies such as the EU27, Canada (CAN), JAPAN, Oth_Europe, and Oceania.

In comparing the magnitude of the changes between Table 4.7 and 4.8 it is obvious that intermediate demand for livestock output constitutes a major share of the total output demand and accounts for the major portion of the land use changes. Unlike the household demand effects, the intermediate demand induces not only conversion of forest to pasture but also conversion of crop land to pasture as there is a decrease in crop land at the global level (Table 4.8). Among the regions, CHIHKG emerges as the region of largest pasture expansion followed by S_S_AFR, BRAZIL, S_o_Amer, and R_S_Asia (Table 4.8).

4.4.3 Emissions due to the land use changes

The results on regional land use change obtained from the GTAP-BIO model simulations are used in the "AEZ_EF v47" model to estimate the induced land use emissions as a result of regional changes in livestock demands for livestock outputs[61]. Tables 4.10, 4.11, and 4.12 present the induced land use emissions due to changes in household, intermediate, and the combined demand. Results in all three tables reflect the huge contribution of deforestation to the total emissions. Particularly, the conversion of forest to pasture accounts for the majority of the emissions. Conversely, the conversion of crop land to pasture reduces emissions. The regions with relatively higher emission are S_S_Afr, CHIHKG, BRAZIL, and S_o_Amer (Tables 4.10, 4.11, and 4.12). Mal_Indo, R_SE_Asia, and R_S_Asia are other regions with major land use emissions, which is consistent with the nature of pasture-based livestock production in these regions which are also the regions where demand for livestock is likely to be higher. At the global level with the increase in household-level demand only, the induced emissions are about 10 billion tons Co_2 e (Co_2 equivalent) (Table 4.10). The emissions almost double to 19.8 billion

[61] For this purpose regional land use change results similar to the ones presented in the Tables 4.7 and 4.9 but disaggregated to the 18 AEZ levels of the GTAP-BIO model are used in the "AEZ_EF V47" model.

tons Co_2 e with the increase in combined demand (Table 4.12), about 9.8 billion tons accounted to the intermediate demand (Table 4.11). Since these emissions are the aggregated emissions for the 18 year period (2004-2022), the average annualized emission due to the increase in the combined demand is about 1.1 billion tons Co_2 e per year. However, given that the 0.65 billion tons Co_2 e per year reported by Gerber et al. (2013) is likely to underestimate the total land use emissions attributed to livestock production, the estimate of 1.1 billion tons Co_2 e per year obtained from this analysis is very plausible.

Notably, total emissions due to household demand are greater than the emissions induced by the intermediate demand (Tables 4.10 and 4.11), even though the net land use changes due to intermediate demand are greater than that of household demand (Tables 4.7 and 4.8). Since there is a net increase in global crop land associated with the increase in household demand (Table 4.7), a net decrease in crop land and a greater increase in pasture with the increase in intermediate demand (Table 4.8), the higher emissions associated with the conversion of forest to crop land due to household demand compared to that of the intermediate demand (Tables 4.10 and 4.11) led to higher total emissions for the household demand.

4.4.4 Sensitivity analysis

As with all models of this type, the results are a function of the magnitude of the parameters. Therefore if the parameters are altered, it is expected that the results would be altered. It is in this spirit that a sensitivity analysis is undertaken. The demand for livestock products comes directly from the preferences of those purchasing it, the final consumers. To incorporate some change in consumer preferences over the time, the elasticity associated with the substitution among livestock products is relaxed by making them more elastic. This in effect amounts to an increase in price sensitivity for any individual livestock product type. This

increase in elasticity is accomplished by altering the substitution parameter (SUBPAR) in the model. The parameter SUBPAR helps to determine how easily goods are substitutable in consumption. The SUBPAR values in the model are decreased by 50% for all regions compared to the baseline case. The decrease in SUBPAR increases own and cross price compensated elasticities. For example, Tables 4.13 and 4.14 show the compensated partial elasticity matrix for CHIHKG for the baseline simulation and the simulation with the reduced SUBPAR. The compensated price elasticities for the CHIHKG region increase substantially with the reduced SUBPAR.

Tables 4.15 and 4.16 present the difference in the percentage changes in the global and regional livestock outputs when SUBPAR is reduced. Compared to the baseline simulation, with the reduced parameter values, the global livestock output increased for all categories. The increased price sensitivity in consumption to both own-price and cross-price changes significantly increased the global output for non-ruminants. At the regional level, INDIA, CHIHKG, MEAS_NAfr, Oth_CEE_CIS, R_S_Asia, Russia, S_O_Amer, and BRAZIL are the regions with the largest increase in non-ruminant output compared to the baseline scenario (Table 4.16).

Table 4.17 shows the results of the “G” columns, the baseline scenario, the "H” columns, the price sensitive scenario, and lists the “I” columns, the difference (H-G). With increased price sensitivity, “I” columns of Table 4.17 indicate that about 3.8 million hectares of forest are spared, while both crop land and pasture area decline by just over 3 million hectares and 767 thousand hectares respectively. Even with the reduction in crop and pasture land, livestock output is higher at global level for the price sensitive version of the simulation compared to the baseline (Tables 4.15 to 4.17). While most regions had a decline in deforestation under the price

sensitive scenario, four regions had an increase, which include BRAZIL, C_C_Amer, MEAS_NAfr, and S_S_AFR. The regions having the most reduction in deforestation are CHIHKG, INDIA, Mal_Indo, R_SE_Asia, and Rest of South Asia (R_S_Asia). These are also the major regions with the largest decrease in the crop land area (Table 4.17).

Table 4.18 compares total emissions from the baseline simulation to the emissions of the price sensitive scenario. At the global level, the total emissions with the reduced SUBPAR is about 17.5 billion tons of Co_2 e., approximately 2.3 billion tons less (about 11% less) than the baseline simulation. The 11% drop in emissions is partly due to the decrease in deforestation and the increase in crop land being used for pasture. The regions with substantial reduction in emissions are CHIHKG, Mala_Indo, R_SE_Asia, R_S_Asia, and INDIA (Table 4.18). The results indicate that more price sensitivity in consumption can lead to a substantial reduction in the global GHG emission.

4.5 Summary and conclusions

Based on regional projections of GDP, population, capital, and skilled and unskilled labor, demand for livestock outputs are forecasted for the period between the years 2004 to 2022. Globally, the demand for non-ruminant output increases the most. Regionally, this expansion is most evident in fast growing economies such as CHIHKG and INDIA. Livestock production and consumption are primarily driven by household and intermediate (processing or industrial) sources. Intermediate demand accounts for the majority of the output changes.

Changes in land use as a result of the growth in livestock output are estimated to be large with a loss of forest amounting to over 43.3 million hectares, a reduction in crop land of about 1 million hectares, and an increase in pasture of over 44 million hectares. Given that the forests sequester more carbon than other land uses, clearing them results in significant emissions of

GHG. Alternatively, changing crop land to pasture helps to reduce GHG emissions. The change in land use due to increased livestock production increase emissions by about 20 billion tons of Co_2 e between 2004 and 2022 or about an average of 1.1 billion tons annually, which is about 15.5% of the total emissions (7.1 billion tons of Co_2 e) from livestock sector as estimated by Gerber et al.(2013) and about 2.2% of the total human induced GHG emissions (49 billion tons of Co_2 e) as estimated by the Intergovernmental Panel on Climate Change for the year 2004 (IPCC, 2007).

Even though the intermediate demand changes account for the majority of the land use changes from livestock production, their share in total emissions from land use changes is slightly smaller than the share of the private household demand. This is primarily due to the expansion of crop land associated with private demand changes which leads to higher emissions. This result is important given the fact that any intervention with an aim of reducing land use emissions from livestock production can achieve higher emission reduction by targeting the private household demand rather than intermediate demand. When consumer response to price changes are made more elastic i.e. more sensitive to price changes and willing to substitute more readily among livestock products, a reduction in deforestation and GHG emissions occur.

The results from this study indicate that there is a potential for significant reduction in GHG emissions from livestock sector through policy interventions that target the consumption pattern of the private households. For this purpose, the intervention should encourage increased substitution among livestock products. Policies that promote adoption of livestock products with relatively lower emission intensity can be helpful in this regard.

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Table 4.1: Countries included in the GTAP-BIO regions

GTAP-BIO regions	Description of the regions	Corresponding countries
USA	United States	Usa
EU27	European Union 27	aut, bel, bgr, cyp, cze, deu, dnk, esp, est, fin, fra, gbr, grc, hun, irl, ita, ltu, lux, lva, mlt, nld, pol, prt, rom, svk, svn, swe
BRAZIL	Brazil	Bra
CAN	Canada	Can
JAPAN	Japan	Jpn
CHIHKG	China and Hong Kong	chn, hkg
INDIA	India	Ind
C_C_Amer	Central and Caribbean Americas	mex, xna, xca, xfa, xcb
S_o_Amer	South and Other Americas	col, per, ven, xap, arg, chl, ury, xsm
E_Asia	East Asia	kor, twn, xea
Mala_Indo	Malaysia and Indonesia	ind, mys
R_SE_Asia	Rest of South East Asia	phl, sgp, tha, vnm, xse
R_S_Asia	Rest of South Asia	bgd, lka, xsa
Russia	Russian Federation	Rus
Oth_CEE_CIS	Other East Europe and Rest of Former Soviet Union	xer, alb, hrv, xsu, tur
R_Europe	Rest of European Countries	che, xef
MEAS_NAfr	Middle Eastern and North Africa	xme,mar, tun, xnf
S_S_AFR	Sub Saharan Africa	Bwa, zaf, xsc, mwi, moz, tza, zmb, zwe, xsd, mdg, uga, xss
Oceania	Oceania countries	aus, nzl, xoc

Source: GTAP-BIO model

Table 4.2: Projected growth (in percentage) in GDP, population, capital, and skilled and unskilled labor (2004-2022)

GTAP-BIO regions	GDP	Population	Capital	Skilled Labor	Unskilled Labor
USA	34.49	16.38	38.24	33.04	6.26
EU27	27.3	4.84	24.55	36.94	-13.56
BRAZIL	89.05	15.80	71.89	76.14	18.89
CAN	44.78	18.17	42.18	33.78	12.45
JAPAN	25.65	-1.76	10.59	26.62	-23.15
CHIHKG	312.68	7.08	319.00	79.36	4.19
INDIA	247.85	26.14	211.37	112.64	32.26
C_C_Amer	77.59	25.85	65.14	105.18	25.83
S_o_Amer	111.81	22.98	85.07	94.56	23.53
E_Asia	105.72	7.96	95.90	67.14	-1.60
Mala_Indo	129.3	20.4	106.39	114.25	22.62
R_SE_Asia	137.00	22.34	120.90	100.87	17.64
R_S_Asia	155.04	29.35	131.10	147.88	45.86
Russia	111.93	-2.76	44.30	22.57	-15.15
Oth_CEE_CIS	154.67	-0.02	71.04	27.13	-10.68
R_Europe	35.78	11.52	35.41	33.97	-5.44
MEAS_NAfr	108.47	31.71	99.06	113.78	17.07
S_S_AFR	143.00	54.08	95.65	160.34	59.46
Oceania	4.41	31.15	48.82	44.40	23.63

Source: GDP, Population and Capital changes from CEPII baseline version 2.1(Foure' et. al, 2012). The data for skilled and unskilled labor are obtained from the baseline projection database prepared by Chappuis and Walmsly (2011)

Table 4.3: Projected growth (in percentage) in the global livestock output (2004-2022)

Livestock output	Percentage change
Milk	63.62
Ruminant*	83.96
Non-ruminant**	110.73

*Ruminant includes live ruminant animals such as cattle, buffalo, sheep, goats etc.
** Non-ruminant includes swine, poultry including eggs etc.

Table 4.4: Projected growth (in percentage) in the regional livestock output (2004-2022)

GTAP-BIO regions	Raw Milk	Ruminant	Non ruminant
USA	31.90	32.60	34.60
EU27	23.20	26.60	26.20
BRAZIL	70.20	73.30	77.00
CAN	48.30	61.00	61.60
JAPAN	21.60	18.50	18.90
CHIHKG	292.70	323.60	216.00
INDIA	188.30	170.90	208.30
C_C_Amer	67.20	46.80	65.80
S_o_Amer	88.80	84.70	86.70
E_Asia	58.20	52.70	58.30
Mala_Indo	97.10	68.60	135.90
R_SE_Asia	119.40	69.20	78.10
R_S_Asia	119.80	125.60	132.80
Russia	80.80	79.20	81.30
Oth_CEE_CIS	106.40	115.60	110.70
Oth_Europe	31.90	32.80	37.60
MEAS_NAfr	110.70	107.20	106.60
S_S_AFR	174.20	153.20	162.90
Oceania	60.70	70.40	78.60

Table 4.5: Projected growth (in percentage) in the regional household livestock demand (2004-2022)

GTAP-BIO regions	Milk	Ruminant	Non ruminant
USA	27.40	27.10	28.30
EU27	17.50	17.90	18.60
BRAZIL	62.30	62.10	63.40
CAN	41.10	40.50	41.00
JAPAN	16.60	18.00	20.60
CHIHKG	166.80	162.10	177.90
INDIA	175.10	183.80	194.10
C_C_Amer	53.00	48.70	54.40
S_o_Amer	89.90	79.90	88.30
E_Asia	40.40	44.50	53.00
Mala_Indo	93.70	102.30	132.30
R_SE_Asia	72.30	80.50	86.80
R_S_Asia	118.00	124.90	127.80
Russia	78.50	92.50	82.00
Oth_CEE_CIS	94.70	101.80	102.40
Oth_Europe	35.30	35.30	40.30
MEAS_NAfr	108.90	108.10	109.00
S_S_AFR	192.50	182.00	175.00
Oceania	63.40	62.90	67.80

Table 4.6: Projected growth (in percentage) in the food industry demand for livestock outputs (2004-2022)

GTAP-BIO regions	Milk	Ruminant	Non ruminant
USA	35.56	35.56	35.56
EU27	26.17	26.17	26.17
BRAZIL	71.19	71.19	71.19
CAN	40.16	40.16	40.16
JAPAN	20.60	20.60	20.60
CHIHKG	156.00	156.00	156.00
INDIA	174.67	174.67	174.67
C_C_Amer	72.96	72.96	72.96
S_o_Amer	80.23	80.23	80.23
E_Asia	55.27	55.27	55.27
Mala_Indo	83.14	83.14	83.14
R_SE_Asia	25.24	25.24	25.24
R_S_Asia	65.47	65.47	65.47
Russia	89.69	89.69	89.69
Oth_CEE_CIS	137.59	137.59	137.59
Oth_Europe	23.48	23.48	23.48
MEAS_NAfr	114.19	114.19	114.19
S_S_AFR	106.06	106.06	106.06
Oceania	60.21	60.21	60.21

Table 4.7: Projected change in land use (in hectare) induced by the change in the household demand for livestock outputs (2004-2022)

GTAP-BIO Regions	Land use change with growth in all sectors (A)			Land use change with household demand for livestock fixed at the baseline level (B)			Land use change due to increase in household demand for livestock (C = A-B)		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	291,008	(10,304)*	(280,720)	472,160	10,752	(482,864)	(181,152)	(21,056)	202,144
EU27	186,976	(88,264)	(98,676)	246,144	(94,104)	(152,044)	(59,168)	5,840	53,368
BRAZIL	4,909,472	(333,844)	(4,575,760)	7,517,648	(55,916)	(7,461,680)	(2,608,176)	(277,928)	2,885,920
CAN	73,904	(4,520)	(69,398)	134,984	(26,820)	(108,138)	(61,080)	22,300	38,740
JAPAN	44,128	(36,179)	(7,952)	49,134	(35,372)	(13,768)	(5,006)	(807)	5,815
CHIHKG	9,482,352	(6,177,248)	(3,304,960)	12,334,512	(8,730,400)	(3,603,968)	(2,852,160)	2,553,152	299,008
INDIA	668,762	(755,568)	86,836	1,066,094	(776,992)	(289,070)	(397,332)	21,424	375,906
C_C_Amer	162,808	(27,524)	(135,312)	201,968	(21,208)	(180,752)	(39,160)	(6,316)	45,440
S_o_Amer	2,506,504	(307,036)	(2,199,440)	4,456,112	(158,636)	(4,297,440)	(1,949,608)	(148,400)	2,098,000
E_Asia	49,760	(40,546)	(9,192)	138,410	(37,916)	(100,480)	(88,650)	(2,630)	91,288
Mala_Indo	745,968	(564,832)	(181,121)	1,153,288	(783,408)	(369,879)	(407,320)	218,576	188,758
R_SE_Asia	839,672	(687,292)	(152,376)	1,202,032	(800,868)	(401,153)	(362,360)	113,576	248,777
R_S_Asia	118,168	(244,816)	126,648	457,176	849,760	(1,306,944)	(339,009)	(1,094,576)	1,433,592
Russia	437,216	(200,216)	(237,040)	847,488	(182,040)	(665,544)	(410,272)	(18,176)	428,504
Oth_CEE_CIS	266,000	(219,112)	(46,880)	430,432	(144,912)	(285,472)	(164,432)	(74,200)	238,592
Oth_Europe	4,278	(1,160)	(3,125)	6,624	(327)	(6,295)	(2,346)	(833)	3,170
MEAS_NAfr	12,204	(75,756)	63,568	20,380	(24,324)	3,984	(8,175)	(51,432)	59,584
S_S_AFR	12,063,280	(9,281,232)	(2,782,080)	20,199,776	(8,845,456)	(11,354,240)	(8,136,496)	(435,776)	8,572,160
Oceania	48,745	(35,708)	(12,960)	67,005	(22,232)	(44,640)	(18,260)	(13,476)	31,680
World	32,911,205	(19,091,156)	(13,819,941)	51,001,367	(19,880,418)	(31,120,386)	(18,090,162)	789,262	17,300,445

*Values in parenthesis are the negative changes

Table 4.8: Projected change in land use (in hectare) induced by change in the intermediate demand for livestock outputs (2004-2022)

GTAP-BIO Regions	Land use change with growth in all sectors (A)			Land use change with intermediate demand for livestock fixed at the baseline level (D)			Land use change due to increase in intermediate demand for livestock (E = A-D)		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	291,008	(10,304)*	(280,720)	389,872	(5,328)	(384,512)	(98,864)	(4,976)	103,792
EU27	186,976	(88,264)	(98,676)	249,488	(74,936)	(174,520)	(62,512)	(13,328)	75,844
BRAZIL	4,909,472	(333,844)	(4,575,760)	6,505,296	(181,312)	(6,324,128)	(1,595,824)	(152,532)	1,748,368
CAN	73,904	(4,520)	(69,398)	126,200	(23,428)	(102,772)	(52,296)	18,908	33,374
JAPAN	44,128	(36,179)	(7,952)	46,762	(35,126)	(11,640)	(2,634)	(1,053)	3,687
CHIHKG	9,482,352	(6,177,248)	(3,304,960)	25,433,632	(6,064,616)	(19,368,992)	(15,951,280)	(112,632)	16,064,032
INDIA	668,762	(755,568)	86,836	950,162	(658,960)	(291,196)	(281,400)	(96,608)	378,032
C_C_Amer	162,808	(27,524)	(135,312)	290,004	(11,352)	(278,704)	(127,196)	(16,172)	143,392
S_o_Amer	2,506,504	(307,036)	(2,199,440)	4,029,008	(183,424)	(3,845,648)	(1,522,504)	(123,612)	1,646,208
E_Asia	49,760	(40,546)	(9,192)	97,242	(35,594)	(61,624)	(47,482)	(4,952)	52,432
Mala_Indo	745,968	(564,832)	(181,121)	768,192	(441,896)	(326,300)	(22,224)	(122,936)	145,179
R_SE_Asia	839,672	(687,292)	(152,376)	1,165,224	(541,860)	(623,412)	(325,552)	(145,432)	471,036
R_S_Asia	118,168	(244,816)	126,648	203,097	243,420	(446,544)	(84,929)	(488,236)	573,192
Russia	437,216	(200,216)	(237,040)	493,008	(197,048)	(296,000)	(55,792)	(3,168)	58,960
Oth_CEE_CIS	266,000	(219,112)	(46,880)	345,140	(144,472)	(200,640)	(79,140)	(74,640)	153,760
Oth_Europe	4,278	(1,160)	(3,125)	5,300	(704)	(4,615)	(1,022)	(456)	1,489
MEAS_NAfr	12,204	(75,756)	63,568	17,083	(46,480)	29,408	(4,879)	(29,276)	34,160
S_S_AFR	12,063,280	(9,281,232)	(2,782,080)	16,998,064	(8,809,792)	(8,188,608)	(4,934,784)	(471,440)	5,406,528
Oceania	48,745	(35,708)	(12,960)	68,983	11,700	(80,736)	(20,238)	(47,408)	67,776
World	32,911,205	(19,091,156)	(13,819,941)	58,181,756	(17,201,207)	(40,981,182)	(25,270,551)	(1,889,949)	27,161,242

*Values in parenthesis are the negative changes

Table 4.9: Projected change in land use (in hectare) induced by change in the combined demand (household plus intermediate) for livestock outputs (2004-2022)

GTAP-BIO Regions	Land use change with growth in all sectors (A)			Land use change with private and intermediate demand for livestock fixed at the baseline level (F)			Land use change due to increase in sum of private and intermediate demand for livestock (G = A-F)		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	291,008	(10,304)*	(280,720)	571,024	15,728	(586,656)	(280,016)	(26,032)	305,936
EU27	186,976	(88,264)	(98,676)	308,656	(80,776)	(227,888)	(121,680)	(7,488)	129,212
BRAZIL	4,909,472	(333,844)	(4,575,760)	9,113,472	96,616	(9,210,048)	(4,204,000)	(430,460)	4,634,288
CAN	73,904	(4,520)	(69,398)	187,280	(45,728)	(141,512)	(113,376)	41,208	72,114
JAPAN	44,128	(36,179)	(7,952)	51,768	(34,318)	(17,455)	(7,640)	(1,861)	9,503
CHIHKG	9,482,352	(6,177,248)	(3,304,960)	28,285,792	(8,617,768)	(19,668,000)	(18,803,440)	2,440,520	16,363,040
INDIA	668,762	(755,568)	86,836	1,347,494	(680,384)	(667,102)	(678,732)	(75,184)	753,938
C_C_Amer	162,808	(27,524)	(135,312)	329,164	(5,036)	(324,144)	(166,356)	(22,488)	188,832
S_o_Amer	2,506,504	(307,036)	(2,199,440)	5,978,616	(35,024)	(5,943,648)	(3,472,112)	(272,012)	3,744,208
E_Asia	49,760	(40,546)	(9,192)	185,892	(32,964)	(152,912)	(136,132)	(7,582)	143,720
Mala_Indo	745,968	(564,832)	(181,121)	1,175,512	(660,472)	(515,058)	(429,544)	95,640	333,937
R_SE_Asia	839,672	(687,292)	(152,376)	1,527,584	(655,436)	(872,188)	(687,912)	(31,856)	719,812
R_S_Asia	118,168	(244,816)	126,648	542,105	1,337,996	(1,880,136)	(423,938)	(1,582,812)	2,006,784
Russia	437,216	(200,216)	(237,040)	903,280	(178,872)	(724,504)	(466,064)	(21,344)	487,464
Oth_CEE_CIS	266,000	(219,112)	(46,880)	509,572	(70,272)	(439,232)	(243,572)	(148,840)	392,352
Oth_Europe	4,278	(1,160)	(3,125)	7,646	129	(7,784)	(3,368)	(1,289)	4,659
MEAS_NAfr	12,204	(75,756)	63,568	25,258	4,952	(30,176)	(13,054)	(80,708)	93,744
S_S_AFR	12,063,280	(9,281,232)	(2,782,080)	25,134,560	(8,374,016)	(16,760,768)	(13,071,280)	(907,216)	13,978,688
Oceania	48,745	(35,708)	(12,960)	87,243	25,176	(112,416)	(38,498)	(60,884)	99,456
World	32,911,205	(19,091,156)	(13,819,941)	76,271,918	(17,990,469)	(58,281,627)	(43,360,713)	(1,100,688)	44,461,687

*Values in parenthesis are the negative changes

Table 4.10: Total induced emission (in 1000 tons Co_2 e) from land use changes due to changes in the household demand for livestock output

GTAP-BIO Regions	Land Conversion Sequences[62]								Total
	F-to-C	P-to-C	CP-to-C	C-to-F	C-to-P	C-to-CP	P-to-F	F-to-P	
USA	11,524	0	0	0	-2,534	-48,509	0	41,183	1,663
EU27	2,585	0	0	0	-22	0	0	11,150	13,714
BRAZIL	0	0	0	0	-49,940	-102,117	0	1,804,984	1,652,928
CAN	11,405	0	0	0	-152	0	0	10,347	21,600
JAPAN	412	0	0	0	-393	0	0	931	950
CHIHKG	1,467,582	6,331	0	0	0	0	0	74,432	1,548,345
INDIA	96,506	0	0	0	-8,182	0	0	136,876	225,201
C_C_Amer	0	0	0	0	-1,533	0	0	21,827	20,295
S_o_Amer	256	0	0	0	-33,949	0	0	1,020,114	986,421
E_Asia	404	0	0	0	-280	0	0	9,717	9,841
Mala_Indo	444,061	0	0	0	-3,500	0	0	146,716	587,278
R_SE_Asia	94,663	0	0	0	-6	0	0	152,009	246,666
R_S_Asia	177,043	0	0	0	-61,217	0	0	60,530	176,356
Russia	17,026	0	0	0	-6,372	0	0	38,848	49,501
Oth_CEE_CIS	1,661	0	0	0	-5,657	0	0	31,172	27,176
Oth_Europe	0	0	0	0	-167	0	0	303	136
MEAS_Nafr	0	0	0	0	-3,884	0	0	3,112	-772
S_S_Afr	343,949	0	0	0	-72,024	0	0	4,097,118	4,369,043
Oceania	2,719	0	0	0	-895	0	0	5,948	7,771
World	2,671,798	6,331	0	0	-250,707	-150,626	0	7,667,318	9,944,113.43

[62] F = forest, C = cropland, P = pasture, and CP = cropland- pasture (land that can alternate between crop cultivation and pasture).

Table 4.11: Total induced emission (in 1000 tons Co_2 e) from land use changes due to changes in the intermediate demand for livestock output

GTAP-BIO Regions	Land Conversion Sequences[63]								Total
	F-to-C	P-to-C	CP-to-C	C-to-F	C-to-P	C-to-CP	P-to-F	F-to-P	
USA	8,192	0	0	0	-1,240	-17,806	0	21,429	10,575
EU27	-2,181	0	0	0	-1,106	0	0	14,005	10,717
BRAZIL	0	0	0	0	-27,611	-60,945	0	1,102,322	1,013,766
CAN	9,642	0	0	0	-124	0	0	8,947	18,464
JAPAN	92	0	0	0	-309	0	0	538	322
CHIHKG	315,839	-6,331	0	0	-33,138	0	0	4,824,257	5,100,628
INDIA	1,835	0	0	0	-8,286	0	0	141,041	134,590
C_C_Amer	0	0	0	0	-3,932	0	0	70,750	66,818
S_o_Amer	-92	0	0	0	-29,268	0	0	795,055	765,695
E_Asia	-188	0	0	0	-357	0	0	5,117	4,573
Mala_Indo	-188,931	0	0	0	-5,928	0	0	103,668	-91,190
R_SE_Asia	-76,725	0	0	0	-11,463	0	0	254,869	166,680
R_S_Asia	2,913	0	0	0	-22,604	0	0	43,123	23,432
Russia	2,215	0	0	0	-910	0	0	5,308	6,613
Oth_CEE_CIS	-1,661	0	0	0	-6,262	0	0	16,399	8,476
Oth_Europe	0	0	0	0	-93	0	0	135	42
MEAS_Nafr	0	0	0	0	-2,180	0	0	1,860	-320
S_S_Afr	38,345	0	0	0	-41,384	0	0	2,581,601	2,578,562
Oceania	-545	0	0	0	-2,298	0	0	9,264	6,422
World	108,751	-6,331	0	0	-198,494	-78,751	0	9,999,689	9,824,864

[63] F = forest, C = cropland, P = pasture, and CP = cropland- pasture (land that can alternate between crop cultivation and pasture).

Table 4.12: Total induced emission (in 1000 tons Co_2 eq.) from land use changes due to changes in the combined demand (household plus intermediate) for livestock output

GTAP-BIO Regions	Land Conversion Sequences[64]								Total
	F-to-C	P-to-C	CP-to-C	C-to-F	C-to-P	C-to-CP	P-to-F	F-to-P	
USA	19,716	0	0	0	-3,774	-66,315	0	62,612	12,239
EU27	404	0	0	0	-1,128	0	0	25,155	24,431
BRAZIL	0	0	0	0	-77,551	-163,062	0	2,907,306	2,666,693
CAN	21,047	0	0	0	-276	0	0	19,294	40,064
JAPAN	505	0	0	0	-702	0	0	1,469	1,272
CHIHKG	1,783,421	0	0	0	-33,138	0	0	4,898,689	6,648,973
INDIA	98,341	0	0	0	-16,468	0	0	277,917	359,791
C_C_Amer	0	0	0	0	-5,465	0	0	92,577	87,112
S_o_Amer	164	0	0	0	-63,217	0	0	1,815,169	1,752,116
E_Asia	216	0	0	0	-637	0	0	14,834	14,414
Mala_Indo	255,131	0	0	0	-9,428	0	0	250,385	496,087
R_SE_Asia	17,938	0	0	0	-11,469	0	0	406,877	413,346
R_S_Asia	179,956	0	0	0	-83,821	0	0	103,653	199,788
Russia	19,241	0	0	0	-7,282	0	0	44,155	56,114
Oth_CEE_CIS	0	0	0	0	-11,919	0	0	47,571	35,653
Oth_Europe	1	0	0	0	-260	0	0	437	177
MEAS_Nafr	0	0	0	0	-6,064	0	0	4,972	-1,092
S_S_Afr	382,294	0	0	0	-113,408	0	0	6,678,720	6,947,606
Oceania	2,174	0	0	0	-3,193	0	0	15,212	14,193
World	2,781,398	0	0	0	-437,208	-229,377	0	17,688,554	19,768,978

[64] F = forest, C = cropland, P = pasture, and CP = cropland- pasture (land that can alternate between crop cultivation and pasture).

Table 4.13: Compensated elasticities in CHIHKG for the baseline scenario

Livestock outputs	Milk	Ruminant	Non ruminant
Milk	-0.2130	0.0001	0.0001
Ruminants	0.0001	-0.2537	0.0002
Non ruminants	0.0001	0.0002	-0.2075

Table 4.14: Compensated elasticities in CHIHKG with the reduced SUBPAR

Livestock outputs	Dairy animals	Ruminant	Non ruminant
Dairy animals	-0.6098	0.0012	0.0602
Ruminants	0.0005	-0.6286	0.0616
Non ruminants	0.0005	0.0012	-0.5498

Table 4.15: Percentage point difference in the global livestock output growth with the reduced SUBPAR compared to the baseline simulation

Livestock outputs	Percentage point difference in growth compared to baseline simulation
Milk	3.40
Ruminant	2.75
Non-ruminant	7.98

Table 4.16: Percentage point difference in the regional livestock output growth with the reduced SUBPAR compared to the baseline simulation

GTAP-BIO regions	Milk	Ruminant	Non ruminant
USA	0.10	0.40	0.40
EU27	0.80	0.40	0.80
BRAZIL	12.80	9.70	10.00
CAN	1.70	1.00	1.40
JAPAN	1.40	1.50	1.10
CHIHKG	-0.70	-0.60	15.00
INDIA	7.70	-0.90	29.70
C_C_Amer	0.80	0.20	2.20
S_o_Amer	10.20	8.30	10.30
E_Asia	5.80	4.30	4.70
Mala_Indo	-0.10	-0.60	1.10
R_SE_Asia	3.60	-2.20	1.90
R_S_Asia	-0.80	-1.60	12.20
Russia	8.20	15.80	11.70
Oth_CEE_CIS	12.60	9.40	12.30
Oth_Europe	1.10	0.20	1.40
MEAS_NAfr	11.30	11.80	14.40
S_S_AFR	-2.20	1.80	4.10
Oceania	3.30	1.60	2.40

Table 4.17: Impact of higher substitution in consumption on the land use change (in hectare)

GTAP-BIO Regions	Land use change due to change in the aggregate demand for livestock output in the baseline scenario (G)			Land use change due to change in the aggregate demand for livestock with the reduced SUBPAR (H)			Difference in land use change due to reduced SUBPAR (I = H - G)		
	Forest	Cropland	Pasture	Forest	Cropland	Pasture	Forest	Cropland	Pasture
USA	(280,016)	(26,032)	305,936	(256,992)	(48,096)	305,104	23,024	(22,064)	(832)
EU27	(121,680)	(7,488)	129,212	(114,896)	(20,176)	135,004	6,784	(12,688)	5,792
BRAZIL	(4,204,000)	(430,460)	4,634,288	(4,568,416)	(527,912)	5,096,464	(364,416)	(97,452)	462,176
CAN	(113,376)	41,208	72,114	(107,440)	32,292	75,206	5,936	(8,916)	3,092
JAPAN	(7,640)	(1,861)	9,503	(7,618)	(2,860)	10,475	22	(999)	973
CHIHKG	(18,803,440)	2,440,520	16,363,040	(15,675,056)	674,496	15,000,576	3,128,384	(1,766,024)	(1,362,464)
INDIA	(678,732)	(75,184)	753,938	(481,876)	(271,136)	753,042	196,856	(195,952)	(896)
C_C_Amer	(166,356)	(22,488)	188,832	(172,464)	(21,672)	194,184	(6,108)	816	5,352
S_o_Amer	(3,472,112)	(272,012)	3,744,208	(3,421,528)	(325,448)	3,746,944	50,584	(53,436)	2,736
E_Asia	(136,132)	(7,582)	143,720	(126,620)	(14,378)	140,992	9,512	(6,796)	(2,728)
Mala_Indo	(429,544)	95,640	333,937	(102,092)	(196,864)	298,957	327,452	(292,504)	(34,980)
R_SE_Asia	(687,912)	(31,856)	719,812	(489,032)	(184,228)	673,275	198,880	(152,372)	(46,537)
R_S_Asia	(423,938)	(1,582,812)	2,006,784	(98,976)	(1,295,420)	1,394,360	324,962	287,392	(612,424)
Russia	(466,064)	(21,344)	487,464	(389,280)	(82,136)	471,360	76,784	(60,792)	(16,104)
Oth_CEE_CIS	(243,572)	(148,840)	392,352	(205,360)	(197,128)	402,688	38,212	(48,288)	10,336
Oth_Europe	(3,368)	(1,289)	4,659	(3,316)	(1,515)	4,840	52	(226)	181
MEAS_NAfr	(13,054)	(80,708)	93,744	(13,435)	(100,072)	113,520	(381)	(19,364)	19,776
S_S_AFR	(13,071,280)	(907,216)	13,978,688	(13,245,584)	(1,524,080)	14,769,792	(174,304)	(616,864)	791,104
Oceania	(38,498)	(60,884)	99,456	(34,076)	(73,100)	107,136	4,422	(12,216)	7,680
World	(43,360,713)	(1,100,688)	44,461,687	(39,514,057)	(4,179,433)	43,693,919	3,846,657	(3,078,745)	(767,767)

Table 4.18: Impact on induced land emission (in 1000 tons CO_2 eq.) with the reduced SUBPAR

GTAP-BIO Regions	Land Conversion Sequences[65]								Emissions with the new SUBPAR (A)	Emissions in the baseline simulation (B)	Difference in emissions (A-B)
	F-to-C	P-to-C	CP-to-C	C-to-F	C-to-P	C-to-CP	P-to-F	F-to-P			
USA	14,074	0	0	0	-4,322	-74,787	0	59,772	-5,263	12,239	-17,502
EU27	88	0	0	0	-2,813	0	0	23,886	21,161	24,431	-3,270
BRAZIL	0	0	0	0	-95,183	-187,099	0	3,158,970	2,876,688	2,666,693	209,995
CAN	17,645	0	0	0	-324	0	0	19,757	37,079	40,064	-2,986
JAPAN	345	0	0	0	-879	0	0	1,528	994	1,272	-278
CHIHKG	768,930	0	0	0	-38,790	0	0	4,494,995	5,225,136	6,648,973	-1,423,837
INDIA	26,252	0	0	0	-28,145	0	0	226,234	224,342	359,791	-135,449
C_C_Amer	0	0	0	0	-5,179	0	0	95,967	90,789	87,112	3,677
S_o_Amer	3	0	0	0	-75,799	0	0	1,789,402	1,713,605	1,752,116	-38,510
E_Asia	114	0	0	0	-1,191	0	0	13,351	12,273	14,414	-2,141
Mala_Indo	0	0	0	0	-47,713	0	0	86,104	38,390	496,087	-457,697
R_SE_Asia	484	0	0	0	-37,947	0	0	298,009	260,546	413,346	-152,800
R_S_Asia	9,134	0	0	0	-67,321	0	0	46,576	-11,611	199,788	-211,400
Russia	8,194	0	0	0	-9,383	0	0	39,032	37,844	56,114	-18,270
Oth_CEE_CIS	0	0	0	0	-17,162	0	0	40,151	22,989	35,653	-12,664
Oth_Europe	0	0	0	-12	-303	0	0	434	119	177	-59
MEAS_Nafr	0	0	0	0	-7,369	0	0	5,125	-2,244	-1,092	-1,153
S_S_Afr	122,084	0	0	0	-137,012	0	0	6,958,418	6,943,490	6,947,606	-4,115
Oceania	32	0	0	0	-3,690	0	0	14,887	11,230	14,193	-2,963
World	967,380	0	0	-12	-580,524	-261,885	0	17,372,597	17,497,556	19,768,978	-2,271,422

[65] F = forest, C = cropland, P = pasture, and CP = cropland pasture.

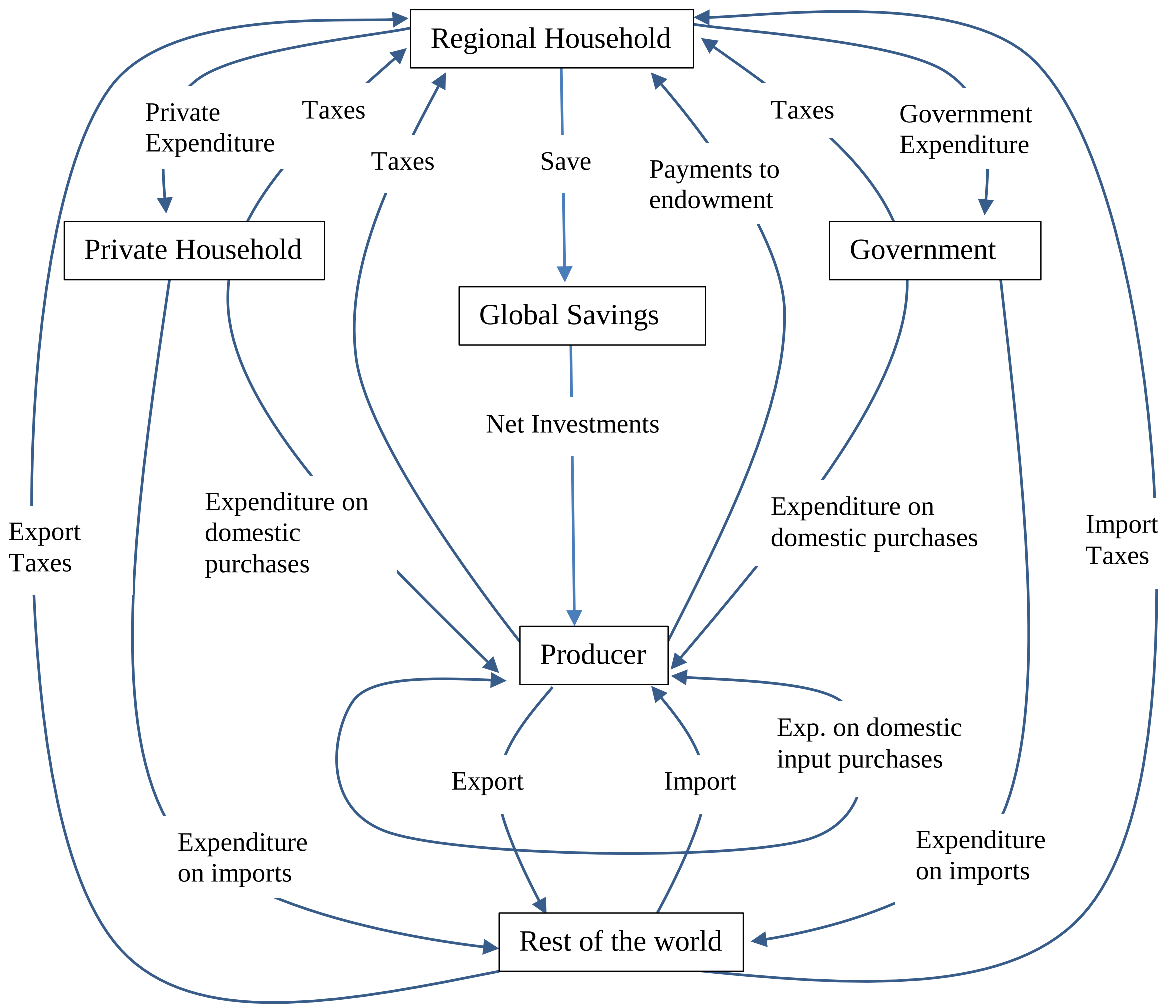

Figure 4.1: Overview of the GTAP model

(Source: Based on Brockmeier, 2001 and Birur, 2010)

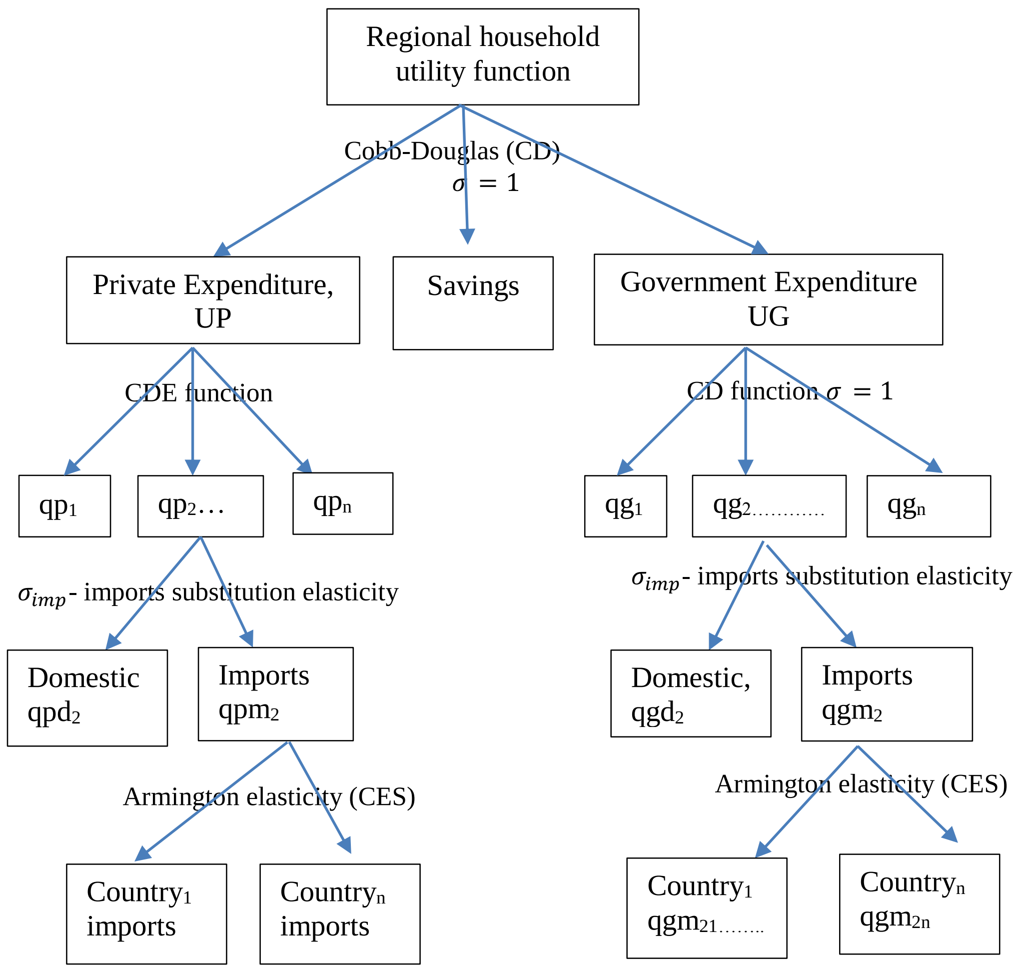

Figure 4.2 Demand structure in the GTAP model

(Source: GTAP model)

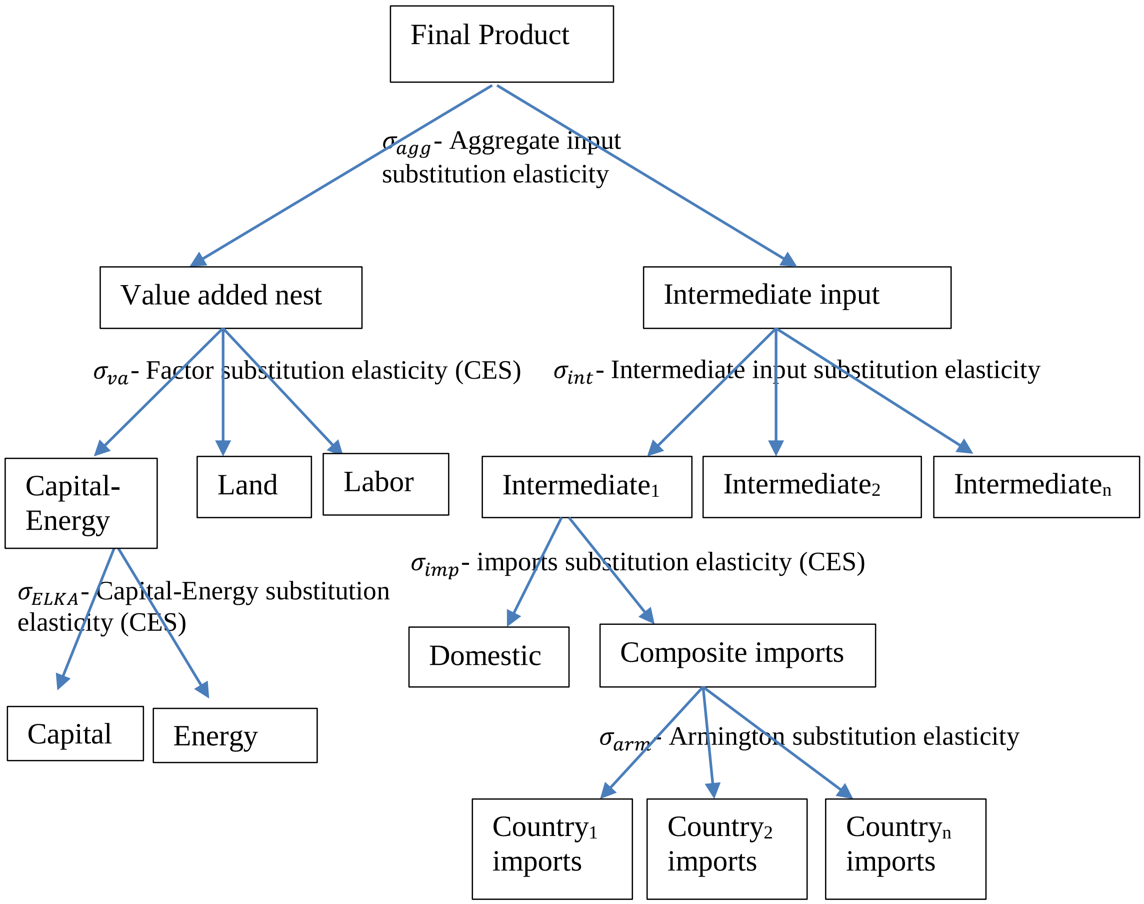

Figure 4.3: Nested production structure in the GTAP model

(Source: GTAP model)

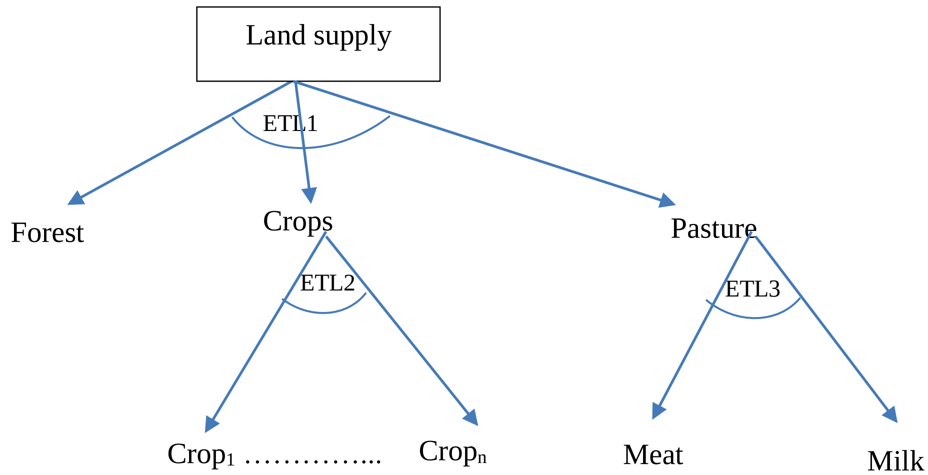

Figure 4.4: Supply of land in the GTAP BIO model

(Source: GTAP-BIO model)

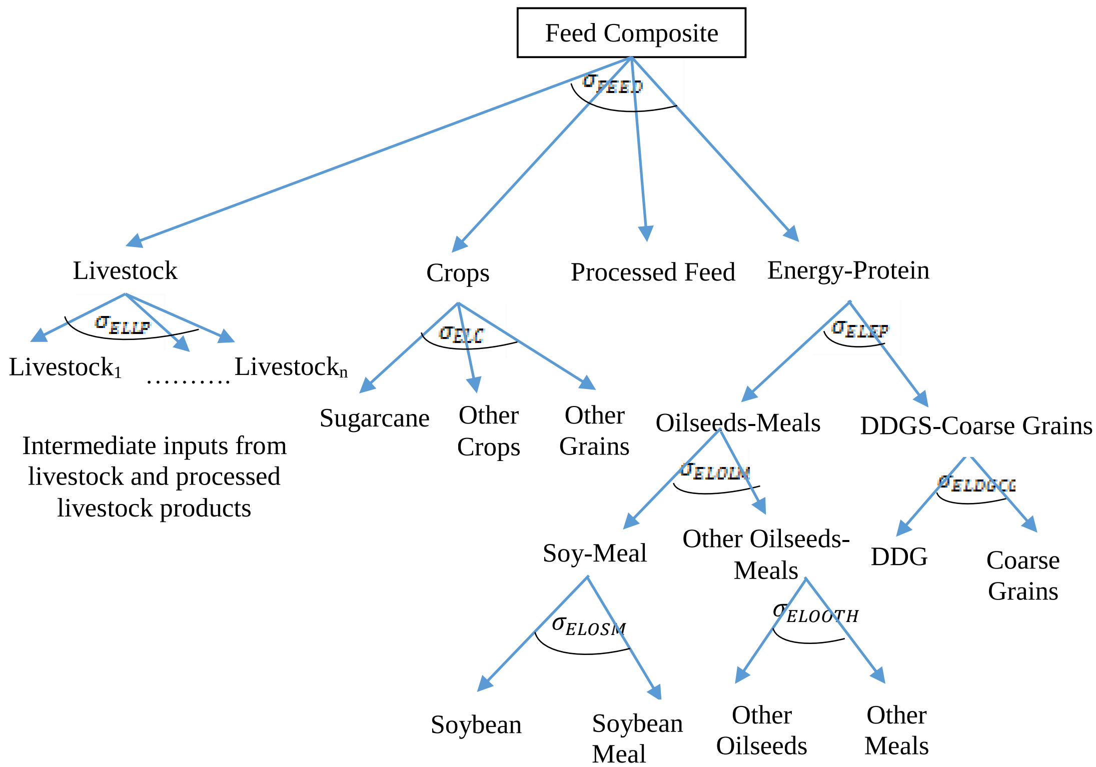

Figure 4.5 : Feed demand structure for livestock industry in the GTAP-BIO model

(Source: Taheripour et al., 2011 and GTAP-BIO model)

APPENDIX 4.A: EXPERIMENTS USED IN THE SIMULATION

Experiment 1: Simulation without fixing the demand for livestock output

Exogenous shocks to GDP, population, capital, and skilled and unskilled labor

shock qgdp(REG) = file shcks.har header "QGDP";

shock pop = file shcks.har header "POPU";

shock qo("Capital", REG) = file shcks.har header "CAPI";

shock qo("sklab", REG) = file shcks.har header "SLAB";

shock qo("Unsklab", REG) = file shcks.har header "ULAB";

The “shcks.har” file contained data on projected growth in GDP, population, capital, and skilled and unskilled labor as outlined in Table 2.

Model Closure: In order to achieve, the state growth in GDP following swap is implemented.

Swap afreg(REG) = qgdp(REG);

This swap makes factor augmenting technology (*afreg*) for each region in the model endogenous and hence the model mathematically solves for the growth in *afreg* until the GDP target is attained.

Experiment 2: Simulation with the household demand for livestock output fixed at the baseline level

This simulation is performed in order to isolate the impact of household demand on land use change. In addition to the shocks and swap mentioned in experiment 1, following swaps are implemented to fix household demand for livestock output at the baseline levels.

swap qp("Dairy_Farms" , REG) = consslack("Dairy_Farms" , REG);

swap qp("Ruminant" , REG) = consslack("Ruminant" , REG);

swap qp("NonRuminant" , REG) = consslack("NonRuminant" , REG);

swap qp("Proc_Dairy" , REG) = consslack("Proc_Dairy" , REG);

swap qp("Proc_Rum" , REG) = consslack("Proc_Rum" , REG);

swap qp("Proc_NonRum" , REG) = consslack("Proc_NonRum" , REG);

Experiment 3: Simulation with the combined demand (household plus intermediate) for livestock output fixed at baseline level

In order to fix intermediate demand in addition to the household demand for livestock output, following swaps are added in addition to the swaps and shocks in simulation 2a.

swap qf("Dairy_Farms" , ALL_INDS,REG) = afall("Dairy_Farms", ALL_INDS,REG);

swap qf("Ruminant",ALL_INDS,REG) = afall("Ruminant" ,ALL_INDS,REG);

swap qf("NonRuminant" , ALL_INDS,REG) = afall("NonRuminant", ALL_INDS,REG);

swap qf("Proc_Dairy" , ALL_INDS,REG) = afall("Proc_Dairy" , ALL_INDS,REG);

swap qf("Proc_Rum",ALL_INDS,REG) = afall("Proc_Rum",ALL_INDS,REG);

swap qf("Proc_NonRum", ALL_INDS,REG) = afall("Proc_NonRum", ALL_INDS,REG);

swap txs("Dairy_Farms",REG,REG) = qxs("Dairy_Farms",REG,REG);

swap txs("Ruminant",REG,REG) = qxs("Ruminant",REG,REG);

swap txs("NonRuminant",REG,REG) = qxs("NonRuminant",REG,REG);

swap txs("Proc_NonRum",REG,REG) = qxs("Proc_NonRum",REG,REG);

swap txs("Proc_Rum",REG,REG) = qxs("Proc_Rum",REG,REG);

swap txs("Proc_Dairy",REG,REG) = qxs("Proc_Dairy",REG,REG);

swap qgm("Proc_Rum",REG)=tgm("Proc_Rum",REG);

swap qpm("Proc_Rum",REG)=tpm("Proc_Rum",REG);

swap qgm("Proc_NonRum",REG)=tgm("Proc_NonRum",REG);

swap qpm("Proc_NonRum",REG)=tpm("Proc_NonRum",REG);

swap qgm("Proc_Dairy",REG)=tgm("Proc_Dairy",REG);

```
swap qpm("Proc_Dairy",REG)=tpm("Proc_Dairy",REG);
swap qgm("Ruminant",REG)=tgm("Ruminant",REG);
swap qpm("Ruminant",REG)=tpm("Ruminant",REG);
swap qgm("NonRuminant",REG)=tgm("NonRuminant",REG);
swap qpm("NonRuminant",REG)=tpm("NonRuminant",REG);
swap qgm("Dairy_Farms",REG)=tgm("Dairy_Farms",REG);
swap qpm("Dairy_Farms",REG)=tpm("Dairy_Farms",REG);
```

APPENDIX 4.B: SUBPAR USED IN THE SIMULATIONS

1) SUBPAR used in the baseline simulations

GTAP-BIO regions	Dairy animals	Ruminant	Non ruminant	Dairy products	Ruminant products	Non-ruminant products
USA	0.30	0.30	0.30	0.30	0.30	0.30
EU27	0.44	0.49	0.47	0.41	0.42	0.44
BRAZIL	0.77	0.77	0.77	0.77	0.77	0.77
CAN	0.40	0.39	0.40	0.40	0.40	0.40
JAPAN	0.35	0.35	0.35	0.35	0.35	0.35
CHIHKG	0.79	0.75	0.78	0.49	0.74	0.77
INDIA	0.82	0.82	0.82	0.82	0.82	0.82
C_C_Amer	0.76	0.73	0.73	0.74	0.76	0.77
S_o_Amer	0.79	0.76	0.78	0.77	0.77	0.78
E_Asia	0.61	0.64	0.65	0.61	0.61	0.61
Mala_Indo	0.81	0.78	0.73	0.76	0.73	0.75
R_SE_Asia	0.87	0.81	0.79	0.75	0.78	0.80
R_S_Asia	0.84	0.84	0.84	0.83	0.83	0.83
Russia	0.76	0.72	0.76	0.76	0.76	0.76
Oth_CEE_CIS	0.77	0.77	0.77	0.77	0.77	0.77
Oth_Europe	0.24	0.24	0.24	0.24	0.24	0.24
MEAS_NAfr	0.75	0.74	0.74	0.75	0.76	0.74
S_S_AFR	0.82	0.81	0.81	0.78	0.78	0.80
Oceania	0.42	0.40	0.41	0.42	0.44	0.42

2) SUBPAR used in the sensitivity simulations

GTAP-BIO regions	Dairy animals	Ruminant	Non ruminant	Dairy products	Ruminant products	Non-ruminant products
USA	0.15	0.15	0.15	0.15	0.15	0.15
EU27	0.22	0.25	0.23	0.21	0.21	0.22
BRAZIL	0.38	0.38	0.38	0.38	0.38	0.38
CAN	0.20	0.20	0.20	0.20	0.20	0.20
JAPAN	0.17	0.17	0.17	0.17	0.17	0.17
CHIHKG	0.39	0.37	0.39	0.25	0.37	0.38
INDIA	0.41	0.41	0.41	0.41	0.41	0.41
C_C_Amer	0.38	0.36	0.37	0.37	0.38	0.38
S_o_Amer	0.39	0.38	0.39	0.38	0.39	0.39
E_Asia	0.30	0.32	0.33	0.30	0.30	0.31
Mala_Indo	0.40	0.39	0.36	0.38	0.36	0.38
R_SE_Asia	0.43	0.40	0.40	0.38	0.39	0.40
R_S_Asia	0.42	0.42	0.42	0.42	0.42	0.42
Russia	0.38	0.36	0.38	0.38	0.38	0.38
Oth_CEE_CIS	0.39	0.38	0.39	0.39	0.39	0.39
Oth_Europe	0.12	0.12	0.12	0.12	0.12	0.12
MEAS_NAfr	0.38	0.37	0.37	0.38	0.38	0.37
S_S_AFR	0.41	0.41	0.40	0.39	0.39	0.40
Oceania	0.21	0.20	0.20	0.21	0.22	0.21

CHAPTER 5

CONCLUSIONS

The three essays included in this dissertation examine various issues relating to biofuels, drought, livestock, and the environment. Using the stochastic EDM, the first essay examines the impact of biofuels policy and 2012 drought on eight commodity markets viz. beef, pork, poultry, corn, soybean, soybean meal, DG, and ethanol. Results suggest that the impact of drought in presence of biofuels mandate is greatest for the grain markets especially the corn market. Among the feed demands, corn feed demand is the most affected by drought. Since meat markets are the secondary recipients of the drought impact i.e. the impact on meat markets is transmitted through the grain markets, the impact on meat prices is relatively less compared to the grain prices. Given the dual impact of drought on the feed prices as well as on the availability of pasture, beef is the most affected compared to the pork and poultry markets. The use of RIN credits provide some relief to the corn market but that effect is not fully transmitted to the meat markets indicating a limited effectiveness of RIN credits as an instrument to mitigate the impact of drought on agricultural markets.

The second essay use a series of econometric models to determine the degree of U.S. market power in importing sugarcane ethanol from Brazil. The residual supply approach is used to estimate the elasticity of sugarcane ethanol supply from Brazil to the United States. The results indicate that the countries competing importing sugarcane ethanol from Brazil have a significant influence in determining the supply of ethanol to

United States. Nevertheless, U.S. importers still have a small degree of market power in importing ethanol from Brazil. Given that U.S. importers are operating at oliogopsony equilibrium, it implies that any policy intervention that restricts the ethanol imports from Brazil may not be optimal for the United States from an importing country perspective.

The third essay uses the GTAP-BIO model to project the growth of livestock output between 2004 and 2022 and estimates the land use changes and the associated GHG emissions induced by the increased livestock production during the period. Regional projections on GDP, population, capital, and skilled and unskilled labor are used in the GTAP-BIO model to project the growth of livestock output in different regions of the world. Globally the increase in non-ruminant output is higher than other livestock outputs. CHIHKG and INDIA are the regions with the largest growth in livestock outputs. Globally, the increase in livestock output results into about 44 million hectare increase in pasture and decrease of about 1 and 43 million hectares in crop land and forest area respectively. This change in land use induces about 20 billion tons of Co_2 e emissions in the world. Although intermediate industrial demand for livestock output accounts for majority of land use changes, their share in total emissions from land use changes are smaller compared to that of private household demand. This implies that reduction/changes in household demand for livestock output can contribute substantially in reducing emissions associated with land use change due to increased livestock production. One way to affect household demand is to change their demand elasticity by influencing/modifying their preference for livestock products. The results from an experiment that increases the sensitivity of household demand to price changes in livestock products indicate substantial reduction in GHG emissions with higher price

sensitivity. In practice, the higher price sensitivity can be achieved by interventions that provide households with a range of choices for various livestock products.