THREE ESSAYS ON U.S. CORN-BASED FUEL ETHANOL MARKETS

by

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(Under the Direction of Michael E. Wetzstein)

ABSTRACT

This study investigates three related issues on U.S. corn-based fuel ethanol markets. The primary objectives involve measuring economic consequences of relaxating the blend wall, building a theoretical framework for the inter-linkage between the fuel and food markets, analyzing the fuel vs. food literature, methodologies and policies for the food before fuel nexus, and addressing the food before fuel debate by empirical studies.

The first essay, submitted to *Energy Economics*, is a companion paper of our previous work published in *Energy Policy* (2011). Based on the theoretical model, empirical studies employing both benchmark value calculations and Monte Carlo simulations are conducted. Our results reveal an anomaly where a relaxation of this blend wall elicits a demand response. Under a wide range of elasticities, this demand response can actually increase the consumption of petroleum gasoline and thus lead to greater energy insecurity.

The second essay, published in *Biofuel/Book 1, InTech*, lays out evidence in support of the hypothesis that the 2007-2008 food before fuel crisis was caused not by growing demand for biofuels but instead by the shift in global policies toward relying primarily on markets to provide adequate agricultural commodities in periods of sharp increases in food demand. Based on this hypothesis and economic theory, policies to advert future food before fuel crises or any other causes of food price volatilities and literature reviews of methodolies are developed.

The third essay, published in *Energy Economics*, employs a Structural Vector Autoregression (SVAR) model along with a Direct Acyclic Graph to conduct an empirical analysis on the inter-linkage between the food and fuel markets. The results support the hypothesis that fundamental market forces of demand and supply are the main drivers of food price volatility. Increased biofuel production may cause short-run food price increases but not long-run price shifts. Decentralized freely operating markets will mitigate the persistence of any price shocks and restore prices to their long-run trends.

INDEX WORDS: Blend Wall, Energy Security, Ethanol, Biofuel, DAG, Food.

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DEDICATION

Dedicated to my parents, Rong Qiu and Hui Huang, and my husband Fuming Wang, for their love and support.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVEIW

1.1 Background

For over a century, America has flirted with biofuel as a vehicle fuel. As early as 1908, ethanol was used in the first flex-fuel vehicle, Model T. Since the 1970s, motivated by the Middle East oil supply disruptions, energy security, and environmental concerns (such as combating climate change), policies supporting the development of biofuel production (especially developing and promoting the ethanol industry) were developed. As summarized by EIA, Zhang et.al (2009), and McPhail (2011), there are a number of milestones supporting the ethanol industry development.

The first key milestone is the subsidy (tax credit). In 1978, the first excise tax exemption for biomass derived fuels was established by the U.S. Energy Tax Act. This act was aimed to establish and support the U.S. biofuel industry with a $0.40 per gallon subsidy for ethanol blended into gasoline. In 1984, this ethanol subsidy increased to $0.60 per gallon. Since then, the amount and type of subsidy have varied. In 2004, Volumetric Ethanol Exercise Tax Credit (VEETC), commonly referred to the “blender’s credit” was implemented by the American Jobs Creation Act. The tax credit was to stimulate the development of ethanol production by passing onto motorists the tax credit (American Coalition for Ethanol, 2009). And in the 2009 fiscal year, this led to $5.61 million in foregone tax revenue (McPhail, 2011).

The second milestone is the Clean Air Act Amendments (Zhang et.al, 2009). In 1988, ethanol was used as an oxygenate in gasoline along with other oxygenates including MTBE (Methyl Tertiary Butyl Ether) and ETBE (Ethyl Tertiary Butyl Ether). In 1990, Clean Air Act Amendments (CAAA, 1990) were announced: Oxygenated Fuels (Gasoline) Program and the Reformulated Gasoline (RFG) programs aiming to elicit more demands for ethanol consumption were established. In 1995, EPA began requiring the use of reformulated gasoline in certain areas, such as metropolitan areas not meeting minimum air quality standards.

The third milestone is the potential contamination of groundwater from MTBE and its subsequent ban in a number of states (Zhang et.al, 2009). In 2000, EPA officially recommended MTBE to be phased out nationally. By October 2003, 18 states had passed legislations that would ban the use of MTBE. Considering ethanol as a substitute for MTBE as an oxygenate in gasoline, the bans induced increased ethanol demand. In 2003, the switch from MTBE to ethanol to make reformulated gasoline led to a significant increase in ethanol demand by mid-year in California, and ethanol production began to exceed MTBE with it eventually dominating as an oxygenate.

The fourth milestone is the Renewable Fuels Standards (RFS). In 2005, the Energy Policy Act established the RFS that ensures the minimum volume of renewable fuels blended in gasoline. This act established a new goal to double the use of renewable fuel by 2012, mainly corn-based ethanol. The mandates provide a production foundation for the ethanol industry leading to long-run stability, although argued by some economists and groups that a blend wall cap of E10 is placing RFS at risk (Nuembery, 2009; PhyOrg.com, 2009; American Coalition for Ethanol, 2009).

The fifth milestone is the promotion of E85 and associated flex-fuel vehicles. In 1992, the Policy Energy Act defined the ethanol blends with at least 85% ethanol as alternative transportation fuels, and this act provided tax deductions for those flex-fuel vehicles. In 1997, flexible-fueled vehicle models began to be produced by major U.S. auto manufacturers, although with the scarcity of E-85 fueling stations, most flex-fueled vehicles still used conventional gasoline fuel. By the end of 2002, more than 3 million of flex-fuel vehicles were in use, and the total number of the flex-fuel vehicles is still growing. By January 2011, there are more than 8 million flexible fuel vehicles on U.S.

Driven by the milestones along with favorable economic conditions (such as the five milestones listed above), the ethanol production experienced an exponential growth during the past decade years (Figure 1.1).

1.2. Problem Statement

1.2.1. Blend-Wall Economics: An Anomaly

Among various ethanol regulation policies, of particular current concern is the relaxation of the "blend wall", the percentage of the ethanol fuel allowed to be blended in conventional gasoline. In October 2010, the EPA partially increased the blend wall from 10% to 15% on 2007 or newer vehicles. However, economics associated with the market consequences of the blend wall increase are limited. A popular prediction supporting the relaxation of the blend wall is mainly centered on the following: an increase in the blend wall from 10% to 15% would allow the ethanol industry to achieve the targeted 36 billion gallons of renewable fuels in the 2007 Energy Bill under Renewable Fuel Standards (RFS), creating a larger and stable foundation for the ethanol industry (Nuembery, 2009; American Coalition for Ethanol, 2009; Tyner, 2009; Wisner, 2010). Second, with the relaxation of the blend wall, the U.S. energy security will be enhanced through consuming less imported fossil fuels (Growth energy, 2009). In addition, a relation of the blend wall will reduce GHG emissions and creating more job opportunities (Dreyer, 2011).

In contrast to the popular belief,   economic theory indicates that an anomaly might occur. Based on a theoretical microeconomics model, the total effects from a relaxation of the blend wall can be decomposed into a positive expansion effect and the negative substitution effect. An anomaly will occur when the positive expansion effect overwhelms the negative substitution effect. In such a case, an increase in the blend wall will elicit more ethanol consumptions as well as petroleum gasoline consumptions. Therefore, the U.S. energy security is prone to be harmed rather than to be enhanced, and most of the economics justifications proposed by those proponents become questionable**.**

1.2.2. Food before Fuel Issue

As early as 1983, Barnard (1983) has noticed the potential disruptive force that U.S. biofuel production can exert on and the world food sectors. Summarized by Zhang et.al (2010a), with the promotion of the biofuel production, farmers face with dual choices−providing biofuel for vehicles or providing foodstuffs for human beings− depending on their relative net returns (Brown, 1980). In the other word, direct competition between biofuel and food production might exist (Rajagopal and Zilberman, 2007 and Von Urff, 2007). A net welfare loss will happen when the benefits of biofuels are outweighed by the negative consequences linked to reduced food availability.

In 2007-2008, global food prices experienced a significant upward spike resulting in political and economic instability, conflicts, and hardships in both the developed and developing world. A widely accepted view attributes this food price spike to the use of crops for the production of biofuel (Diao et al., 2008; Abbott et. al, 2008). Motivated by the worldwide oil price volatilities, energy security, and environmental concerns, increasing amounts of agricultural commodities are used as inputs for ethanol production rather than as food.

In contrast to the popular belief that the 2007-2008 food price spike was a result of shifts in crop usage from food to fuel, the following is hypothesized:

- Fundamental market forces of demand and supply were the main drivers of the 2007-2008 food price spikes.
- In the short-run, agricultural commodity prices increase from biofuel or other demand shocks.
- In the long-run, global competitive agricultural commodities markets will respond to commodity price shocks, restoring prices to their long-run trends. However, there may be a lag time in such response, due to inherent friction within the markets, costly or irreversible decisions, and uncertainty. Such friction can yield a potential short-run volatility in food prices.

1.3. Objectives

The overall objective of this dissertation is to describe how U.S. ethanol policies/regulations affect the ethanol, conventional gasoline, and E85 markets; capture the inter-linkages between the U.S. ethanol market and the food market.

The overall objective will be addressed through three essays with the following specific objectives.

1. Conduct empirical analysis on the economic impacts of relaxing the blend wall on the U.S. fuel market.

Detailed objectives include:

- Summarize comparative statics elasticities published in the companion paper (Zhang et.al., 2010b).
- Employ published parameter elasticities, prices, and quantities from current data sources to estimate benchmark values of comparative statics elasticities.
- Employ Monte Carlo simulations for calculating the means and standard deviations of the comparative statics results.
- Calculate the probability of the anomaly that a relaxation of the blend wall leads to an increase of petroleum gasoline consumption.
- Investigate the effect of parameter elasticities on the comparative statics elasticities.

2. Conduct a literature review of the theory, methodology, and policies for the post 2008 food before fuel crisis, and build a theoretical framework of the food before fuel issue.
3. Based on the theoretical framework in Essay2, quantify the interactions between the food and fuel markets by employing a Structural Vector Autoregression (SVAR) model.

Detailed objectives include:

- Identify structural supply-demand shocks influencing energy and agricultural commodity prices.
- Illustrate how U.S. agricultural commodity prices respond to demand and supply shocks in a short- and long run.
- Quantify the relative importance of each structural shock in explaining the volatility of agricultural commodity prices in a short- and long run.
- Picture the dynamic causal flows within energy and agricultural commodity markets.

1.4. Structure of the Study

This dissertation consists of five chapters. This chapter (Chapter 1) is the introduction, Chapters 2-4 are three essays, and Chapter 5 is the conclusion. Chapter2, (Essay 1): An Ethanol Blend Wall Shift is Prone to Increase Petroleum Gasoline Demand, was submitted to *Energy Economics* . It is also a companion paper of a joint work published in *Energy Policy* (2010). Chapter 3 (Essay 2): The Post 2008 Food before Fuel Crisis: Theory, Literature, and Policies, was published as a chapter in Biofuel/Book1 (2011). Chapter 4 (Essay3): Considering Macroeconomic Indicators in the Food before Fuel Issue, is an empirical analysis employing SVAR models based on the theoretical framework established in Essay2, and was published in *Energy Economics*. Conclusions and discussions of future research are presented in Chapter 5

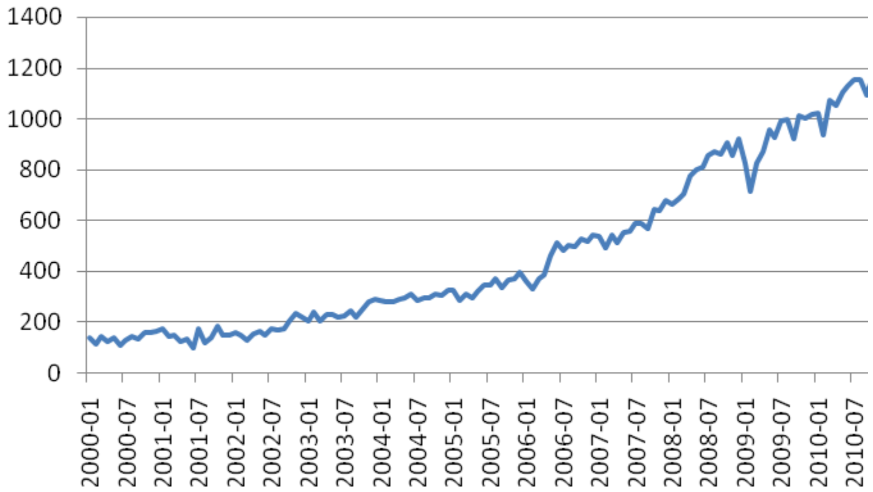

Figure 1.1. U.S. Total Production of Fuel Ethanol (Million Gallons)

Source: EIA

CHAPTER 2

AN ETHANOL BLEND WALL SHIFT IS PRONE TO INCREASE PETROLEUM GASOLINE DEMAND [1]

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[1] Qiu,C., G. Colson, and M.E. Wetzstein. 2011. Submitted to *Energy Economics*, 12/06/2011.

Abstract

In 2010, the U.S. Environmental Protection Agency announced a waiver allowing an increase in the fuel-ethanol blend limit (the "blend wall") from 10% (*E10*) to 15% (*E15*). Justifications for the waiver are reduced vehicle fuel prices and less consumption of petroleum gasoline, leading to greater energy security. Empirical investigations of this waiver using Monte Carlo simulations reveal an anomaly where a relaxation of this blend wall elicits a demand response. Under a wide range of elasticities, this demand response can actually increase the consumption of petroleum gasoline and thus lead to greater energy insecurity. The economics supporting this result and associated policy implications are developed and discussed.

2.1. Introduction

The U.S. ethanol regulation restricting the percentage of ethanol fuel allowed in conventional vehicles is popularly termed the "blend wall." Prior to October 2010, the regulation required no more than 10% ethanol, *E10*, to be used in U.S. conventional non-flex-fueled vehicles. After this date, the U.S. Environmental Protection Agency (EPA) partially granted a waiver request by Growth Energy to increase the blend wall from 10% to 15% on 2001 or newer vehicles. Any blends higher than 15% require a flex-fuel vehicle capable of running on higher ethanol/gasoline blends. This includes the current *E85* blend containing 70% to 85% ethanol and emerging mid-range blends, *E30* and *E40*, with 30% and 40% ethanol, respectively.

A number of popular blend wall predictions support the necessity and urgency of relaxing the blend wall (Tyner, 2009; Wisner, 2010). The underlying justification for this blend wall shift (relaxation) is that a blend wall cap of 10% restricts the ability to achieve the 36 billion gallons of renewable fuels set in the 2007 Energy Bill under the Renewable Fuel Standard (RFS). With U.S. blended gasoline consumption essentially flat and ethanol at the blend wall of 10%, the rising renewable mandates limit the supply avenues for ethanol. Without the ability to increase ethanol use in conventional vehicles, the increased mandated ethanol must seek alternative avenues such as the *E85* market.

The EPA is responsible for implementing the RFS and has established a tracking system using renewable identification numbers (RINs), which allow for credit verification and trading. The total 36 billion gallon mandate is divided into four nested categories: total renewable fuels, advanced biofuels, biodiesel, and cellulosic ethanol (Schnepf and Yacobucci, 2012). Each category has its own volume requirements. The EPA may waive the required mandates if implementation would severely harm the economy or the environment(Meyer and Thompson, 2011). In the last three years (2010 through 2012), EPA has lowered the cellulosic volume mandates (Bracmort, 2012).

The RFS aims to provide a market for the ethanol industry and thus promote stable long-run demand for the industry. However, the current cap of *E10* will place the RFS at risk (Nuembery, 2009). The blend wall also suppresses ethanol prices that stymie the ethanol industry's growth. The American Coalition for Ethanol has stated that unless the blend wall is allowed to shift, demand for U.S. biofuels will come to a standstill in the short run and will place the future of cellulosic biofuels in jeopardy (American Coalition for Ethanol, 2009). In particular, the RFS mandate requires 20 billion gallons of cellulosic ethanol or other non-corn based biofuels by 2020. The blend wall in constraining the amount of ethanol used for blending dampens investment interest in cellulosic ethanol development. This has potentially contributed to the EPA having to waive the cellulosic biofuel mandates.

The ethanol industry believes their future success depends on the EPA continuing to shift the blend wall to higher levels. The major rational in support for shifting the blend wall is increased energy security through the use of less foreign petroleum gasoline. Growth Energy, a U.S. advocacy group supporting ethanol use, filed the Green Job waiver with the U.S. EPA that resulted in a partial blend wall shift. The waiver requested a blend wall shift from 10% to 15% with the justification that this shift will help accelerate U.S. renewable fuel consumption and increase energy security by substituting conventional gasoline with ethanol as well as reducing dependence on foreign oil. In addition, supporters of the shift from 10% to 15% argue that it will eliminate more GHG emissions, reduce transportation costs for consumers, and create more high-skilled job opportunities in rural communities (Dreyer, 2011). The shift will also boost the production of cellulosic ethanol (American Coalition for Ethanol, 2009). With the *E10* blend market predominantly supplied by corn-based ethanol, without a blend wall shift there will be limited entry opportunities for cellulosic ethanol.

There is no question that increasing the blend wall will help foster growth for the ethanol industry and help the U.S. meet RFS mandates through increased ethanol production. However, De Gorter and Just (2009) have raised the question of whether a major motivation for biofuels - decreased petroleum gasoline consumption - will be hindered or assisted by tax credits and mandates. They theoretically determine tax credits along with mandates subsidize fuel consumption instead of biofuels, which can increase petroleum gasoline consumption and hinder energy security. In a pure ceteris paribus framework, conventional wisdom would project that increasing the blend wall from 10% to 15% would displace petroleum gasoline consumption and thus increase U.S. energy security. However, as explored in Zhang et al. (2010b), when considering the entire biofuel market that consists of not only *E10* but also higher blends such as *E85*, such a straightforward assessment of the impact on petroleum gasoline consumption does not follow because of the interplay between different blends. In their theoretical work, they indicate that an increase in the blend wall from 10% to 15% may lead to an increase in the price of *E85* and a lower price for the new 15% blend. If this occurs, the lower price of the *E15* creates an expansion effect on the consumption of *E15* that increases the use of petroleum gasoline. Overall, while a shift in the blend wall will lead to more ethanol being used in blending fuels, contrary to the arguments of blend wall waiver proponents there is potential that more petroleum gasoline is used in producing blended fuels as well.

To see this result, consider Figure 2.1. from Zhang et al. (2010b), which decomposes the total effect of a blend wall shift on total petroleum gasoline consumption into substitution and expansion effects. The curve $E\gamma^o$ is an isoquant measuring the ability to substitute ethanol, Q_e, for fossil fuel, Q_G, holding the the level of blended fuel constant at $E\gamma^o$. Points A and B represent different blends of fossil fuel and ethanol with A representing *E10* and B representing a higher ethanol blend ratio. For the substitution effect, given the technological ability to substitute ethanol for petroleum gasoline in the blended fuel, a shift in the blend wall, holding the quantity of the blended gasoline constant, always yields a negative effect on the gasoline petroleum consumption. This is represented as a movement from A to B. Thus, with no expansion effect, the total effect would correspond to the negative substitution effect. With a zero expansion effect, a positive blend wall shift (from A to B) will result in more ethanol and less petroleum fuel consumption. This will then enhance energy security with less dependence on foreign petroleum gasoline. As advocates of the shift indicate, it will reduce the price of blended fuels. Such a price decline can cause a positive expansion effect, movement from B to C. Depending on the magnitude and direction of both the substitution and expansion effects, an anomaly occurs when the positive expansion effect offsets the negative substitution effect. A positive shift in the blend wall would then result in an increase in petroleum gasoline consumption (Zhang et al., 2010b). In Figure 2.1., the total effect on fossil fuel equals the sum of the negative substitution and the positive expansion effect. With the expansion effect greater in absolute value to the substitution effect, the total effect is positive.

While the theoretical possibility of a blend wall shift to increase petroleum gasoline emerges from their model, it is an empirical question whether in fact this will occur and to what degree. As a unique contribution to the literature, in this study the Zhang el al. (2010b) results are employed as a foundation to empirically estimate the magnitude of price and quantity responsiveness. In particular, estimates are derived on the likely direction and magnitude of total petroleum gasoline consumption from a positive shift in the blend wall. Based on published elasticities and other parameter values, Monte Carlo analysis is employed for measuring the direction and magnitude of a blend wall shift. Results indicate only if the blend wall increases to the point of allowing *E74* does total petroleum gasoline consumption not increase with a blend wall shift. Specifically, the empirical results reveal the shift to *E15* will likely result in an increase in total petroleum gasoline consumption. This result is of major energy policy importance in the analysis of alternative policies to wean the United States from its addiction to foreign petroleum gasoline. Results indicate the waiver is likely to increase rather than reduce United States' dependence on foreign petroleum gasoline.

2. 2.Theoretical Development

2.2.1. Theoretical Model

The following theoretical framework serves as the foundation for the empirical analysis of the effects of a blend wall shift. For this framework, the theoretical model developed in Zhang et al. (2010b) is employed that casts the ethanol market as a two sector industry with an ethanol refining sector and a blending sector. This construction is consistent with prior efforts toward investigating the economic effects of bioenergy policies (Böhringer et al., 2009; Kangas et al., 2011; Kretschmer et al., 2009; Kretschmer and Peterson, 2010; Lankoski and Ollikainen, 2011; Strand, 2011; Timilsina et al., 2011).

Ethanol market supply, Q_e^S, is specified as

$$Q_e^s = Q_e^s(p_e|\bar{r}), \tag{2.1}$$

where p_e is the competitive price of ethanol, with $\partial Q_e^s/\partial p_e > 0$ and $\bar{r}$ a vector of input prices. Two blended fuels are considered in the blending sector: *E85*, which constitutes 85% ethanol and

15% petroleum gasoline, and *Eγ,* where *γ* is the proportion of ethanol used in the intermediate blended ethanol fuel. The inverse demands of *E85* and *Eγ* are captured respectively as

$$p_{85} = p_{85}(E_{85}^{D}|\bar{x}) \tag{2.2a}$$

and

$$p_{\gamma} = p_{\gamma}(E_{\gamma}^{D}|\bar{x}) \tag{2.2b}$$

where p_{85} and p_{γ} are the prices of *E85* and *Eγ* respectively, and E_{85}^{D} and E_{γ}^{D} are the quantities demanded with $\bar{x}$ the corresponding vector of demand shifters.

A representative blender aims to maximize the total profit of blending *E85* and *Eγ*. The associated equilibrium F.O.C.s yield blender's demand for ethanol, *e*, as a function of *E85* and *Eγ* prices p_{85} and p_{γ}, respectively, and petroleum gasoline price p_g, $e = e(p_{\gamma}, p_{85}, p_e, p_g)$. Assuming the price of petroleum gasoline is exogenous and summing all the representative blender's demand functions for ethanol, the market demand function of ethanol could be characterized as $\mathrm{Q_e^D}(\mathrm{p}_{\gamma}, p_{85}, \mathrm{p_e}|\ \mathrm{p_g})$, where $\mathrm{Q_e^D}$ is a function of *E85*, *Eγ*, and ethanol prices based on the given price of petroleum gasoline.[1] Market equilibrium exists where ethanol supply equals to ethanol demand

$$\mathrm{Q_e^D}(\mathrm{p}_{\gamma}, p_{85}, \mathrm{p_e}|\ \mathrm{p_g}) = Q_e^s(\mathrm{p_e}|\bar{\mathrm{r}}). \tag{2.3}$$

2.2. 2. Comparative Statics

Based on the market supply for ethanol (2.1), the inverse market demands for *E85* and *Eγ* (2.2), equilibrium conditions for *E85* and *Eγ* (stated in Zhang et al., 2010b), and ethanol's market equilibrium condition (2.3), comparative statics associated with shifting the blend wall are derived and summarized in Table 2.1. Specifically, a positive shift in the blend wall will increase the prices of ethanol and *E85,* the quantities of ethanol in blending the blended fuel, *Eγ* , the total quantity of ethanol, Qe, and the consumption of the blended fuel, *Eγ*. Moving in the opposite direction are the price of the blended fuel, *Eγ,* the quantity of *E85* along with quantity of ethanol and petroleum gasoline used in blending *E85*.

These unambiguous results are in contrast to indeterminate results for a positive blend wall shift on petroleum gasoline used for blending *Eγ*, and the total petroleum gasoline consumption. The direction of petroleum gasoline used in blending *Eγ* is indeterminate unless an assumption is made on the elasticity of the quantity of *Eγ* with respect to the blend wall. If a relaxation of the blend wall leads little or no increase in the *Eγ* fuels, then the shift will unlikely result in an increase in petroleum gasoline consumption. In contrast, even a slightly inelastic response of the quantity of *Eγ* with respect to the blend wall might cause an increase in gasoline consumption. Specifically, under a wide range of elasticities, a relaxation of the blend wall will elicit an increase in the consumption of petroleum gasoline used in blending *Eγ.* The impact of a positive blend wall shift on the total consumption of petroleum gasoline is similar to the impacts on the consumption of petroleum gasoline used in blending *Eγ.* The only difference is an adjustment for the effect of a blend wall shift on the consumption of *E85.* The adjustment is the response of *E85* with respect to the blend wall multiplied by the ratio of petroleum gasoline used in blending *E85* to the total petroleum gasoline used in blending *Eγ.* Depending on how responsive *Eγ* is to a blend wall shift, and the ratio of gasoline used for *E85* relative to *Eγ,* total petroleum gasoline consumption may either increase or decrease with a positive shift in the blend wall. Given the large level of petroleum gasoline used in blending *Eγ*, this adjustment is fairly small. Therefore, a relaxation of the blend wall will likely increase total gasoline consumption.

2.3. Parameter Values

To assess the magnitudes of the comparative statics for a change in the blend wall, *γ*, this study employs published elasticities, quantities, and fuel price histories that are summarized in Table

2.2. Monthly data from May, 1989 to February, 2011 are employed in this study. The real petroleum gasoline rack price is obtained from Energy Information Administration (EIA), and is measured in \$/gallon. The ethanol price is net of the \$0.45 federal tax credit and deflated, denoted by nominal price/CPI*100, where the nominal monthly ethanol price is obtained from the Office of Energy Policy and New Uses, USDA. Data on the quantity of petroleum gasoline and ethanol are obtained from Energy Information Administration (EIA), and are measured in gallons.

Prices of blended gasoline could not be obtained directly from current resources, but are calculated as the weighted average of ethanol and petroleum gasoline. In terms of *E10* and *E85*, the American Coalition for Ethanol estimates 99% of ethanol fuel is used in blending *E10* with the remaining 1% for *E85* (Kolrba, 2007). All the benchmark values for the prices and quantities are values observed in February, 2011.

Estimates of parameter elasticities are from published articles with the own ethanol demand ε^D_{e,p_e} and supply elasticities ε^S_{e,p_e}, along with the cross elasticity for gasoline, $\varepsilon^D_{e,p_\gamma}$, from the Luchansky and Monks (2010) empirical ethanol supply and demand model. However, no cross elasticity estimates for the *E85* price response on ethanol, $\varepsilon^D_{e,p_{85}}$ are available. As a measure of this responsiveness, the own ethanol price elasticity of demand, ε^D_{e,p_e}, estimated by Luchansky and Monks (2010) was employed. With *E85* consisting of 85% ethanol, this should serve as a reasonable surrogate for the cross elasticity. Finally, based on an extensive literature review, the Parry and Smalls (2005) demand elasticity for gasoline was employed for the own blended fuel demand elasticity.

2.4. Benchmark Results

Employing the benchmark values of prices, quantities, and elasticities summarized in Table 2.2. to calculate the comparative statics in Table 2.1. provides estimates of the directions and magnitudes of a given blend wall shift. All the results presented in Table 2.3. yield the theoretical expected signs in Table 2.1., and present monotone trends with respect to a blend wall shift. In Table 2.3., four blend walls are considered: 10%, 12%, 15%, and 20%. Consistent with the theoretical model, a blend wall shift is prone to increase the prices of ethanol and *E85*, and increase the quantities of ethanol used in blending *Eγ*. In contrast, the price of the blended fuel and the quantity of *E85* along with quantity of ethanol and petroleum gasoline used in blending *E85* respond in an opposite direction. The quantity of petroleum gasoline used in blending *Eγ*, and the total gasoline consumption increase as a response to the upward shift in the blend wall. This indicates that conditions for the positive values of $\varepsilon^{g}_{Q_\gamma,\gamma}$ (the elasticity of the petroleum gasoline used in blending *Eγ*. with respect to the blend wall) and $\varepsilon_{Q_G,\gamma}$ (the elasticity of the total petroleum gasoline consumption with respect to the blend wall) hold as listed in Table 2.1.

For all the elasticities, the responsiveness of prices and quantities present a different monotone trend as the blend wall shifts. As the prices of ethanol and *E85*, quantities of *Eγ*, and ethanol used in blending *Eγ* increase as a response to a blend wall upward shift, the magnitude of responsiveness increase as well. By contrast, the responsiveness to blend wall shifts of the price of *Eγ* and quantities of gasoline and ethanol used in *E85* rise, although those prices and quantities decrease with a positive blend wall shift. Specifically, the responsiveness of prices of *Eγ*, ethanol, and gasoline blended in *E85* increase in absolute value as anticipated.

As indicated in Table 2.3., most of the comparative statistic values are inelastic (absolute values less than 1), indicating that most of the prices and quantities are not responsive to a blend wall shift. Specifically, the elasticities of gasoline and ethanol used in *E85* with respect to the blend wall, $\varepsilon_{Q_{85}^{e},\gamma}$ and $\varepsilon_{Q_{85}^{g},\gamma}$ are identical and close to zero. The quantity of *E85* is much less responsive to a blend wall shift than the others as well− the blend wall shift only yields marginal impacts on the quantity of *E85*. This may result from the very low percentage of the total gasoline and ethanol production funneling into the *E85* market. The U.S. *E85* market is currently limited, with a small number of retailers and flex-fuel vehicles.

In contrast, the price and quantity of *Eγ*, the quantity of ethanol and gasoline used in blending *Eγ,* and the total gasoline consumption are very elastic to the relaxation of the blend wall. As the blend wall shifts, the total gasoline consumption and the quantity of gasoline used in *Eγ* increase in an almost identical magnitude, consistent with the condition that only a low proportion of total gasoline consumption is used in blending *E85*. Of particular interest is the price of *Eγ*. With an upward blend wall shift, the price of *Eγ* decreases by a relatively large magnitude. This significant decrease offsets impacts from the ratio of ethanol to petroleum gasoline used in blending *Eγ* even with an adjustment, and thus leads to the increase of quantity of gasoline used in E*γ* *w*ith a corresponding increase in total gasoline consumption. A positive shift in the blend wall will then likely increase total gasoline consumption and lead to greater energy insecurity due to the positive expansion effect likely offsetting the negative substitution effect. This result is counter to the impetus of many of the proponents of the policy shift toward higher blend wall levels.

2.5. Parameter Simulations

Building upon the assessment in the previous section employing benchmark values from the literature for prices, quantities, and elasticities in the biofuel market, in this section Monte Carlo analysis is performed over the range of values cited in previous research contained in Table 2.2.

All simulations use benchmark values of prices and quantities, and 100,000 independent random draws of the parameter elasticities based on a uniform probability density function. Simulated means and corresponding standard deviations for the comparative statistic parameters are reported in Table 2.4.

All the comparative statics results hold identical signs with the theoretical results in Table 2.1. and present the same monotone trends as the results in Table 2.3. However, different values for comparative statics are obtained. Similar to the results in Table 2.3., most of the comparative statics elasticities are inelastic, except for the price and quantity of *Eγ,* the quantity of ethanol and gasoline used in Eγ, and the total gasoline consumption.

Corresponding standard deviations for the comparative statics present monotone patterns with respect to the blend wall shifts. Relative to their associated mean values, the standard deviations are all small, with the price of *Eγ* particularly small, indicating a narrow range of parameter values around the mean values. However, although still small, the standard deviations associated with the quantity of ethanol and gasoline used in *Eγ* and *E85* and total gasoline consumption are relatively larger compared with their mean value indicating a wider range of values. These relatively small standard errors are associated with the range of parameters employed (Table 2.2.). Alternative parameter values, both in terms of benchmark values and range, will yield alternative Monte Carlo means and standard deviations. However, the low standard deviations indicate the mean values are fairly robust to parameter variations. In particular, it would take parameter estimates well outside of their ranges to elicit a decline in total gasoline consumption with a shift in the blend wall. The robustness of this result indicates the significance of the results in terms of the positive impact a blend wall shift will have on increasing total petroleum gasoline consumption.

Investigating the potential probability of relaxing the blend wall leading to increased petroleum gasoline consumption, an empirical CDF for the elasticity of petroleum gasoline consumption with respect to the blend wall, $\varepsilon_{Q_G,\gamma}$, is established. Table 2.5. lists the probabilities of $\varepsilon_{Q_G,\gamma}$ above the threshold value of zero with different values of the blend wall−one minus the empirical CDF values. As indicated by Table 2.5., at blend walls of 10% to 40%, a positive blend wall shift will lead to an increase of petroleum gasoline consumption with a probability of 100%. At any blend walls higher than 40%, the probability that an upward shift of the blend wall leads to an increase in petroleum consumption decreases. When the blend wall is greater than 70%, the possibility of a positive value for $\varepsilon_{Q_G,\gamma}$ overwhelms the corresponding possibility of negative values. For example, at a blend wall of 85%, the possibility that a relaxation of the blend wall leads to an increase in petroleum gasoline consumption is only 3%, indicating that it is fairly unlikely that an increase in the blend wall will increase the total petroleum gasoline consumption.

2.6. Sensitivity Analysis

The wide ranges of parameter values in Table 2.2. that lead to some large standard deviations in Table 2.3., suggest investigating the effect of the parameter elasticities on the comparative static elasticities. In order to investigate the sensitivity of the comparative statics to ranges of parameter elasticities, Monte Carlo simulations are implemented. As an example, only the blend wall of *E10* is analyzed. Simulations are conducted over 100,000 draws, and corresponding plots for sensitivity analysis are presented in Figures 2.2.-2.4.[2]

In terms of the own ethanol price elasticity of demand, ε^{D}_{e,p_e}, and the ethanol demand elasticity to the blended fuel price, $\varepsilon^{D}_{e,p_\gamma}$, they only have a relatively large effect on the responsiveness of ethanol price, $\varepsilon_{p_e,\gamma}$, to a shift in the blend wall (Figures 2.2. and 2.3.). As the own ethanol price elasticity of demand becomes more inelastic, the responsiveness of ethanol price to a shift in the blend wall increases. This the result of a blend wall shift causing an increase in ethanol demand, so they move in the same direction and have similar effects on the ethanol price. This result is expected, given a shift in the blend wall increases the quantity of ethanol. The own ethanol demand elasticity and ethanol demand elasticity to the blended fuel price are close to being proportional to the inverse elasticities (price flexibilities) $\varepsilon_{p_e,\gamma}$. In terms of Figure 2.3., the more inelastic the cross price elasticity of ethanol demand to *Eγ*, the more elastic is the ethanol price to a blend wall shift. Again, this is the result of the blend wall shift and ethanol demand moving in the same direction and having similar effects on the ethanol and blend prices.

In Figure 2.4., a change in the own price elasticity of demand for blended fuel, $\varepsilon^{D}_{E\gamma,p_\gamma}$, exhibits relatively large impacts on the effect that a shift in the blend wall has on the quantity of ethanol used in blending *Eγ,* $\varepsilon^{e}_{Q\gamma,\gamma}$; with moderate impacts on the elasticity of total gasoline consumption, the quantity of *Eγ,* and petroleum used in *Eγ* to the change of the blend wall, $\varepsilon_{Q_G\gamma}$, $\varepsilon_{E_\gamma\gamma}$ and $\varepsilon^{g}_{Q\gamma,\gamma}$, respectively. As indicated in Figure 2.4., as the own *Eγ* price elasticity of demand, $\varepsilon^{D}_{E\gamma,p_\gamma}$becomes less responsive, it increases the responsiveness of $\varepsilon_{E\gamma,\gamma}$, $\varepsilon_{Q^e_\gamma,\gamma}$, $\varepsilon_{Q^g_\gamma,\gamma}$, and $\varepsilon_{Q_G,\gamma}$. As the own price elasticity of *Eγ* becomes more inelastic, the rise in the ethanol price associated with a positive blend wall shift will not elicit as large of a decrease in *Eγ*, leading to more responsiveness in the total quantity of *Eγ*, ethanol and gasoline blended in *Eγ*, and the total gasoline consumption.

All the comparative statics elasticities exhibit very small responses to a range of the own ethanol price elasticity of supply, ε^{S}_{e,p_e} and own demand elasticity for *E85*, $\varepsilon^{D}_{E85,p_{85}}$. Thus, changes in the ethanol supply elasticity have only a minor impact on how prices and quantities respond to a blend wall shift. In terms of the own demand elasticity for *E85,* the lack of an influence is the result of only a low percentage of the total gasoline and ethanol production funneling into the *E85* market. The U.S. *E85* market is currently limited, with a small number of retailers and flex-fuel vehicles.

2.7. Implications

The results of this analysis indicate that relaxing EPA's regulation on a maximum 10% ethanol blend for conventional gasoline, the blend wall, will likely increase the prices for ethanol and *E85* and lower the price for *Eγ*. These price effects are caused by a higher demand for ethanol and increased supply of *Eγ* and a lower supply of *E85*. A positive shift in the blend wall drives a larger price wedge between *Eγ* and *E85*. This reduces the demand for *E85* and potentially retards the shift toward flex-fuel vehicles. Results indicate total petroleum gasoline consumption will positively respond to an increase in the blend wall, indicating the positive expansion effect offsets a negative substitution effect. Although a relaxation of the blend wall reduces the quantity of *E85* and associated petroleum gasoline, effects on petroleum gasoline are quite small. *E85* only accounts for a relatively small market share. The results reinforce the comparative statics analysis that allowing higher ethanol fuel blends to be available for all vehicles potentially has the adverse spillover effect of reducing the demand for flex-fuel vehicles.

The empirical results support the anomaly of the blend wall waiver increasing petroleum fuel consumption. A relaxation of the blend wall is prone to increase rather than decrease total petroleum gasoline demand. Rather than enhancing the security of the energy sector, a relaxation of the blend wall might exacerbate energy insecurity by failing to reduce the dependence on foreign petroleum. In addition, it is likely to retard adoption of flex-fuel vehicles.

With these results as a foundation, relaxation of the blend wall might not be a sustainable choice for the energy sector. As announced by the EPA, *E15* can only be used in a few vehicles in certain model years–post 2000 model years. A long-run strategy might be to retain the current blend wall restrictions on conventional non-flex fuel vehicles and thus reduce any comparative advantage conventional vehicles have over flex-fuel vehicles. This would provide increased incentives for U.S. motorists to drive flex-fuel vehicles and open the fuel-ethanol sector to the total vehicle fuel market without any restrictions (Zhang et al., 2010b). Such a comparative-advantage strategy is successful in Brazil, where the growth of the Brazilian automobile fleet based on flex-fuel technology is a major driving factor of the long-run ethanol demand (de Freitas and Kaneko, 2011). As suggested by Timilsina et al. (2011), a carbon tax on fossil fuels with the generated revenue used to subsidize biofuels would also significantly increase biofuels in general and *E85* in particular.

In terms of policy direction, policies that foster increased demand for *E85* would lead to greater demand for ethanol and less petroleum gasoline. However, Tatum et al. (2010) estimate that the cross elasticity of *E85* price with respect to the gasoline price does not differ from unity, so a rise in gasoline prices will be matched in percentage terms by a corresponding rise in the price of *E85*. Thus, the current market forces indicate that *E85* will not be price competitive with gasoline. Policies should then be directed toward discouraging the driving of conventional vehicles and providing incentives for increased availability and consumer willingness to use alternative fuels. However, retaining the blend wall would require a large increase in filling stations offering *E85* and an increase in flex-fuel vehicles. Currently, out of the approximately 115,000 U.S. filling stations, only 2% offer E85 blended fuel (DOE, 2012). Although the cost of producing flex-fuel vehicles is approximately the same as conventional fuels vehicles, the number of flex-fuel vehicles produced and stations offering *E85* would have to increase rapidly. While this may be possible as exemplified by the recent changes in the Brazilian automotive sector which, from 2003 to 2007, saw an increase in production of flex-fuel vehicles relative to total production from 3% to 70%, fuel retailing remains a major hurdle. Installing new *E85* pumps is expensive and particularly difficult for small and independently owned and operated fuel stations. This high initial cost which is necessary for significant expansion of *E85* plays a role in retarding the growth of the fuel. For *E15*, which is only approved for post 2000 vehicles, a similar cost for new pumps also is present under a shift of the blend wall. Hence, the question is if the U.S. should concentrate on establishing *E15* stations for conventional vehicles or *E85* stations for flex-fuel vehicles. The results of this study indicate that if the policy objective is concerned with energy security or at least developing a portfolio of vehicle fuels, establishing *E85* stations is probably the correct direction.

One alternative is the development of biofuels that do not require engine modifications and thus can be used to fuel conventional gasoline vehicles and be distributed in the same infrastructure as petroleum gasoline. Such fuels, called biogasoline, are created by turning sugar directly into gasoline and are currently under development. With the RFS mandate of 20 billion gallons from non-corn based or advanced biofuels out of 36 billion gallons of domestic biofuel production per year by 2022, the development of the advance biofuel biogasoline has substantial incentives. However, its development faces the economic viability problem of high initial investment cost. Information asymmetry inhibits private financial institutions from underwriting high-cost uncertain projects such as biogasoline refineries. Government support in the form of loan guarantees may then be necessary for the development of a viable biogasoline industry to replace the current ethanol sector. Without such government support, ethanol is likely to retain its dominance as the major U.S. biofuel for at least this decade. Thus, for a continued viable renewable fuels sector, the ethanol industry should direct their efforts toward policies that discourage conventional fueled vehicles and encourage alternative fuels.

Footnotes

[1] The assumption of an exogenous petroleum gasoline price assumes the petroleum fuel sector does not impact the price of ethanol. Results by Zhang et al. (2010a) support this assumption with their findings that in the short-run petroleum gasoline prices do not Granger cause ethanol price movements.

[2] Only the sensitivity analysis figures that exhibited relatively large impacts are reported.

Table 2.1. Comparative Statics Results (Zhang, et al., 2010b)

Elasticity Response to a Shift in the Blend Wall, γ	Equation[a]
Ethanol price, p_e	$\varepsilon_{p_e,\gamma} = \varepsilon^D_{e,p_\gamma} \frac{1}{\gamma} \frac{1}{0.85} \frac{p_g}{p_\gamma} / A > 0$
Conventional blend, Eγ, price, p_γ	$\varepsilon_{p_\gamma,\gamma} = \frac{p_e p_g}{\gamma p_\gamma} \frac{\left[\left(\frac{\varepsilon^S_{e,p_e} - \varepsilon^D_{e,p_e}}{0.85 p_e} - \frac{\varepsilon^D_{e,p_{85}}}{p_{85}}\right)\right]}{A} < 0$
E85 price, p_{85}	$\varepsilon_{p_{85},\gamma} = \varepsilon^D_{e,p_\gamma} \frac{p_e}{p_\gamma p_{85}} \frac{p_g}{\gamma} / A > 0$
Conventional blend, Eγ	$\varepsilon_{E\gamma,\gamma} = \frac{\epsilon_{p_\gamma,\gamma}}{\epsilon^D_{p_\gamma,E\gamma}} > 0$
E85	$\varepsilon_{E85,\gamma} = \frac{\epsilon_{p_{85},\gamma}}{\epsilon^D_{p_{85},E85}} < 0$
Market quantity of ethanol, Q_e	$\epsilon_{Q_e,\gamma} = \varepsilon^S_{e,p_e} \varepsilon_{p_e,\gamma} > 0$
Quantity of ethanol used in Eγ, Q^e_γ	$\varepsilon_{Q^e_\gamma,\gamma} = \frac{\gamma E\gamma}{Q^e_\gamma}\left(1 + \varepsilon_{E\gamma,\gamma}\right) > 0$
Quantity of gasoline used in Eγ, Q^g_γ	$\varepsilon^g_{Q_\gamma,\gamma} = \frac{\gamma E\gamma}{Q^g_\gamma}\left(\varepsilon_{E\gamma,\gamma} \frac{1-\gamma}{\gamma} - 1\right) > 0$, if $\varepsilon_{E\gamma,\gamma} > \frac{\gamma}{1-\gamma}$
Quantity of ethanol used in E85, Q^e_{85}	$\varepsilon_{Q^e_{85},\gamma} = \frac{0.85E85}{Q^e_{85}} \varepsilon_{E85,\gamma} < 0$
Quantity of gasoline used in E85, Q^g_{85}	$\varepsilon_{Q^g_{85},\gamma} = \frac{0.15E85}{Q^g_{85}} \varepsilon_{E85,\gamma} < 0$
Total gasoline consumption, Q_G	$\varepsilon_{Q_G,\gamma} = -\frac{Q^e_\gamma}{Q_G} + \varepsilon_{E\gamma,\gamma} \frac{Q^g_\gamma}{Q_G} + \varepsilon_{E85,\gamma} \frac{Q^g_{85}}{Q_G} > 0$, if $\varepsilon_{E\gamma,\gamma} > \frac{\gamma}{1-\gamma} - \frac{Q^g_{85}}{Q^g_\gamma} \varepsilon_{E85,\gamma}$

[a] $A = \left(\varepsilon^D_{e,p_e} - \varepsilon^S_{e,p_e}\right) \frac{1}{\gamma} \frac{1}{0.85} + \varepsilon^D_{e,p_{85}} \frac{1}{\gamma} \frac{p_e}{p_{85}} + \varepsilon^D_{e,p_\gamma} \frac{1}{0.85} \frac{p_e}{p_\gamma} < 0$, and p_g is price of petroleum gasoline.

ε^D_{e,p_e} and ε^S_{e,p_e} are the own price elasticity of ethanol demand and supply, respectively.

$\varepsilon^D_{e,p_\gamma}$ and $\varepsilon^D_{e,p_{85}}$ are the elasticity of ethanol demand with respect to the price of Eγ and E85, respectively.

$\epsilon^D_{p_\gamma,E\gamma}$ and $\epsilon^D_{p_{85},E85}$ are the price flexibilities of Eγ and E85 with respect to their quantities.

Table 2.2. Parameter Values

Parameter	Description	Source	Benchmark Value	Range
p_e	Per unit price of ethanol (dollars per gallon)	Ethanol and Biofuels News	1.137	
p_g	Per unit price of petroleum gasoline (dollars per gallon)	U.S. Energy Information	3.215	
p_{85}	Per unit price of E85 (dollars per gallon)	Ethanol and Biofuels News	1.449	
Qe	Total quantity of ethanol (million gallons)	U.S. Energy Information Administration	1066.8	
ε_{e,p_e}^{D}	Own ethanol price elasticity of demand	Luchansky and Monks	−2.26	−2.92 - −1.61
ε_{e,p_e}^{S}	Own ethanol price elasticity of supply	Luchansky and Monks	0.24	0.22 - 0.26
$\varepsilon_{e,p_\gamma}^{D}$	Ethanol demand elasticity with respect to gasoline price	Luchansky and Monks	−2.13	−3.06 - −2.08
$\varepsilon_{E85,p_{85}}^{D}$	Own E85 price elasticity of demand	Anderson	−13.00	−20.00 - −6.00
$\varepsilon_{E\gamma,p_\gamma}^{D}$	Eγ demand elasticity with respect to gasoline price	Parry and Small	−0.55	−0.90 - −0.30

Table 2.3. Benchmark Values for the Comparative Statics

Elasticity Response to a Shift in the Blend Wall	Elasticity	Blend Wall[a]			
		E10	E12	E15	E20
Ethanol price	$\varepsilon_{p_e,\gamma}$	0.557	0.562	0.571	0.585
Eγ price	$\varepsilon_{p_\gamma,\gamma}$	−1.048	−1.058	−1.074	−1.101
E85 price	$\varepsilon_{p_{85},\gamma}$	0.372	0.375	0.381	0.390
Eγ	$\varepsilon_{E\gamma,\gamma}$	1.906	1.924	1.952	2.002
E85	$\varepsilon_{E85,\gamma}$	−0.029	−0.029	−0.029	−0.030
Market quantity of ethanol	$\epsilon_{Q_e,\gamma}$	0.134	0.135	0.137	0.140
Quantity of ethanol used in Eγ	$\varepsilon_{Q_\gamma^e,\gamma}$	2.906	2.924	2.952	3.002
Quantity of gasoline used in Eγ	$\varepsilon_{Q_\gamma,\gamma}^{g}$	1.795	1.788	1.766	1.752
Quantity of ethanol used in E85	$\varepsilon_{Q_{85}^e,\gamma}$	−0.029	−0.029	−0.029	−0.030
Quantity of gasoline used in E85	$\varepsilon_{Q_{85}^g,\gamma}$	−0.029	−0.029	−0.029	−0.030
Total gasoline consumption	$\varepsilon_{Q_G,\gamma}$	1.794	1.787	1.775	1.751

[a] Simulated standard deviations in the parentheses.

Table 2. 4 Monte Carlo Simulated Mean and Standard Deviations for the Comparative Statics

Elasticity Response to a Shift in the Blend Wall	Elasticity	Blend Wall[a]			
		E10	E12	E15	E20
Ethanol price	$\varepsilon_{p_e,\gamma}$	0.676	0.682	0.692	0.706
		(0.106)	(0.106)	(0.107)	(0.108)
Eγ price	$\varepsilon_{p_\gamma,\gamma}$	−1.044	−1.053	−1.067	−1.091
		(0.004)	(0.005)	(0.006)	(0.009)
E85 price	$\varepsilon_{p_{85},\gamma}$	0.451	0.455	0.461	0.471
		(0.071)	(0.071)	(0.071)	(0.072)
Eγ	$\varepsilon_{E\gamma,\gamma}$	1.913	1.927	1.954	1.997
		(0.619)	(0.624)	(0.632)	(0.645)
E85	$\varepsilon_{E85,\gamma}$	−0.039	−0.039	−0.040	−0.041
		(0.015)	(0.015)	(0.016)	(0.016)
Market quantity of ethanol	$\epsilon_{Q_e,\gamma}$	0.162	0.164	0.166	0.170
		(0.026)	(0.026)	(0.027)	(0.027)
Quantity of ethanol used in Eγ	$\varepsilon_{Q_\gamma^e,\gamma}$	2.913	2.927	2.954	2.997
		(0.619)	(0.624)	(0.623)	(0.645)
Quantity of gasoline used in Eγ	$\varepsilon_{Q_\gamma^g,\gamma}$	1.801	1.791	1.777	1.747
		(0.619)	(0.624)	(0.632)	(0.645)
Quantity of ethanol used in E85	$\varepsilon_{Q_{85}^e,\gamma}$	−0.039	−0.039	−0.040	−0.041
		(0.015)	(0.015)	(0.016)	(0.016)
Quantity of gasoline used in E85	$\varepsilon_{Q_{85}^g,\gamma}$	−0.039	−0.039	−0.040	−0.041
		(0.015)	(0.015)	(0.016)	(0.016)
Total gasoline consumption	$\varepsilon_{Q_G,\gamma}$	1.801	1.791	1.777	1.746
		(0.619)	(0.624)	(0.632)	(0.645)

[a] Simulated standard deviations in the parentheses.

Table 2.5. Monte Carlo Simulated Probabilities for a Shift in the Blend Wall to Increase Total Gasoline Consumption, $\boldsymbol{\varepsilon_{Q_G,\gamma}} > 0$

Blend Wall, γ	Probability $\varepsilon^{*}_{Q_G,\gamma}$ > 0
10%	100%
12	100
15	100
20	100
30	100
40	100
50	100
60	97
70	51
80	12
85	0
90	0

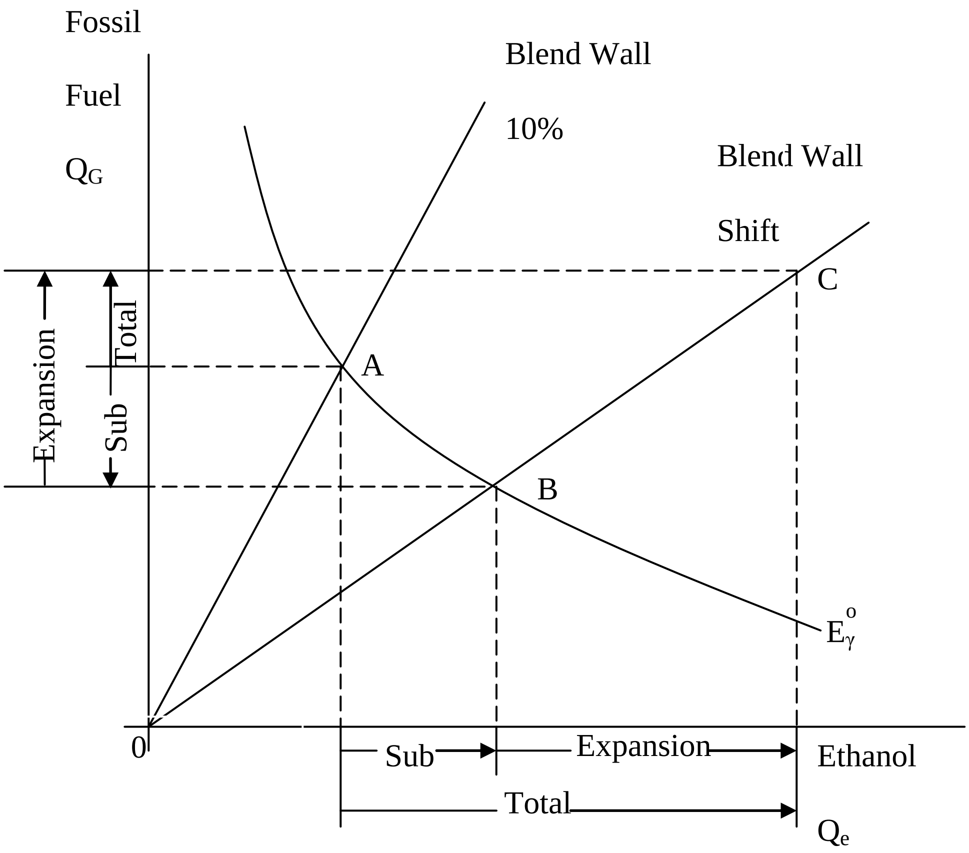

Figure 2.1. Total Effect of the Blend Wall Decomposed into the Substitution and Expansion Effect

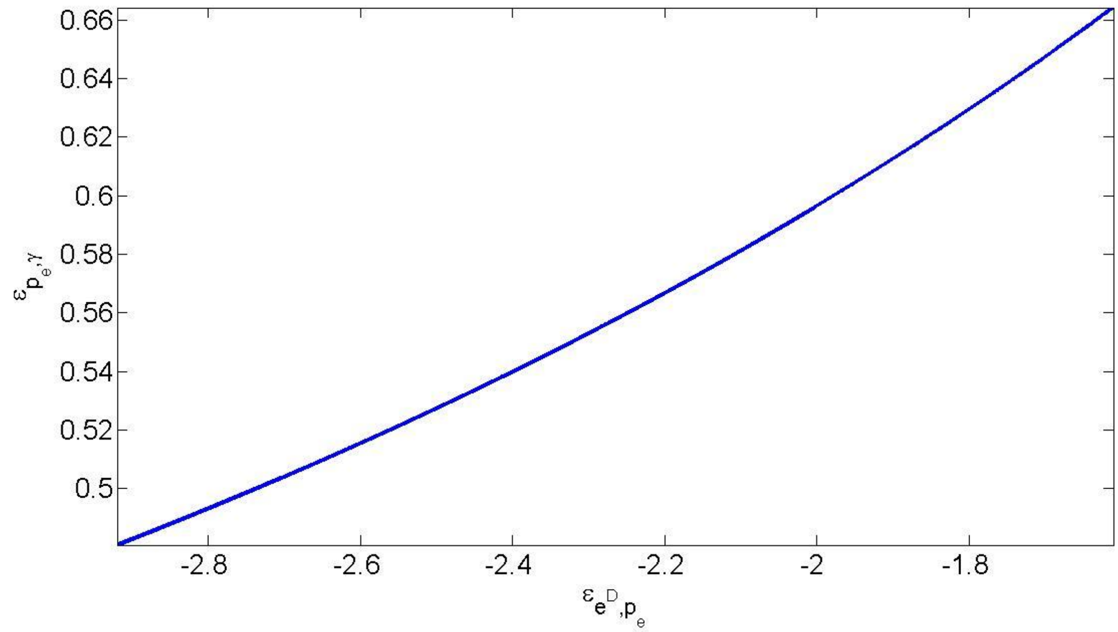

Figure 2.2. Response of the Elasticity of Ethanol Price to the Blend Wall, $\varepsilon_{p_e,\gamma}$ to a Range of the Elasticity of the Own Ethanol Price of Demand, ε^{D}_{e,p_e}

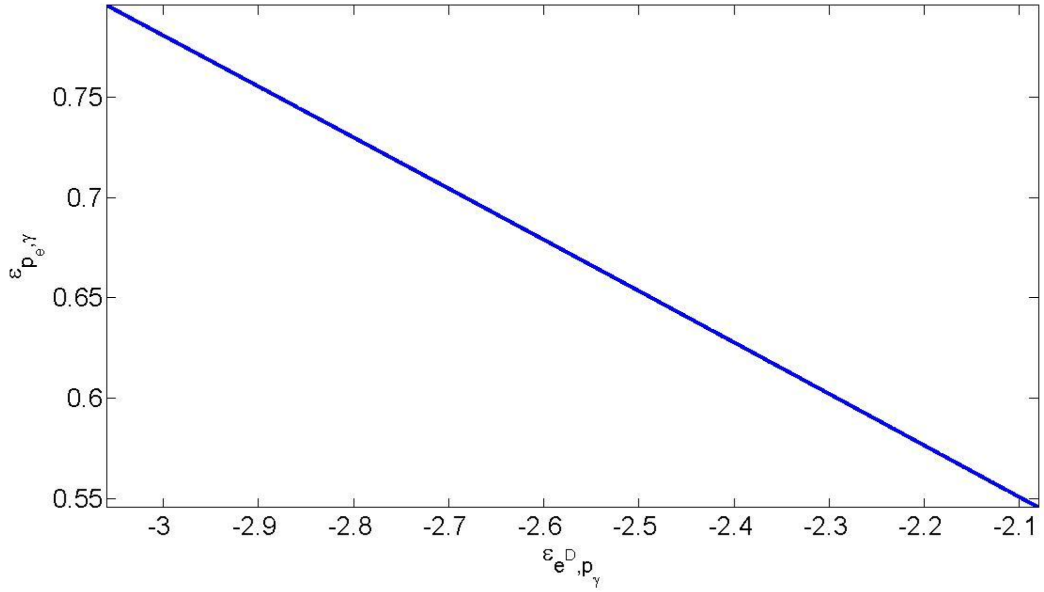

Figure 2.3. Response of the Elasticity of Ethanol Price to the Blend Wall, $\boldsymbol{\varepsilon_{p_e,\gamma}}$ to a Range of the Cross Price Elasticity of Ethanol Demand to the Eγ Price, $\boldsymbol{\varepsilon^{D}_{e,p_\gamma}}$

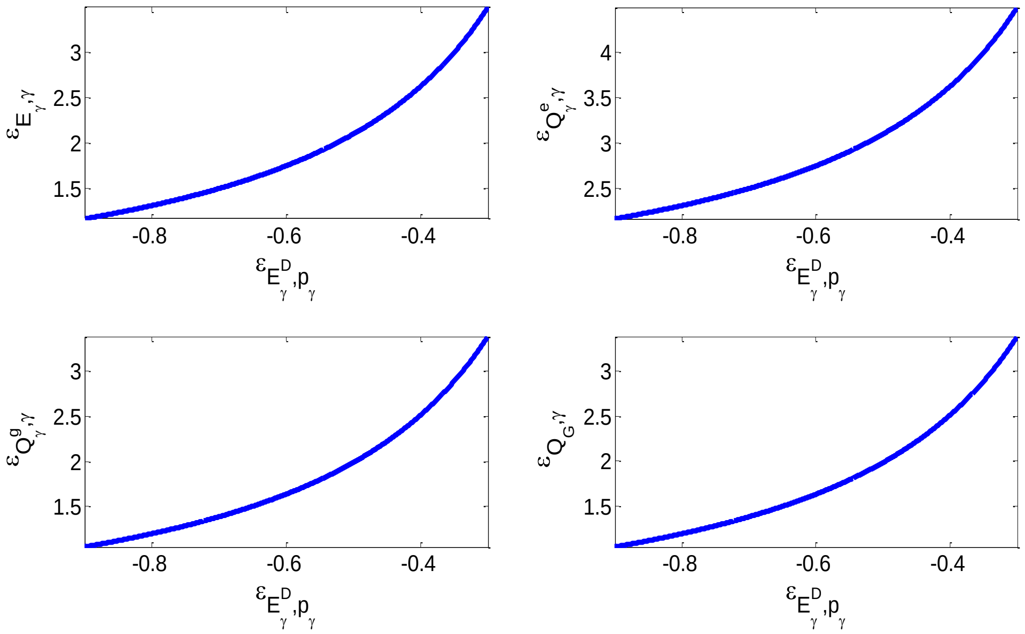

Figure 2.4. Responses of the Comparative Statics to a Range of the Own *Eγ* Price Elasticity of Demand

CHAPTER 3

THE POST 2008 FOOD BEFORE FUEL CRISIS:

THOERY, LITERATURE, AND POLICIES[2]

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[2] Qiu,C., G. Colson, and M.E. Wetzstein. 2011. *Biofuel/Book 1*, 81-104.
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Abstract

The chapter lays out evidence in support of the hypothesis that the 2007-2008 food before fuel crisis was caused not by growing demand for biofuels but instead by the shift in global policies toward relying primarily on markets to provide adequate agricultural commodities in periods of sharp increases in food demand. Based on this hypothesis and economic theory, policies to advert future food before fuel crises or any other causes of food price volatilities are developed.

The chapter suggests that in the long-run, markets will adjust, so government policies involving food subsidies, price controls, and export restrictions are not warranted. However, in the short-run, it is important to ensure food availability to all. Policies, including agricultural commodity buffers are required to blunt food price short-run spikes resulting from market shocks including biofuel volatilities, weather, conflicts, and terrorism.

3.1. Introduction

As early as 1983, research began to appear indicating the potential for biofuel production to emerge as a disruptive force in US and world food sectors (Barnard, 1983). Of particular concern in early and present research is that increased use of agricultural outputs for energy, as opposed to foodstuffs, could ultimately lead to a net welfare loss where the benefits of biofuels are outweighed by the negative consequences linked to reduced food availability. This dilemma emerges due to the direct competition between biofuel and food production for the same renewable and nonrenewable resources critical for their sustainability (Rajagopal and Zilberman, 2007 and von Urff, 2007). In 2007-2008, global food prices experienced a significant upward spike resulting in political and economic instability, conflict, and hardships in both the developed and developing world. Figure 3.1. illustrates the United Nations FAO monthly food price index and the cereals price index since 2000. As indicated in the figure, in 2006 food prices started to rise with the most rapid increases occurring in 2007 through the middle of 2008 when an equally rapid price decline occurred. Relative to the general food price index, the increase in cereal prices was more pronounced.

The effects of the spike in food prices was particularly acute in parts of Africa, Asia, the Middle East, and South America where significant portions of household budgets are spent on food (e.g., 50-70% of typical household budgets in Africa are spent on food, Diao et al., 2008). This resulted in not only a worsening of poverty statistics, but also led to aggressive national protectionist food policies, civil unrest, malnutrition, and deaths. In general, populations most vulnerable to significant rises in food prices are those in countries that suffer food deficits and import oil. These two features are directly correlated with a countries income status, with the majority of the 82 low-income countries having food deficits and being net oil importers (Senauer, 2008; Runge and Senauer, 2007). With assumption of biofuels produced mainly with corn, causing food price inflation, countries where corn is the major food grain will generally experience larger increases in food costs, while countries with rice as the major food will experience less of an increase. Countries where wheat and/or sorghum are the major food grains fall in between. Consequently, the highest percentage cost increases are observed in Sub-Saharan Africa and Latin America and the lowest percentage cost increases are in Southeast Asia (Elobeid and Hart, 2007).

A widely considered view both in policy circles and the domain of public perception is that the dominant underlying driver of the 2007-2008 price spike was increased use of crops for the production of biofuels (Diao et al., 2008; Abbott et. al, 2008). This shift from fossil fuels to biofuels, which has in large part been fostered through national agriculture and energy policies motivated by increased oil price volatility, energy security ambitions, and environmental concerns, is particularly prominent among many Kyoto Protocol signatory countries (Balcombe and Rapsomanikis, 2008). In effect, the emergence of a significant biofuel market has given producers a choice of supplying food or fuel depending on their relative net returns (Brown, 1980, Zhang et. al, 2010a). However, the rapidly growing market for biofuels has given rise to the perception that rapid biofuel expansion generates upward pressure on global food prices, exacerbating global hunger problems (Runge and Senauer, 2007). Figure 3.2. illustrates this rapid biofuel growth for U.S. ethanol production. Some estimates have even placed the number of malnourished people globally at 1.2 billion, twice the number without any effects on the food supply due to biofuels (Runge and Senauer, 2007). These concerns have given rise in some policy circles of calls for agricultural and energy policies be reprioritized where food takes precedence before fuel (in short food before fuel).

In contrast to this perception, evidence is provided countering the hypothesis that the 2007-2008 food price spike was the result of shifts in crop usage from food to fuel. Instead evidence is presented supporting the hypothesis that the food crisis was the result of a shift in global policies toward relying primarily on markets to provide adequate agricultural commodities in periods of supply shortfalls and demand increases. Given this evidence and underlying supporting economic theory, policies capable of adverting future food crises are presented.

This hypothesis addressing the root of the global food crisis is first framed in the context of the historical underpinnings of the 2007-2008 food price spike and the prevailing economic view at that time supporting policies contributing to the spike. The literature warning of the potential for biofuels to disrupt global agricultural commodity prices is then presented in an economic theory context. One of the key predictions of economic theory is that global competitive agricultural commodities markets will respond to commodity price shocks, restoring prices to their long-run trends. However, due to inherent frictions in the market, costly or irreversible decisions, and uncertainty, there is a lag time in such response, thus yielding potential short-run volatility in food prices.

3.2. Theory

Surges and downturns of ethanol and food prices are not isolated incidents, but economic consequences (Gohin and Chantretnd, 2010; Von Braun et al., 2008; Mcphail and Babcock, 2008; Chen el al., 2010; Balcombe and Rapsomanikis, 2008). Kappel et al. (2010) argue that fundamental market forces of demand and supply were the main drivers of the 2007-2008 food price spike. In a supply and demand model, economic theory suggests agriculture will respond to a commodity price increase from a biofuel or other demand shock. As illustrated in Figure 3.3., a demand shock will shift the demand curve outward from Q_D to Q_D'. This results in a short-run increase in the agricultural commodity price, from p_e to p_e', leading to existing firms earning short-run pure profits (total revenue above total costs). The magnitude of this increase in price depends on how responsive supply, in the short run, is to the demand shift (represented as an increase in supply from Qe to Q_S. However, in the long-run, existing firms will expand production and new firms will enter yielding a further increase in supply. Assuming no cost adjustments, this increase in supply will restore the market price to the long-run equilibrium price pe. Furthermore, given the relative unresponsiveness of demand and supply for staple food commodities, small shifts in demand leads to a significant movement in prices.

Abbott, et al. (2008) identified three major agricultural demand shifters causing the 2007-2008 food price spike: increased food demand, low value of the dollar, and a new linkage of energy and agricultural markets. These demand shifters drove up the prices of agricultural commodities in 2007 and 2008. In 2009, high market prices spurred increased crop-production shifting supply outward and the global economic downturn at the end of 2008, sharply decreased demand and as a result led to lower agricultural commodity prices. Figure 3.4. illustrates this agricultural commodity price volatility for the U.S. corn market. U.S. corn prices rapidly increased in 2007-2008, but with a downturn in economic activity (the Great Recession), price precipitously declined. With a resurgence of current economic activity corn prices specifically rebounded along with agricultural prices in general. As indicated in Figure 3.2., U.S. ethanol production continued to increase during the economic downturn as corn prices fell. The high correlation of biofuel production with agricultural commodity prices during the 2007-2008 food price spike did not continue through the Great Recession.

Generally the responses to the demand shifters are rapid, while supply-utilization adjustments are slower. A shift in demand will elicit an immediate price increase response. While the supply response will take a number of months as agriculture gears up to increased production. With this supply and demand model, the issue is how rapid is this supply response and what is its magnitude. If supply is able to rapidly respond to a demand shift, then there is no food before fuel issue. If not, then there is cause for concern.

The underlying driver of the 2007-2008 food price spike was the lack of sufficient food stocks to rapidly buffer the price spike and avoid a food before fuel issue. In the late 20th century, many economists and government policymakers assumed open markets were more efficient in stabilizing agricultural commodity prices then maintaining commodity buffer stocks. One example of this view is an article by Jha and Srinivasan (2001) where they conclude that by liberalizing trade, agricultural commodity stocks are no longer required to stabilize prices. With free trade, when a region experiences a shortfall in grains, it can supplement supply by importing from a grain surplus region. This theory works well when there are ample supplies of grains. However, when there is a global grain shortage, without food buffers a food price spike can occur as was experienced in 2007-2008 food price spike. The global agricultural system has historically responded to changing patterns of demand (Prabhu et al., 2008). The issues are: are there sufficient agricultural endowments for a supply response to a demand shift, such as a biofuel shock, and if so, how rapid is this response.

Chen et al. (2010) suggests that increasing derived demand for corn, from biofuel production, has led to acreage declines and associated price increases of other crops (wheat and rice). They see a short-run constraint on agricultural endowments, leading to commodity price increases. However, in the long run, the potential for increasing agricultural production is high.

Within the U.S. there is about 35 million acres of idle cropland representing approximately 10% of current cropland in use, along with about 75 million acres of cropland in pasture (Marlow et al., 2004). Africa's abundant arable land and labor offer the potential for it to be a major exporter food (Juma, 2010). Global agriculture in general and U.S. agriculture in particular appear capable of adjusting without major difficulties to even high levels of biofuel production (Webb, 1981; Kerckow, 2007). This ability of agriculture to supply growing demand is supported by Licker et al., 2010 who indicate approximately 50% more corn, 40% more rice, 20% more soybeans, and 60% more wheat could be produced if the top 95% of the crops' harvested areas met their current climatic potential.

In 1979, Vincent et al., (1979) indicated the days of cheap corn are not over. Prices may be more stable as corn production expands to meet ethanol requirements and second generation ethanol, increased buffer stocks, and new technologies emerge (Vincent et al., 1979). This prediction of stable agricultural commodity prices would still hold if supply responses are rapid enough to mitigate demand shocks or global buffer stocks are expanded.

In a game theory context, Su (2010) illustrates how rational expectations will lead to consumers stockpiling commodities when prices are low. This type of rational expectations theory can be directly applied to governments where it would be feasible for them to stockpile agricultural commodities in times of relatively low prices to blunt possible future price spikes. Maintaining a buffer stock of agricultural commodities will provide a rapid supply response to blunt a demand shock and avoid a short-run food before fuel issue. If the world economy recovers from the economic slowdown without food production growing sufficiently to replenish stocks, food prices and hunger may rise again (Kappel et al., 2010).Currently in 2011 food prices are rising which is one underlying cause of the recent uprisings in North Africa and Middle East.

3.3. Methodologies

With this underlying theory of global competitive agricultural markets as a foundation, the two main methods, computable general equilibrium (CGE) and time series models, for food before fuel analysis are investigated. The advantages and disadvantages of these models are outlined in Table 3.1.

3.3.1. Computable General Equilibrium Models (CGE)

CGE models are widely employed in addressing the food before fuel issues, although with different modeling strategies and focuses (Elobeid and Tokgoz, 2007; Ignaciuk and Dellink, 2006; Arndt et al. 2008; Rosegrant el al., 2008; Tyner and Taheripour, 2008; Yang et al., 2008; Saunders et al., 2009; Gohin and Chantret, 2010; Mcphail and Babcock, 2008; Vincent et al., 1979, Hanson et al., 1993; Saunders et al., 2009). Their advantage is a historical data set containing prices and quantities is not required. Only estimates on the elasticities (responsiveness of one variable to a change in another variable) are required. These estimates could be derived empirically, theatrically, or expert opinion. However, a shortcoming of CGE models is their failure to precisely illustrate the time trends and price volatility, and they are not directly applied to the estimation at a particular point in time (Ignaciuk and Dellink, 2006). An exception is Gohin and Chantret (2010) who model the long-run relationship between food and energy prices and examine an array of energy and agricultural commodities with a wider set of macroeconomic factors.   Furthermore, CGE models rely on exogenously determined elasticities among energy and agricultural commodity variables. This leads to a predetermined relation between food and fuel which makes it challenging to distinguish the short- and long-run impacts. If these elasticities are not supported by theory and empirical evidence, the conclusions they derive concerning the linkages among food, fuel, and other variables including global economic activity are questionable.

3.3.2. Time Series Models

An alternative avenue of research attempts to determine linkages between food and fuel using time-series models estimated with historical data (Imai et al., 2008; Baek and Koo, 2009; Zhang et al., 2010a; Saghaian, 2010; Esmaeili and Shockoohi, 2011). Time-series models, such as autoregressive distributed lag (ADL) models, are widely used for empirical analysis of food before fuel (Bentzen and Engsted, 2001; Dimitropoulos et al., 2005; Hunt et al., 2005; Baek and Koo, 2009; Chen et al., 2010). Such models are efficient techniques for illustrating dynamics and measuring the interaction among prices in a time series context, as well as considering both short- and long-run effects (Chen et al, 2010). For example, with a structural break considered, Baek and Koo (2009) used an ADL model to investigate the short-run and long-run impacts of market factors such as energy prices on U.S. food prices. Chen et al. (2010) built a model where the price of grain is established as a function of its own price and other current and lagged variables such as the prices of oil, soybeans, and wheat.

However, the validity of the ADL approach is questionable on unit roots grounds (Bentzen and Engsted, 2001). ADL is an efficient approach when time-series data are stationary, but for non-stationary data it could yield spurious results unless all the variables are cointegrated . Thus, cointegration tests and vector error correction models (VECM) are suggested as more appropriate techniques to capture possible non-stationary characteristics (Bentzen and Engsted, 2001). These methods are generally augmented with supplementary analysis including Granger casualty tests, pairwise correlation matrix analysis, scree tests, and proportion of variance methods.

3.4. Supply

With energy as a key input into producing agricultural commodities, as prices of energy rise the potential exists for food price inflation. Table 3.2. outlines the impacts energy has on the supply of agricultural commodities.

3.4.1. Energy Input Effects on Agricultural Commodity Prices

Conforming to economic theory, prevailing empirical literature indicates that agricultural prices, which are a function of production costs, have a positive relationship with energy prices. The impact these higher energy prices have on agricultural production costs, short-run price volatility, and long-run price trends are investigated in terms of the underlying chapter hypothesis.

Previous spikes in food prices are usually considered as supply driven, and volatility of food prices were considered as a consequence of supply shocks (e.g. weather, pests, and diseases) (Mcphail and Babcock, 2008). Under this scenario, research on how the energy sector influences the agricultural sector considered energy as an agricultural production cost.

This increased energy cost is reflected directly in fuel costs associated with field operations, transportation, and processing and indirectly in increased cost of factors with energy as a major component (e.g., fertilizer and pesticides) (Musser et al., 2006). By substituting other inputs (e.g. reduced tillage technology, improved drying and irrigation systems, and efficient application and timing of fertilizers) the effects of higher energy costs can be mitigated (Musser et al., 2006; Von Braun et al., 2008).

Baffes (2007) indicated that the pass-through of oil price changes to fertilizer and agricultural commodities was high relative to other inputs, thus relatively high oil prices will be passed-through leading to high agricultural commodity prices. However, with lags in cost adjustments, these energy cost-push effects on agricultural commodity prices might not exist in the short-run (Gohin and Chantret, 2010; Von Braun et al., 2008).

The magnitude of these energy cost-push effects are subject to energy use relative to other inputs (Muhammad and Kebede, 2009). For energy-intensive agricultural commodities, with other factors fixed, an increase of energy prices would shift the supply curve of agricultural commodities to the left, which subsequently increases agricultural commodity prices (Chen et al., 2010). However, for labor-intensive agricultural commodities an increase in energy prices might yield insignificant impacts on agricultural commodity prices. Thus, although considered as a key production input for agricultural commodities, care is required in concluding that higher energy prices directly imply higher agricultural commodity prices, especially in the short-run. Gohin and Chantret (2010) results indicate other factors (biofuels, trade restrictions, speculative demands, climatic events, higher demands, and lower stocks) besides oil prices affecting the cost of agricultural production may better explain agricultural commodity prices.

3.4.2. Supply Potential of Bioenergy

Perlack et al. (2005) determined within the U.S. forestland and agricultural land, the two largest potential biomass sources, there exists over 1.3 billion dry tons per year of biomass potential. This is enough to produce biofuels meeting over one-third of the current demand for transportation fuels. The United States can produce nearly one billion dry tons of biomass annually and still continue to meet food, feed, and export demands. This biomass resource potential can be produced with relatively modest changes in land use. In contrast, Reilly and Paltsey (2007) estimate that large increases in domestic biofuel production would result in the U.S. becoming a net importer of food as opposed to an importer of oil.

Within China, current biofuel development paths could pose significant impacts on China's food supply and trade, as well as the environment. Yang et al. (2009) conducted a study on the land and water requirements for biofuel in China, and found that 3.5-4% of the total corn production was used for ethanol production. They predicted that by 2020, 5%-10% of the cultivated land in China will be used for ethanol-production crops, and that biofuel development will have significant impacts on China's food supply. Food and bioenergy demands can be satisfied at the same time without rising agricultural commodity prices, but significant research and development efforts in agronomy, technology, and markets will be required to ensure efficient, sustainable land use (Rosegrant et al., 2008; Yang et al., 2008).

Natural endowment redistribution is another consequence of the food vs. fuel competition. Increased biofuel production imposes adverse effects on land and water recourses (Rosegrant et al., 2008). With the expansion of biofuels, more natural ecosystems are switched to agricultural use, releasing CO2 originally stored in ecosystems into the atmosphere (Chakravorty et al., 2009; Fargione et al., 2008). Searchinger et al. (2008) estimated that GHG emission would double over 30 years and last for 167 years due to conversion from natural habitat to cropland caused by increased of biofuel production.

3.5. Demand

Although supply is considered to play a significant role in the long-run relationship between energy and agricultural commodities, the role of demand should not be ignored or underestimated (Gohin and Chantret, 2010). The 2007-2008 food price spike focused research on investigating the demand side. The expanding biofuel market has provided producers a choice of supplying food or fuel depending on their relative net returns. The issue is: can agriculture respond to the growing demand for food and fuel in a time frame sufficiently rapid to avoid commodity price inflation. The literature investigating the food versus fuel demand linkage is mixed. Research has either assumed or empirically derived a direct link between biofuels and food prices, where increased crop demand for biofuel production is limiting its supply for food and thus driving up the food prices. Along with the supply effects on food and fuel markets, Table 3.2. also lists the demand effects of expanding biofuels on food.

3.5.1. Previous Research

Past research concluded, of the factors causing rising food prices (increased biofuel production, weak dollar, and increased food production cost due to higher energy prices), the most important is the large increase in biofuel production in the U.S. and the EU (Martin, 2008; Mitchell, 2008; OECD-FAO, 2007). Without these increases, global wheat and corn stocks would not have declined appreciably and price increases would have been moderate. Since the Energy Act of 2005, a stronger relationship between corn and biofuel (ethanol) has emerged (Muhammad and Kebed, 2009). Although still questionable, biofuel is considered a key transmitter of energy prices to the agricultural prices (Arndt et al., 2008; Chakravorty et al., 2009; Chen et al., 2011; Elobeid and Hart, 2007; Hochman et al. 2010; Ignaciuk et al., 2006; Ignacuik and Dellink, 2006; Runge and Senauer, 2007; Lazear, 2008; Mitchell, 2008; Muhammad and Kebed, 2009; Rajagopal, 2009; Sexton et al., 2009; Taheripour and Tyner, 2008; Yahaya, 2006).

Recently, corn price volatility has contributed to the integration between the energy market and the agricultural commodity market (Mcphail and Babcock, 2008). However, this direct linkage between food and fuel prices are not consistent with recent trends and fail to illustrate the connection among food and fuel prices (Chen et al., 2010). The strong positive correlation between U.S. ethanol production and agricultural commodity prices during the 2007-2008 price spike, quickly reversed to a negative correlation in the years following the spike (see Figures 3.2.

and 3.4.). U.S. ethanol production continued to rise with commodity prices falling. A major weakness of these studies is not differentiating between the short- versus long-run food before fuel impacts. Gohin and Chantret (2010) attribute these inconsistencies to the omission in previous studies of macroeconomic linkages. Macroeconomic activity is hypothesized to be the underlying driver of both food and fuel prices.

In sum, Kilian (2009) discusses the importance of differentiating impacts (shocks) between demand and supply, given each of them is associated with different magnitudes, patterns, and persistence. But one of the main shortcomings for most papers is a failure to distinguish the source (demand or supply) and the magnitude of energy price influences on agricultural commodities (Chen et al., 2010). Of the studies which indicate a direct link between biofuels and agricultural commodity prices, they either employed models with a pre-built-in exogenous link between fuel and food, which is characteristic of CGE models or just assumed there is a relationship.

3.5.2. Current Research Trends

Other literature indicates more complex linkages with possible differing short- and long-run relations (Balcombe and Rapsomanikis, 2008 ; Diao et al., 2008; Daschle, 2007; Kerckow, 2007; Perlack et al., 2005; Prabhu et al., 2008; Webb, 1981; Senauer, 2008; and Zhang et al., 2010a). This research indicates, in the short run, there probably is some causation between ethanol and agricultural commodity prices (Senauer, 2008; Zhang et al., 2009; Zhang et al., 2010a). However, results indicate no long-run relationship. In support of these results, Esmaeili and Shokoohi (2011) indicate only a possible indirect relation between oil and agricultural commodity prices. Economic theory suggests global competitive markets will restore prices to their long-run equilibrium trends after any agricultural price shocks due to increased biofuel demand or other shocks (Figure 3.3.) (Zhang et al., 2009; Zhang et al., 2010a). As an example, using a world-market economic model, the rapid growth in biofuels will trigger a sharp rise in crop production at the expense of pasturelands and forests (Hertel et al., 2010). Further, Balcombe and Rapsomanikis (2008) found oil prices determine the long run equilibrium of both sugar and ethanol prices in Brazil. Sugar prices Granger-caused ethanol prices, but not the other way around. In the long run, farm prices (the prices of grains, dairy products, meats, and other farm produced commodities) and wages drive food prices. Claims that food prices are most strongly affected by energy price changes are not supported. Reducing energy prices will not reduce food prices (Lambert and Miljkovic, 2010). Furthermore, second and third generation biofuels have the potential to shift biomass production onto marginal croplands, reducing biofuel's food-price impacts.

3.5.2.1. Macroeconomic Activity

This market response was a determinant in recent agricultural commodity price volatility: rising in 2007-2008, declining in 2009-2010, and then rising again in late 2010. Price volatility is also due to the heating up and cooling off of macroeconomic activity. Such activity is possibly the underlying cause of both food and fuel price instability (Kilian, 2009). Initial research in this direction, Balcombe and Rapsomanikis (2008) extend the supply-demand framework, which focuses only on biofuel and agricultural markets, by considering oil prices along with ethanol and sugar prices. Gohin and Chantret (2010) compared the relationship between the macro-linkages of the energy sector with the food sector, but do not consider biofuels. Additional research in this vein by Harri et al. (2009), Harrison (2009), Hayes et al. (2009), Sheng-Tung et al. (2010), and Yang et al. (2008) suggests a link between oil prices and agricultural commodity prices. Saghaian (2010) indicates that although there is a strong correlation among oil and commodity prices, the evidence for a causal link from oil to commodity prices is mixed. Considering five variables (oil, ethanol, corn, soybeans, and wheat prices) there are no causal links between the energy and agricultural sectors. However, the results of Granger causality tests indicate crude oil prices Granger cause corn, soybeans, and wheat prices.

When considering these global macro-linkages, international trade patterns and balances come into play. Hanson et al. (1993) have demonstrated that with fixed exchange rates and exogenous oil prices, U.S. agricultural commodity prices slightly declined with a doubling of crude oil prices; while with a fixed trade balance, farm prices increased. Saghaian (2010) also concludes that exchange rates are correlated with energy and agricultural markets, and attributes the correlation to oil prices denominated in U.S. dollars. A rise in oil prices increases the supply of U.S. dollars, which depreciates the dollar along with an increase in grain exports and higher food prices (Saghaian, 2010; Abbott et al., 2008).

Different baskets of agricultural commodities might lead to different conclusions on the relationship between the food and fuel prices. Imai et al. (2008) suggest the persistent impacts of a price change of oil on food might differ among countries and foods, and might be affected by the type of data used. For example, in China, their results indicate oil prices yield significantly positive effects on wheat and fruit prices, while imposing no effects on the price of rice and vegetables. In contrast, oil prices have positive effects on the India’s price of wheat, rice, and fruit and vegetables.

3.5.3. Public Policies

Public policies might be another important channel through which macroeconomic linkages of energy and food markets is built, especially in recent years. Those policies (including subsidies and mandates) are playing a more significant role in the interaction between food and energy prices, especially in developed countries such as the U.S. and EU (Von Braun and Torero, 2009; Gohin and Chanret, 2010; Balcombe and Rapsonmanikis, 2008; Vincent et al., 1979; Hanson et al., 1993). U.S. ethanol demand is mainly driven by government support, thus shocks to ethanol demand are considered as policy driven more than market driven (McPhail and Babcock, 2010). Senauer (2007) estimated that the U.S. $0.51per gallon tax credit has distorted the food vs. fuel competition, making corn valued more as a fuel than a food input. Balcombe and Rapsonmanikis (2008) using Brazil as an example, found the growth of Brazil's ethanol market has been realized not only by the supply-demand linkage between the ethanol-sugarcane market, but also by various other factors including government policies, technical changes, and the manufacturing of flex-fuels vehicles. Chen et al. (2010) indicate that production subsidies which encourage biofuel crops might result in significant impacts to the environment and the economy. They state that not only high oil prices but also government subsidies would result in a higher derived demand of corn-based ethanol, as well as price increases in various agricultural commodities.

3. 5.4. Modeling Shortcomings

Specific channels of food and fuel interaction are not clearly defined or quantified. With current empirical methodologies and data, it is challenging to distinguish simultaneous supply-demand linkages and isolate impacts from macroeconomic variables. Insufficient theoretical understanding and observations among energy and agricultural commodity prices might generate misleading causal conclusions (Saghaian, 2010). As an example, without understanding the market channels linking agricultural commodity markets with energy markets, exogenesis model elasticity assumptions may be invalid. Those shortcomings led to the post 2007-2008 forecasts of relatively high agricultural commodity prices when commodity prices actually declined (3.4.).

Theoretically understanding the simultaneous supply-demand linkage and isolating the impacts from macro effects may yield improved parameter estimates (Saghaian, 2010). Structural vector autoregressive models, such as Kilian (2009) and Mcphail (2010), may offer improved estimation techniques for investigating the co-movements of food and fuel variables. With endogeneity allowed, these techniques provide for the decomposition of demand and supply impacts.

Previous research generally specified linear models leading to pairwise linear correlations. As stated by Balcombe and Rapsomanikis (2008), oil, sugar, and ethanol markets could be treated as a nexus or perceived as separate when prices move within certain thresholds. Once prices fall outside a threshold, substitution effects between oil and ethanol would induce the transmission of price from market to market, introducing nonlinear behavior. Such threshold effects could be better captured by nonlinear models. Examples of nonlinear models are Balcombe and Rapsomanikis' (2008) use of Bayesian Monte Carlo Markov chains and Azar's (2003) use of a bottom up approach to investigate the competition between biomass and food. Alternatively, Baek and Koo (2009) and Chen et al., (2010) introduced structural breaks to divide the time-series data to capture the short-run and long-run impacts of energy prices and exchange rates on the food prices.

In summary, the literature solely investigating biofuel and food prices or the literature exogenously assuming a link exists suggest that indeed there is a direct and significant relationship between food and fuel. However, when considering more complex connections in terms of short- versus long-linkages and macroeconomic impacts such a direct relationship is questionable. Demand shocks, including sharp fluctuations in biofuel prices and macroeconomic shocks, and supply shocks in agricultural production probably do cause short-run agricultural commodity price inflations but not in the long-run. The underlying driver of both energy and agricultural prices is macroeconomic activity.

3.6. Policy

In this section, policy implications are addressed surrounding the hypothesis that the 2007-2008 food price spike was caused by the shift in global policies toward relying primarily on markets to provide adequate agricultural commodities in periods of sharp increases in food demand. This hypothesis and accompanying support from economic theory suggests in the long-run markets will adjust to changes in crop usage, hence government policies such as food subsidies, price controls, and export restrictions are not warranted. However, in the short-run, due to inherent volatility throughout the food and biofuel production chains, tailored government policies are necessary to avoid future price spikes. As a reference for the discussion on both efficient and inefficient policies directed toward the food before fuel issue, a listing of policy prescriptions is provided in Table 3.3.

3.6.1. Long Run

3.6.1.1. Supply

3.6.1.1.1. Free Competitive Markets

As indicated by economic theory and supported by empirical research, global competitive markets will lead to long-run stable agricultural commodity markets (Webb, 1981; Kerckow, 2007). U.S. farmers and technology will more than keep pace with demand not only for food but also for fuel (Daschle, 2007). Productivity gains for corn averaged nearly 3% per year, and the annual U.S. corn crop increased from 7 billion bushels in 1980 to nearly 12 billion bushels in 2006. However, competitive markets require a constant infusion of pubic sponsored research and outreach to maintain current productivity growth (Arndt, 2008; Christiaensen, 2009;

Hochman, et al., 2008; Johnson, 2009; Prabhu et al., 2008; Rosegrant et al., 2008; Sexton, et al., 2009; Yang et al., 2008). Low levels of agricultural productivity in Africa are a major constraint to both poverty reduction and long-term economic growth (Diao et al., 2008). Productivity gains in Africa are possible by increasing smallholder access to a modern package of inputs and management – improved seed, modern fertilizers and pesticides, and irrigation−along with enhanced integrated regional markets−low transportation costs, information systems, financial services, grades and standards, farmer and trader organizations, and commodity exchange systems (Diao et al., 2008; Kerckow, 2007; Prabhu et al., 2008). A shift to biofuels from mainly perennial, lignocellulosic plants and low input crops will contribute to a sustainable utilization of lower quality soils with limited water supply including degraded areas (Kerckow, 2007). However, there is concern that widespread planting of energy crops will accelerate the deterioration of the world's cropland base (Brown, 1980). In conjunction with advancing technology gains, efforts should be directed toward arresting topsoil erosion losses.

Providing more support to agencies such as the Consultative Group on International Agricultural Research (CGIAR) would be an important avenue toward stable food prices (Prabhu et al., 2008). In real 2008 dollars, U.S. investment in agricultural development abroad fell to $60 million in 2006, down from an average of $400 million a year in the 1980s. In developed countries, public investment in research, which had grown annually by more than 2% in the 1980s, shrank by 0.5% annually between 1991 and 2000. Global official aid to developing countries for agricultural research fell by 64% between 1980 and 2003. The decline was most marked in poor countries, especially in Africa. This reduction in investment is directly associated with reduced growth in agricultural productivity (Runge & Runge, 2010). A reason for this decline in public investment is that agricultural technology is difficult to ascribe to specific actions by a government and is unlikely to address the immediate impacts of food and energy price volatility (Arndt, 2008).

3.6.1.1.2. Inefficient Market Controls

The empirical relationship between biofuel and agricultural commodity prices suggests policies should be directed toward mitigating the short-run impacts on food prices. Effective adjustments require they send efficient market price signals. Imposing inflexible food subsidies or price controls distort market prices resulting in market inefficiencies leading to more volatile food prices and reduced security of the world's food supply (Collins and Duffield, 2005; Elam, 2008; Senauer, 2008). Food subsidies benefit consumers in the short-run, but at the expense of future investments due to the financial requirement for subsidization. Subsidies are not well targeted, are expensive, and exacerbate the burden of macroeconomic adjustment (Arndt, 2008). Price controls send negative price signals to producers that blunt the incentives for increasing supply (Johnson, 2009). More flexible policies should be designed that are responsive to agricultural and energy market realities (Elam, 2008). All such policy responses should reflect not just changes in world prices but also local price effects (Dewbre et al., 2008).

3.6.1.2. Demand

On the energy side of the equation, reducing the acceleration of global energy consumption and improving energy efficiency will lead toward sustainable energy and agricultural markets (Kerckow, 2007). U.S. and EU government policies providing incentives for biofuel production should be reconsidered in light of their impact on short-run food prices (Chen et al. 2011). As an example, increasing the U.S. Corporate Average Fuel Economy (CAFÉ) standard would cost approximately a third as much as it costs to subsidize ethanol (Doering, 2006). Alternatively, removing tariffs on ethanol imports in the U.S. and EU would allow more efficient producers, such as Brazil and other developing countries, including many African countries to produce ethanol profitable for export to meet the mandates in the U.S. and EU (Arndt, 2008; Kerckow, 2007; Mitchell, 2008). Devadoss and Kuffel (2010) determine the current U.S. $0.57 per gallon import tariff on ethanol should be a $0.09 subsidy if the U.S. is interested in efficiently achieving the policy goals of reducing reliance on imported petroleum and reducing GHG emissions. An energy policy that more strongly emphasizes energy conservation is required (Elam, 2008). An example is subsidized public transport, but public transport passengers are typically not among the most vulnerable groups to high food prices, and such public subsidies are expensive and difficult to administer (Arndt, 2008).

U.S. government incentives and regulations favorable to biomass production, rather than investing in basic research and development for conservation and renewable sources of energy, enhances the profitability of biofuels over food (Runge and Senauer, 2007). Under current U.S. government incentives and regulations, the food vs. fuel choice is tilted toward fuel (Reilly and Paltsey, 2007).

3.6.2 Short Run

3.6.2.1. Trade Liberalization

For food importing countries, relying on agricultural productivity gains from other countries is a passive and risky policy. Instead they should consider watching their importing countries for possible major supply changes due to biofuel production or other factors and consider diversifying their agricultural imports (Brown, 1980). Food importing as well as exporting countries should work toward completing the Doha Round of World Trade Organization (WTO) negotiations leading toward more efficient agricultural free trade with regulations on food export restrictions (Christiaensen, 2009; Johnson, 2009; Von Braun et al., 2008).

Trade liberalization is much easier to administer than a subsidy and is consistent with a fundamental open economy policy. Non-price distorting policies include expanding social protection programs but such programs come with considerable cost or require a fundamental redistribution of income from the wealthy to the poor (Christiaensen, 2009; Prabhu et al., 2008; Yang et al., 2008). In the short-run, suspending ethanol blending mandates, subsidies, and ethanol import tariffs would cause a market response and lower agricultural commodity prices (Prabhu et al., 2008).

3.6.2.2. Global Food Monitoring With Buffer Stocks

As far back as the 1980s it was suggested to establish a global food-price monitoring system that is sensitive to short-run price volatility from biofuel impacts or other market shocks (Brown, 1980). If such a monitoring system was in place prior to the 2007-2008 food price spike, the spike may have been avoided. However, instead policies were adopted that directly reduce supply by holding some acreage fallow as a way of reducing the cost of managing agricultural surpluses. The United States still has millions of acres enrolled in such programs. Those policies must be reconsidered in a world in which inventories have dwindled and critical food shortages can emerge and go unmet, as they did in the 2007-2008 food price spike (Johnson, 2009).

In conjunction with monitoring, global agricultural commodity stocks should be maintained to buffer short-run price spikes (Christiaensen, 2009). The dismantling of public food reserves led to the 2007-2008 food price spikes (McMichael, 2009). As in the past, if government and private grain dealers had large inventories, the 2007-2008 food price spike would not have occurred. Food vs. fuel would have not been an issue. Recently, these precautionary inventories were allowed to shrink with the idea countries suffering crop failures could always import the food they required (Jha and Srinivasan, 2001). However, with no food in reserve, the global spike in food and biofuel demand resulted in a short-run rise in food prices when agricultural trade could not satisfy this world demand (Myers and Kent, 2003). World organizations including the International Monetary Fund and the World Bank have responded with policies and programs which commit funds for both immediate food aid and long-run increases in agricultural productivity (Singh, 2009).

Markets will adjust to shocks, but in cases of global supply shortfalls, such adjustments come at a high price of social discord and stress. The recent uprising in North Africa and the Middle East is predicated on high food price inflation. The aim is to avoid or at least buffer future price spikes by governments focusing on the public good to reinsure the global food supply (Christiaensen, 2009). An example where grain stocks were used to mitigate price increases is China's use of grain stocks to moderate the domestic price rise during the 2007-2008 food price spike (Yang et al., 2008).

However, in cases of localized food shortages or an unavoidable global price spike, expanded emergency response and humanitarian assistance programs are required to assist food-insecure people along with strengthened food-import financing. A closer look at the efficiency of current U.S. food aid programs also reveals many avenues for improved efficiency. The U.S. has been slow to change its food aid policies. As just one example, the U.S. currently requires a minimum share of its food aid be shipped on U.S.-flag vessels. This requirement costs U.S. taxpayers $140 million in 2006, which is roughly equal to the cost of non-emergency food aid to Africa (Bageant et al., 2010).

3.6.2.3. Food vs. Agricultural Commodities

The distinction between high world prices for agricultural commodities and the consumer costs of food is an important one. In developed countries consumers generally do not buy raw agricultural commodities at international prices. In many cases the proportion of agricultural commodity cost in their food is relatively small compared with the processing costs. In contrast, for consumers in many developing countries, the proportion of agricultural commodity to food costs can be large. Agricultural commodity price inflation will thus have a disproportionate effect on developed relative to developing countries. The degree to which the price of traded agricultural commodities and the price of food are related depends on factors that dampen price transmission. In the search for appropriate policy response, it is important to measure consumer effects correctly and to apportion properly the causes of current high food prices (Dewbre et al., 2008).

A final public action is to educate consumers to expect greater food price volatility, so they can adjust and plan (Yang et al., 2008). Without agricultural commodity supply buffers, food and agricultural commodity prices, particularly in the developing world, will continue to be volatile.

3.7. Summary and Conclusions

The chapter lays out evidence in support of the hypothesis that the 2007-2008 food price spike was not only caused by growing demand for biofuels but also by more complicated macroeconomic factors, such as public policies. Literature is presented in a supply and demand framework. On the supply side, how energy inputs are affecting the agricultural sector in terms of production costs are reviewed. Conforming to economic theory, results indicate agricultural commodity prices are driven by production costs with higher prices of energy inputs implying higher agricultural production costs. However, care is required in concluding that higher energy prices directly imply higher agricultural commodity prices, especially in a short-run. Other factors (biofuels, trade restrictions, speculative demands, climatic events, higher demands, and lower stocks) besides oil prices affecting the cost of agricultural production may better explain agricultural commodity prices.

Within the supply-demand framework, two main methods (CGE and econometric approaches) are employed for food before fuel analysis. CGE models are widely adopted with a consideration of macro-linkages. However, they rely on exogenously determined elasticities among fuel and agricultural commodity variables. If these elasticities are not supported by theory and empirical evidence, the conclusions derive concerning the linkages among food, fuel, and other variables including global economic activity may be questionable.

In contrast, econometric approaches attempt to determine these linkages with Granger casualty tests, pairwise correlation matrixes, cointegration tests, and VECMs. Results suggest considering both the short-run price volatility of commodities as well as the long-run commodity price trends.

Implications from this literature review suggest a possible modification in the CGE models and other numerical models which may assume a direct long-run link between fuel prices and agricultural commodity prices. The resulting forecasts of high agricultural commodity prices precipitating from high fuel prices may be misleading. Based on time series results, a reshaping of these models may be in order. Yet the results have implications far beyond suggesting modifications in economic modeling. In the short run, it is important to ensure food availability to all, but most importantly to the global poor. Spikes in agricultural commodity prices, whether caused by biofuels, climate, or just human mistakes, cause irreparable harm to the global poor.

Policies, including agricultural commodity buffers, designed to blunt these short-run price spikes should be reconsidered as a tool to reduce food volatility (Zhang et al., 2010a).

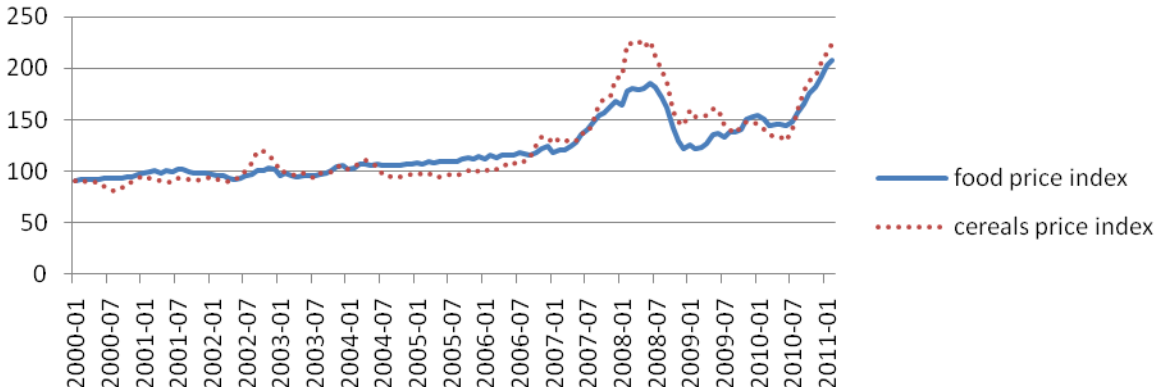

Figure 3.1. UN FAO Monthly Food Price Index (2002-2004=100).

Source: http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en/

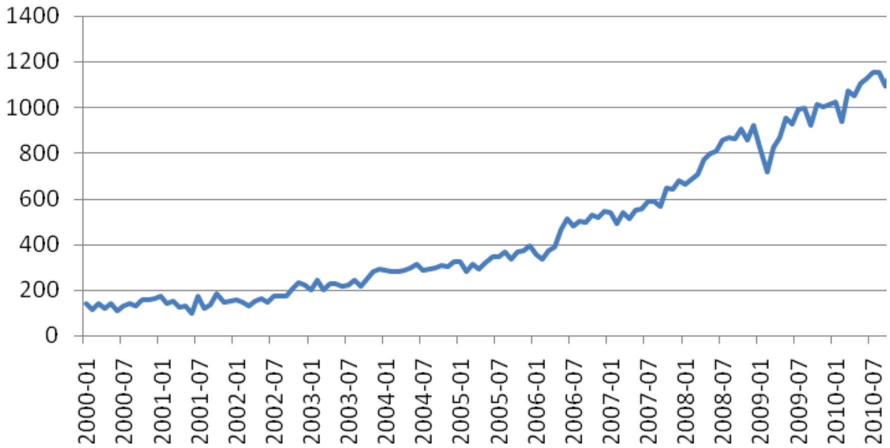

Figure 3.2. U.S. Total Production of Fuel Ethanol (Million Gallons)

Source*: *http://www.eia.gov/totalenergy/monthly.cfm#renewable

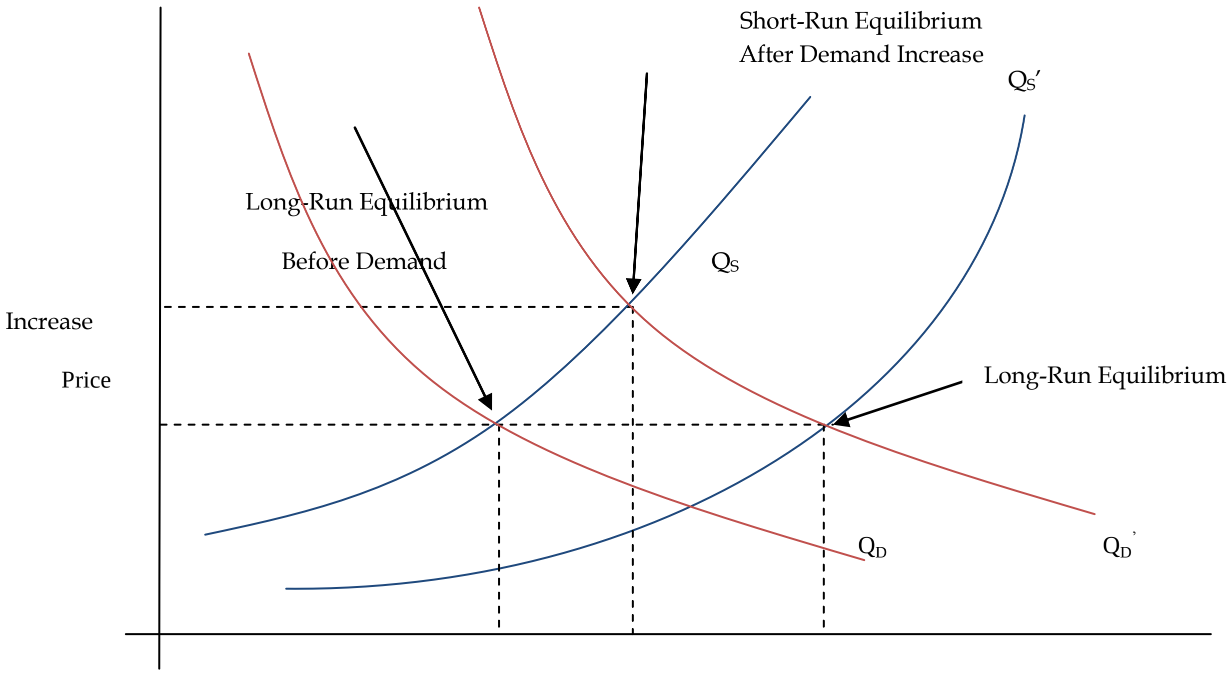

Figure 3.3. Supply and Demand Short- and Long-run Shifts

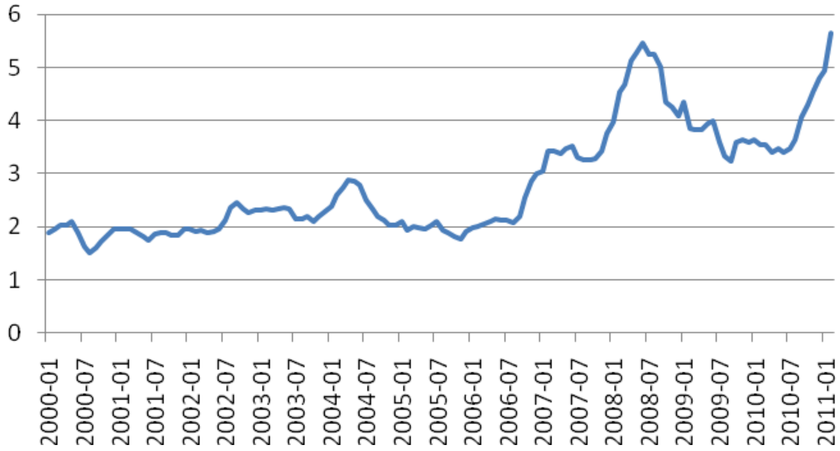

Figure 3.4. U.S. Corn Price (dollar per bushel)

Source: http://quickstats.nass.usda.gov/#36836568-52F8-393F-9658-05B4E5C1DFB2

Table 3.1. Methodologies Addressing the Food before Fuel Issue

Computable General Equilibrium (CGE) Models

- Advantages
  - Limited data requirements
- Disadvantages
  - Not based on estimated time trends and price volatility
  - Rely on exogenously determined elasticities among food and fuel variables
  - Unless expressly modeled, challenging to distinguish short- and long-run impacts

Time Series Models

- Advantages
  - Efficient in illustrating the dynamics and measuring the interaction among prices
  - Considers both the short- and long-run impacts
- Disadvantages
  - Spurious results are possible for non-stationary data

Table 3.2. Supply and Demand Effects on Food and Fuel Markets

Supply

Although fuel is a key input in agricultural production, caution is required in concluding fuel prices directly cause agricultural commodity prices.

In the long run, the potential exists for supplying biomass to meet the growing demand for biofuels.

Increased biofuel production may impose adverse effect on environmental resources.

Demand

Past research establishing a direct link between food and fuel prices are not consistent with recent trends.

The major weakness, in past research, is not differentiating short- and long-run impacts and not considering macroeconomic linkages.

Current research trends indicate, in the short run, there is probably some causation between food and fuel, but no long-run relation exists.

Macroeconomic activity possibly is the underlying cause of both food and fuel price instability.

Table 3.3. Policy Prescriptions

- **Short-Run Policies**
  - Economically Efficient
    - Completing negotiations on reducing agricultural trade restrictions
    - Global food-price monitoring
    - Precautionary agricultural commodity buffer stocks
    - Emergency response and humanitarian assistance programs
    - Educate consumers to expect greater food price volatility
  - Inefficient
    - Government incentives and regulations favorable to biomass production
    - Policies directed toward maintaining fallow acreage
- **Long-Run Policies**
  - Economically Efficient
    - Allow free markets to adjust to changes in crop usages
    - Constant infusion of public sponsored research and outreach
    - Shift to sustainable perennial crops arresting topsoil erosion
    - Improving energy efficiency
    - Subsidize public transport
    - Diversify food and fuel imports
  - Inefficient
    - Food and biofuel subsidies
    - Price control
    - Export and import restrictions

CHAPTER 4

CONSIDERING MACROECONOMIC INDICATORS IN THE FOOD BEFORE FUEL NEXUS[3]

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[3] Qiu,C., G. Colson, C. Escalante and M.E. Wetzstein. 2012. *Energy Economics.* 34(6): 2021-2028. Reprinted here with permission of the publisher.

Abstract

A Structural Vector Autoregression (SVAR) model along with a direct acyclic graph are employed to decompose how supply/demand structural shocks affect food and fuel markets. The results support the hypothesis that fundamental market forces of demand and supply are the main drivers of food price volatility. Increased biofuel production may cause short-run food price increases but not long-run price shifts. Decentralized freely operating markets will mitigate the persistence of any price shocks and restore prices to their long-run trends. The main policy implications are that oil, gasoline, and ethanol market shocks do not spillover over into grain prices, which indicates no long-run food before fuel issue. In the short-run, grain prices can spike due to market shocks, so programs designed to blunt these price spikes may be warranted.

4.1. Introduction

A popular view, both in policy circles and public perception, contends a dominant underlying driver of the 2007-2008 food-price spike was increased use of crops for the production of biofuels (Abbott et al., 2008; Chakrabortty, 2008; Diao et al., 2008; Mitchell, 2008). This shift from fossil fuels to biofuels is particularly prominent among many Kyoto Protocol signatory countries (Balcombe and Rapsomanikis, 2008). Fostered through national agriculture and energy policies, this shift is motivated by increased oil price volatility, energy security ambitions, and environmental concerns. The rapidly growing market for biofuels has given rise to the perception that biofuel expansion generates upward pressure on global food prices, exacerbating global hunger problems (Runge and Senauer, 2007). This increase in food prices is mainly associated with corn prices, where nominal prices increased from $3.51 per bushel in June 2007 to $5.48 a year later, then down to $3.41in June 2010 and a year later up to $6.38 (Farmdoc, 2011). In 2009, 119 out of 416 million tons of U.S. corn production went into ethanol fuel refining (Brown, 2011). These concerns have precipitated calls for agricultural and energy policies to be reprioritized where food takes precedence before fuel (in short, food before fuel).

In contrast to this perception, evidence is provided countering the hypothesis that a shift from fossil fuel toward biofuels has caused a food before fuel issue. Instead, evidence is presented supporting the hypothesis that fundamental market forces of demand and supply are the main drivers of the food-fuel nexus. Increased biofuel production may cause short-run food price increases but not long-run price shifts. Decentralized freely operating markets will mitigate the persistence of these price shocks and restore prices to their long-run trends. The global agricultural market structure is composed of many producers who are very supply price responsive. In the short run, as prices rise there will be a price response that in the long run will mitigate their rise and restore prices to their long-run equilibrium trend.

This evidence is based on the results from developing a structural vector auto-regression (SVAR) model considering crude oil supply; real economic activity; real prices of crude oil, gasoline, and ethanol; gasoline demand; ethanol supply; and the corn price and quantity supplied. Structural impulse response functions and forecast error variance decomposition along with a directed acyclic graph are employed for deriving evidence on the food-fuel nexus.

4.2. Theory

As outlined by Qiu et al. (2011), surges and downturns of ethanol and food prices are not isolated incidents, but economic consequences (Gohin and Chantret, 2010; Von Braun et al., 2008; McPhail and Babcock, 2008; Chen et al., 2010; Balcombe and Rapsomanikis, 2008). Kappel et al. (2010) argue that fundamental market forces of demand and supply were the main drivers of the 2007-2008 food price spikes. With the emergence of biofuel and grain market linkages, heightened short-run grain-price volatility is likely (Hertel and Beckman, 2011). While a market supply response will likely mitigate this short-run volatility and return prices to their long-run trend. Economic theory in general suggests agriculture will respond to a grain price increase from biofuels or other demand shocks. As illustrated in Figure 4.1., a demand shock will shift the demand curve outward from Q_D to Q_D'. This results in a short-run increase in the agricultural commodity price, from P_e to P_e'. The magnitude of this increase in price depends on how responsive supply, in the short run, is to the demand shift (represented as an increase in quantity from Q_e to Q_S). However, in the long-run, agriculture will expand production yielding a further increase in supply. Assuming no cost adjustments, this increase in supply will restore the market price to the long-run equilibrium price P_e.

Generally the responses to the demand shifters are rapid, while supply-utilization adjustments are slower. A shift in demand will elicit an immediate price increase response. While the supply response will take a number of months as agriculture gears up to increase production. With this supply and demand model, the issue is how rapid is this supply response and what is its magnitude. If supply is able to rapidly respond to a demand shift, then there is no food versus fuel issue. If not, then there is cause for concern.

In 1979, Vincent et al., (1979) indicated the days of cheap corn are not over. Prices may be more stable as corn production expands to meet ethanol requirements and as second generation ethanol, increased buffer stocks, and new technologies emerge. This prediction of stable agricultural commodity prices would still hold if supply responses are rapid enough to mitigate demand. A positive shock in demand leading to a rise in price will generally elicit a supply response, but if there is much of a delay the price rise will be persistent overtime. Furthermore, expanding global economic activity will continue to put upward pressure on both food and fuel prices.

4.3. Methodology

4.3.1. Structural Vector Autoregressive (SVAR) Model

In empirical research on the food before fuel issue, Vector Autoregression (VAR) and Computable General Equilibrium (CGE) models are the two dominant methods employed (Qiu et al., 2011). However, it is generally difficult to distinguish contemporaneous supply-demand linkages and isolate impacts from economic variables in these models. In general, VAR models are widely used in macroeconomic analysis. Such models are an efficient tool for capturing the dynamic interactions among variables.

In terms of fuel vs. food, a number of studies have employed multivariate models. Employing VAR, Nazlioglu and Soytas (2011) found oil prices neither directly nor indirectly through exchange rates affect agricultural prices in Turkey. Zhang et al. (2010a) employing a vector error corrections model in examining the relation between fuel prices (ethanol, gasoline, and oil) and prices of agricultural commodities (corn, rice, soybeans, sugar, and wheat) indicate commodity prices in the long run are neutral to fuel price changes. Similarly, Kaltalioglu and Soytas (2011) and Serra et al. (2011a) both employ a generalized autoregressive conditional heteroskedasticity model and find no volatility spillover between oil and agricultural commodity prices. In contrast, Harri, et al. (2009) and Serra et al. (2011b) did discover agricultural commodity prices are linked to energy prices (oil, gasoline, and ethanol) for corn, cotton, and soybeans, but not for wheat. Further, Du et al. (2011), employing Bayesian Markov Chain Monte Carlo methods find evidence of volatility spillovers among crude oil, corn, and wheat markets.

A major shortcoming of these models is their failure to combine economic implications (Hamilton, 1994). Thus, Structural Vector Autoregression (SVAR) models are proposed to mitigate such shortcoming and identify the relevant innovations. With SVAR, unpredictable changes in the prices and demand/supply are decomposed into mutually orthogonal components with economic interpretations. However, SVAR models do not solve possible omitted variables bias and policy misspecification. In VAR models, shocks reflect omitted variables and if they are correlated with the included variables, then the estimates will be biased. Changing policy rules may lead to misspecification in constant parameter VAR models, just as they might in standard multi-equation econometric models. Also, in terms of SVAR models, there is a tendency to rationalize a specific causal relation in order to justify a recursive ordering so the SVAR collapses to a recursive VAR for ease of estimation.

Literature is limited on SVAR models addressing the food before fuel issue. Kilian (2009) employed a SVAR model to identify dynamic effects of different shocks in the global crude oil market by decomposing those shocks into crude oil supply shocks, specific crude oil demand shocks, and aggregate shocks to all industrial commodities. He subsequently extended the model by including the gasoline market (Kilian, 2010). With Kilian's model as a foundation, McPhail (2011) analyzed the impacts of expanding U.S. ethanol markets on the global oil markets. But Kilian's and McPhail's articles only identify contemporaneous dynamic innovations within the energy market. Limited research has quantified simultaneous structural innovations between the food and fuel markets. Zhang et al. (2007) employed SVAR models to capture contemporaneous interactions among ethanol, corn, gasoline, and MTBE, but macroeconomic effects are excluded in their work. Almirall et al. (2010) employed SVAR to analyze how U.S. crop prices responded to shocks in acreage supply, but they only considered ethanol in the fuel markets. Specifically, the effects from gasoline and crude oil were excluded, and possible macroeconomic impacts were not considered.

The interest in SVAR modeling that links the energy and agricultural markets is growing with forthcoming articles by McPhail et al. (2012) and Mutuc et al. (2012). McPhail et al. (2012) presents an abbreviated SVAR model in an effort to consider the corn price response to a speculative corn demand shock simultaneously with the ethanol and oil market. They simplify the SVAR by not modeling the gasoline market and not fully modeling ethanol and corn markets. Further, they assume macroeconomic activity, the gasoline market, ethanol price, and corn supply are not impacted by corn demand, oil price, ethanol demand, and corn price shocks.

Their results indicate the long-run effect of speculation is minimal and any short-run effect is short lived (within one month). Mutuc et al. (2012) also develop an abbreviated SVAR model by considering the oil market and real cotton prices. Their results indicate oil prices only explain 3% of the long-run variability in cotton prices.

With Kilian (2009, 2010), McPhail (2011), Zhang et al. (2007), and Almirall et.al (2010) as a foundation, a SVAR model is developed that links macroeconomic impacts with the food and fuel market sectors. In contrast to previous studies, the food and fuel markets sectors are more fully developed by considering the demand and supply for gasoline, ethanol, and corn. With this expanded market consideration, the linkages between fuel and food can be further explored. The analysis focuses on corn, which is the leading input in U.S. ethanol refining and a major food crop. For the fuel sectors, crude oil, gasoline, and ethanol are considered and the real Baltic Exchange Dry Index (BDI) is employed as a measurement of global economic activity.

Theoretically the SVAR model is specified by letting y_t represent an (n x 1) vector containing n market variables for corn, oil, gasoline, ethanol, and economic activity at time *t*. The dynamics of y_t are assumed to be governed by a VAR (p) model,

$$y_t = B_0 + B_1 y_{t-1} + B_2 y_{t-2} + \cdots + B_i y_{t-i} + \cdots + B_p y_{t-p} + e_t.$$

With contemporaneous correlations among those variables considered, the VAR model is rewritten following a SVAR model

$$Ay_t = AB_0 + AB_1 y_{t-1} + AB_2 y_{t-2} + \cdots + AB_i y_{t-i} + \cdots + AB_p y_{t-p} + Ae_t$$

$$= A_0 + \sum_{i=1}^{p} A_i y_{t-i} + \varepsilon_t$$

where $A_0 = AB_0, A_i, = AB_i$, and $\varepsilon_t = Ae_t$. The error term ε_t is assumed to be the vector of serially uncorrelated structural variables with variance-covariance matrix defined as a diagonal

$$E\ (\varepsilon_t) = 0,$$

$$E\ (\varepsilon_t{}'\varepsilon_t) = \Omega,$$

$$E\ (\varepsilon_t{}'\varepsilon_s) = 0,\ \ t \neq s$$

The reduced form for the SVAR model is then

$$y_t = A^{-1} A_0 + \sum_{i=1}^{p} A^{-1} A_i y_{t-i} + e_t\ , \tag{4.1}$$

where it is assumed that A^{-1} is a recursive matrix of A, and $e_t = A^{-1}\,\varepsilon_t$.

The economic linkages between the food and fuel markets are incorporated by defining

$$y_t = (So_t, R_t, Po_t, Pg_t, Dg_t, Pe_t, Se_t, Pc_t, Sc_t)', \tag{4.2}$$

where So denotes crude oil supply, R represents real economic activity, Po, Pg, and Pe are the real prices of crude oil, gasoline, and ethanol, respectively, Dg is gasoline demand, Se denotes ethanol supply, and Pc and Sc are the corn price and supply, respectively, employed as food indexes.

Based on Kilian (2009, 2010) and McPhail (2011), the decomposed matrix form of $e_t = A^{-1}\,\varepsilon_t$ is:

$$\begin{pmatrix} e_t^{So} \\ e_t^{R} \\ e_t^{Po} \\ e_t^{Pg} \\ e_t^{Dg} \\ e_t^{Pe} \\ e_t^{Se} \\ e_t^{Pc} \\ e_t^{Sc} \end{pmatrix} = \begin{pmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 & 0 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & 0 & 0 & 0 & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} & 0 & 0 & 0 \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & a_{76} & a_{77} & 0 & 0 \\ a_{81} & a_{82} & a_{83} & a_{84} & a_{85} & a_{86} & a_{87} & a_{88} & 0 \\ a_{91} & a_{92} & a_{93} & a_{94} & a_{95} & a_{96} & a_{97} & a_{98} & a_{99} \end{pmatrix} \begin{pmatrix} \varepsilon_t^{So,shock} \\ \varepsilon_t^{R,shock} \\ \varepsilon_t^{Do,shock} \\ \varepsilon_t^{Sg,shock} \\ \varepsilon_t^{Dg,shock} \\ \varepsilon_t^{De,shock} \\ \varepsilon_t^{Se,shock} \\ \varepsilon_t^{Dc,shock} \\ \varepsilon_t^{Sc,shock} \end{pmatrix},$$

where *Do* denotes crude oil demand, *Sg* denotes gasoline supply with *De* and *Dc* representing ethanol and corn demand, respectively. In the fuel and food markets, supply and demand shocks are both included as well as shocks from real economic activities. Following Kilian (2009,

2010) and McPhail (2011), definitions and examples of those structural shocks are summarized in Table 4.1.

4.3.2.1. Oil Market

Considering first the oil market, it is assumed that crude oil supply will respond to the oil supply shocks instantaneously without responding to the oil demand shocks and aggregate economic shocks contemporaneously. Even if precautionary oil demand shocks exist, they will not affect oil production in the short-run (oil supply is very inelastic in the short run). Crude oil supply is mainly controlled by OPEC that has established capacity constraints. Capacity is based on the expected long-run global economic growth and not on short-run demand shocks. Real economic activities are responsive to oil supply shocks and aggregate economic shocks through the current global fossil based economy. The element $\alpha_{23} = 0$ is based on the Kilian and Vega's (2008) finding that no feedback exists from macroeconomic factors to the oil price within a month. Crude oil price is influenced by the interactions of oil demand-supply as well as macro-economy shocks (Killian, 2009).

4.3.2.2. Gasoline Market

Turning to the gasoline market**,** the gasoline price has a relatively sluggish response to gasoline demand shocks compared with the gasoline supply shocks. Given enough gasoline storage, the short-run gasoline supply could be treated as perfectly elastic (Kilian, 2010). Thus, due to the lag of information transmission, gasoline demand shocks would not change the gasoline price instantaneously, while supply shocks, such as refinery accidents or cost shocks from the price change of imported oil, will be passed onto gasoline prices within the same month. Gasoline demand changes are attributed to shocks from the oil market, macroeconomic activities, and gasoline demand/supply.

4.3.2.3. Ethanol Market

For the ethanol market, structural shocks from the oil market, macroeconomic activities, and gasoline market are assumed to affect the ethanol market contemporaneously, based on the blending of ethanol with petroleum gasoline in the U.S. production of conventional fuels. The assumption is $\alpha_{67} = 0$, indicating that the short-run demand of U.S. ethanol is perfectly elastic (McPhail, 2011). It is also assumed that $\alpha_{68} = \alpha_{69} = \alpha_{78} = \alpha_{79} = 0$, based on the rationale that with the current U.S. government policies, the food versus fuel choice is tilted toward fuel (Reilly and Paltsev, 2007). The demand for ethanol is a market derived demand based on government policies, so the price of ethanol is not determined by its cost of production−the interaction of corn demand and supply.

4.3.2.4. Corn Market

Real economic activity shocks are considered to yield impacts not only in the energy markets (oil, gasoline, and ethanol) but also in the corn market. The underlying hypothesis is that macroeconomic activities play a role in food and fuel market volatilities. Within the corn market, it is assumed that corn prices and supply respond to structural shocks from fuel markets in addition to macroeconomic activities. In the agricultural input markets, fuels are key inputs in crop production and within the output market, biofuel (ethanol) is in direct competition with food for the corn input. While Abbott et al. (2009) have identified increased demand for corn as a major driver of cron prices; economic theory indicates supply shocks will not elicit the same price response. This is modeled by setting $\alpha_{89} = 0$. Prior to the mid 20th century private and public stocks of food avoid any price effects from a food supply shock. These stocks would buffer any price response from a positive corn demand shock. In the late 20th century, many economists and government policymakers assumed open markets were more efficient in stabilizing agricultural commodity prices than maintaining commodity buffer stocks. One example of this view is an article by Jha and Srinivasan (2001) where they conclude that by liberalizing trade, agricultural commodity stocks are no longer required to maintain stable prices when faced with a supply shock. With free trade, when a region experiences a shortfall in corn, it can supplement supply by importing from a corn surplus region. Thus, corn storage and open markets will mitigate any effect a supply shock will have on corn prices.

4.3.3. Directed Acyclic Graph (DAG)

Structural impulse response functions and forecast error variance decomposition are employed to measure the relative response of the variables (2) to structural shocks. For investigating causality a Directed Acyclic Graph (DAG) is employed. Although Granger causality tests are widely employed in econometric analysis, its validity outside a 2-dimensional system is limited– how one variable causes another via a third variable might be omitted or biased in estimation. An alternative addressing this limitation is DAG that can picture contemporaneous causality structures/flows within fuel and food markets.

Defined by Bessler and Akleman (1998) and Bessler and Yang (2003), DAG represents causal flows among the set of variables (2). A DAG model is composed of *V* the variables (vertices) (2) and a set of symbols relating the variables within a set of ordered pairs. Specifically, it considers the pair of variables y_1 and y_2 in a set V with causal relations (edges):

$y_1 - y_2$	undirected causation,
$y_1 \rightarrow y_2$	direct causation,
$y_1 \leftrightarrow y_2$	bi-direct causation,
$y_{1\ o}{-}_{o}\, y_2$	non-direct causation,
$y_{1\ o}{-}\, y_2$	partially direct causation,

where the direction of the arrows denote the causal flows. The rationale under DAG is that conditional independence could be captured by the recursive product decomposition

$$P(y_1, y_2, \ldots, y_9) = \prod_{i=1}^{9} P(y_i|py_i),$$

where P is the joint probability of variables, $y_1, y_2, \ldots, y_9$, and py_i is a subset of variables that precede y_i.

Spirtes, et al. (1993) developed an algorithm to detect DAGs for causal relationships. In their algorithm, causality patterns within the DAG are implemented in a stepwise process: First, a general undirected graph is built with all the variables connected by undirected edges; second, correlations and partial correlations are calculated, where edges with zero correlations or conditional correlations are removed sequentially (Bessler and Akleman, 1998); third, based on the d-separation criterion, remaining edges are directed (Pearl, 1995).

As a test for whether partial/conditional correlations are significantly different from zero, a Fisher's Z test is employed where

H_0: Conditional correlation between two structural shocks is not significantly different from zero.

H_a: Conditional correlation between two structural shocks is significantly different from zero.

The test statistic is defined in Bessler and Yang (2003). An example of mating DAG with a SVAR model is provided by Babual, at al. (2004).

4.4. Data

For estimating the SVAR model and determining the DAG causality among the variables, monthly time series data from January 1994 to October 2010 are utilized. For the fuel markets, world oil supply, U.S. real imported crude oil prices, U.S. ethanol production, and U.S. real regular retail gasoline prices were obtained from the Energy Information Administration (EIA).

Following McPhail (2011), the U.S. product supply of finished motor gasoline deducting the U.S. oxygenate plant production of fuel ethanol is used as a surrogate for U.S. gasoline consumption, both of which are from EIA. Nominal monthly ethanol prices were obtained from the Office of Energy Policy and New Uses, USDA.

U.S. nominal corn prices are collected from the Foreign Agricultural Service, USDA with corn supplies collected from the Economic Research Service, USDA. However, supplies are only provided on a quarterly scale, so for transforming to monthly data, a cubic spline interpolation is employed. This is a standard nonparametric smoothing technique used in economics and statistics for converting quarterly data into monthly intervals (Conover, 1999; Habermann and Kindermann, 2007).

The Consumer Price Index data were collected from the Bureau of Labor Statistics, with 1982-1984 as the baseline year. Real prices are then calculated as nominal price/CPI*100. All fuel prices and supplies are measured in gallons, corn prices are measured in $/bushel, and corn supplies are measured in bushels.

Following Kilian's (2009) study, real Baltic Exchange Dry Index (BDI) is used as a measurement of the global real economic activities. BDI serves as an indicator of changes in the global demand for raw materials and commodities driven by the global business cycle. In previous studies, the exchange rate is employed as a surrogate of global real economic activities, where results indicate it has influenced energy and agricultural commodity markets (Hanson et al., 1993; Gohin and Chantret, 2010; Saghaian, 2010; Abbott et.al., 2008). However, the exchange rate is a bilateral concept. For measuring the real global economic activities, an exchange rate index could be developed. However, such an index would be difficult to develop and would require a large collection of exchange rates. As an alternative, real BDI is used as a proxy of real economy activities.

Spurious regressions are avoided by testing all variables (2) with Augmented Dickey-Fuller (ADF) tests with trend considered. As U.S. ethanol supply and world crude oil supply experienced exponential expansion, even logarithm transformations might fail to capture those corresponding shocks. Thus, first differences for the logged data (except for corn prices and supply) are calculated. ADF statistics for the first differences of the logarithmic data are stationary (Table 4.2).

4.5. Results

Joint consideration of the Akaike Information criterion, Schwarz Baysian criterion, and the Hannan and Quinn criterion suggests a lag of four to be selected in our SVAR models. The least-squares method is then employed equation-by-equation. Impulse response functions with 95% bootstrapped confidence intervals and forecast error variance decomposition results are presented as follows.

4.5.1. Structural Impulse Response of Corn Prices

Figure 4.2. illustrates how corn prices respond to the structural shocks over a 16 month interval. In most of the time horizons, a positive real economy shock increases corn prices in both the short- and long-run. The corn price peaks at month 4. This sluggish peak might result from a lag in information transmission from the shipping industry to the corn market. As economic activity expands, measured by shipping rates, there is lag in a corn price response. This indicates corn prices are a lagging indicator of economic activity.

Conforming to economic theory, a positive corn demand shock elicits an immediate increase in the corn price, and the magnitude is the largest among all the structural impulse response functions. This is consistent with our hypothesis that given the relative unresponsiveness of supply for staple food commodities, small shifts in demand can lead to a significant movement in prices. An ethanol demand shock has a similar effect on corn prices, but at a relatively much smaller impact.

Corn prices decrease as a response to both a corn and ethanol supply disruption, and overshoot in the early months. Compared with a corn demand shock, impacts from corn and ethanol supply shocks are weak. The delayed response of corn prices with response to a supply shock may occur as a result of public and private stocks of corn. These stocks will tend to mitigate a supply shock. The response function for an ethanol shock exhibits the same pattern as a corn supply shock, but on a larger scale.

Gasoline demand and supply shocks along with oil demand shocks are relatively weak in their impact on corn prices. Fossil market shocks appear to not have much of a spillover into the corn market. An exception is an oil supply shock, where an increase in oil supply yields a marked increase in corn price within the first month. Oil supply in our fossil fuel-dominated economies appears to permeate most, if not all, sectors. The economic expansion effect of an oil supply shock appears to be driving up prices with corn as the representative commodity.

Overall, lack of persistence in the corn prices with respect to all the structural shocks supports the theory of rapid market responses mitigating shocks' effects and the perfectly competitive markets are efficient in responding to price signals (Zhang et al, 2010a).

4.5.2. Structural Forecast Error Variance Decomposition of Corn Prices

Table 4.3. lists how each structural shock contributes to the forecast error variance of corn prices. In the first month, the majority of the corn price volatility (approximately 95%) is explained by a corn demand shock. An ethanol demand shock is a distant second accounting for 4% of the

forecast error variances. Ethanol supply, oil and gasoline markets, along with real economy shocks, play limited roles in the corn price variations.

The relative importance and proportion of the shocks in explaining corn price variation change through time, but finally stabilize within a year. Although a corn demand shock still accounts for the largest proportion of the corn price variation, its relative importance decreases significantly. By contrast, the relative importance of corn supply shocks increases. Over 5% of the corn price variations are accounted from corn supply shocks in one year. Increased proportion of corn supply shocks in explaining corn prices indicates the importance of grain stocks and a key role that grain supply plays in long-run price stabilization. Reduced tillage technology, improved drying and irrigation systems, and efficient application and timing of fertilizer and improvements of technologies will increase the supply of corn, which will buffer the short-run price spikes in a long run.

Although real economic activity contributes more in the corn price variations, the increasing magnitude is fairly small, less than 3%, indicating that real economic activity plays a limited role in the corn price variation. In terms of the oil and gasoline markets, in the long-run, shocks in these markets account for a much larger proportion of corn price variations relative to the first month, thus supporting the pass-through effects of the energy input (Chen et al., 2010).

There is no large change in the proportion explained by ethanol demand in the long-run than in the short-run. The proportion explained by ethanol demand shocks is almost invariant (approximately 4.10%) after month 24. This indicates even with the current U.S. government incentives and regulations on the food versus fuel choice that are tilted toward fuel, ethanol demand shocks only contribute a fairly small proportion of the forecast error variances of the corn price.

4.5.3. Causality Analysis: Directed Acyclic Graphs

Results for contemporaneous causality relationships between the food and fuel markets are illustrated in Figure 4.3. Corn prices are not significantly directly caused by any other prices or quantities. There are no spillover effects on corn prices from the oil, gasoline, or ethanol markets. Thus, this indicates no direct or indirect causes of corn prices, which contradicts the popular food versus fuel assumption.

As byproducts from the DAG, the corn price is a direct cause of the ethanol price. An increase in the input price (corn) will shift the output (ethanol) supply curve, yielding an increase in the price of ethanol. Gasoline demand is directly caused by both corn and ethanol supply. This indicates the more ethanol used in conventional blended fuels the greater is the demand for blended fuels. A possible increase in corn and ethanol supply may result with the recent shift in U.S. blended fuels. As opposed to E10 (10% ethanol and 90% petroleum), for some models of automobiles, E15 (15% ethanol with 85% petroleum gasoline) is now allowed. As demonstrated by Zhang, et al. (2010b), this shift toward higher ethanol blends has the effect of increasing the demand for blended fuels. Figure 4.3. also indicates the ethanol price is directly caused by the price of gasoline. These relations support the theory that gasoline and ethanol are complements (Zhang, et.al., 2010b). As expected, the oil price is a direct cause of real economic activity and gasoline prices.

4.6. Conclusions

In this study, a Structural Vector Autoregression (SVAR) model is employed to decompose how supply/demand structural shocks affect corn prices. Results based on the SVAR model indicate the own demand shocks generate the strongest impulses on the corn prices in the short-run, but those impacts die out eventually along with the other impulse response functions in a long-run.

This finding supports the hypothesis that in the short run, food prices increase as a response to positive demand shocks; however, in the long run, global competitive corn markets restore prices to their long-run trends.

Structural error forecast variance decompositions indicate that both in the short-and long-run, volatility in corn prices are mainly governed by their own demand shocks. This is consistent with Kappel et al. (2010) that fundamental market forces of demand and supply were the main drivers of the 2007-2008 food price spike. However, the relative importance of each structural shock in explaining the variation of corn prices is different. The proportion of ethanol demand/supply shocks in explaining corn price volatilities are relatively small both in short- and long- run, indicating that influences from the ethanol market are still weak. It implies that although the food before fuel choice is tilted toward fuel, ethanol demand shocks only contribute a fairly small proportion of price volatilities compared to the impacts from own demand shocks from the corn market. Although real economic activity shocks contribute more in the long run, the corresponding proportion in explaining the corn volatility is still fairly small.

A Directed Acyclic Graph (DAG) based on the SVAR model further supports the results. No direct causes of corn prices are observed in the DAG, which reinforces the other results that corn price movements and volatilities are mainly driven by their own demand shocks. Results also support the theory of a complementary relation between ethanol and gasoline.

Results indicate that agricultural corn prices serve as a market signal. The decentralized competitive corn markets will respond to the demand shocks instantly, while in a long run, decentralized freely operating markets will mitigate the persistence of these shocks and restore prices to their long-run trends. Although there is a time lag in the supply response to the demand shock. Spikes in agricultural commodity prices, whether caused by biofuels, climate, or just human mistakes, cause irreparable harm to the global poor. Thus, in the short run, it is important to ensure food availability to all, but most importantly to the global poor. In the long-run, markets will adjust. Policies, including agricultural commodity buffers, designed to blunt these short-run price spikes should be reconsidered as a tool to reduce food volatility (Zhang et al., 2010a).

Table 4.1. Summary of Structural Shocks

Structural Shocks	Definition	Example
Oil supply, $\varepsilon_t^{So,\ shock}$	Unexpected events in oil exporting countries	Wars and revolutions: The Libyan revolution, Strait of Hormuz blockade
Real economic activity, $\varepsilon_t^{R,\ shock}$	Global economic activity turn	The recent global Great Recession
Oil demand, $\varepsilon_t^{Do,\ shock}$	Speculative demand shift	2006-2007 rapid expansion of Asia markets
Gasoline supply, $\varepsilon_t^{Sg,\ shock}$	Gasoline supply shift	Accidents and weather affecting refineries: Hurricane Katrina
Gasoline demand, $\varepsilon_t^{Dg,\ shock}$	Shift in income, price, and preferences	Asia 2011 fall in automobile demand from tightening financial markets
Ethanol demand, $\varepsilon_t^{De,\ shock}$	Policy shifts	U.S. policy shifts: 2006 phase out of MTBE
Ethanol supply, $\varepsilon_t^{Se,\ shock}$	Input price shifts	2008 high corn prices precipitating ethanol refinery closings
Corn demand, $\varepsilon_t^{Dc,\ shock}$	Consumer preference shift	Fall 2011 accelerated decline in meat production using corn
Corn supply, $\varepsilon_t^{Sc,\ shock}$	Unanticipated weather impacts, improvement of drought and irrigation systems or production technologies	2011 season drought

Table 4.2. Augmented Dickey-Fuller Test Results (With Trend)

Data (log difference)	**Augmented Dickey-Fuller Statistics**[a]				
	Lag1	**Lag2**	**Lag4**	**Lag8**	**Lag12**
	Supply and Demand				
Crude Oil Supply	−9.53	−9.54	−8.32	−6.15	−5.03
Gasoline Demand	−14.41	−10.32	−6.01	−8.93	−5.81
Ethanol Supply	−11.50	−8.45	−7.49	−6.07	−4.21
Corn Supply	−8.80	−10.06	−8.15	−20.46	−5.34
	Prices				
Crude Oil	−8.02	−7.17	−6.22	−5.22	−4.87
Ethanol	−10.32	−7.74	−6.81	−4.77	−4.73
Gasoline	−10.25	−7.50	−7.77	−6.42	−4.42
Corn	−7.57	−6.84	−6.53	−4.25	−3.60
	Real Economic Activities				
Baltic Exchange Dry Index	−9.53	−7.92	−6.33	−4.51	−4.42

[a] All coefficients are significant at the 1% level, except for corn lag 12 that is significant at the 5% level.

Table 4.3. Forecast Error Variance Decomposition of Corn Prices

Month	Shocks								
	Oil supply	Real economic	Oil demand	Gasoline supply	Gasoline demand	Ethanol demand	Ethanol supply	Corn demand	Corn supply
1	0.12	0.31	0.00	0.02	0.04	4.16	0.80	94.55	0.00
2	4.38	0.22	1.84	3.65	1.57	3.21	2.00	79.18	3.97
4	4.21	0.21	1.79	5.64	1.79	2.93	4.93	74.37	4.13
6	4.72	2.79	1.66	7.12	2.29	3.19	5.47	68.72	4.04
12	5.69	2.67	1.70	8.07	3.54	3.91	5.71	63.76	4.95
18	5.73	2.68	1.81	8.14	3.93	3.98	5.75	62.79	5.18
60	5.74	2.70	1.92	8.23	4.30	4.11	5.74	61.86	5.40

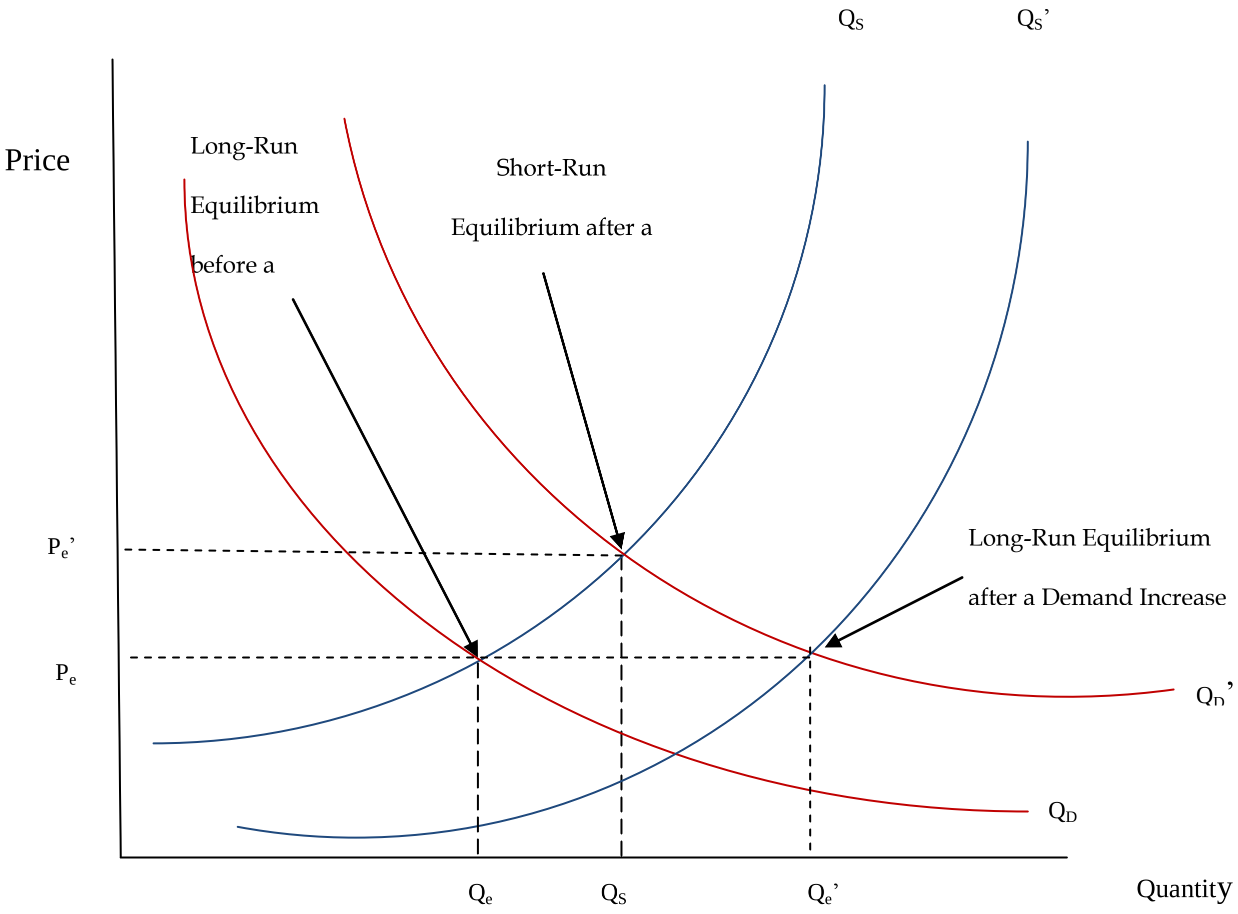

Figure 4.1. Supply and Demand Short- and Long-Run Shifts

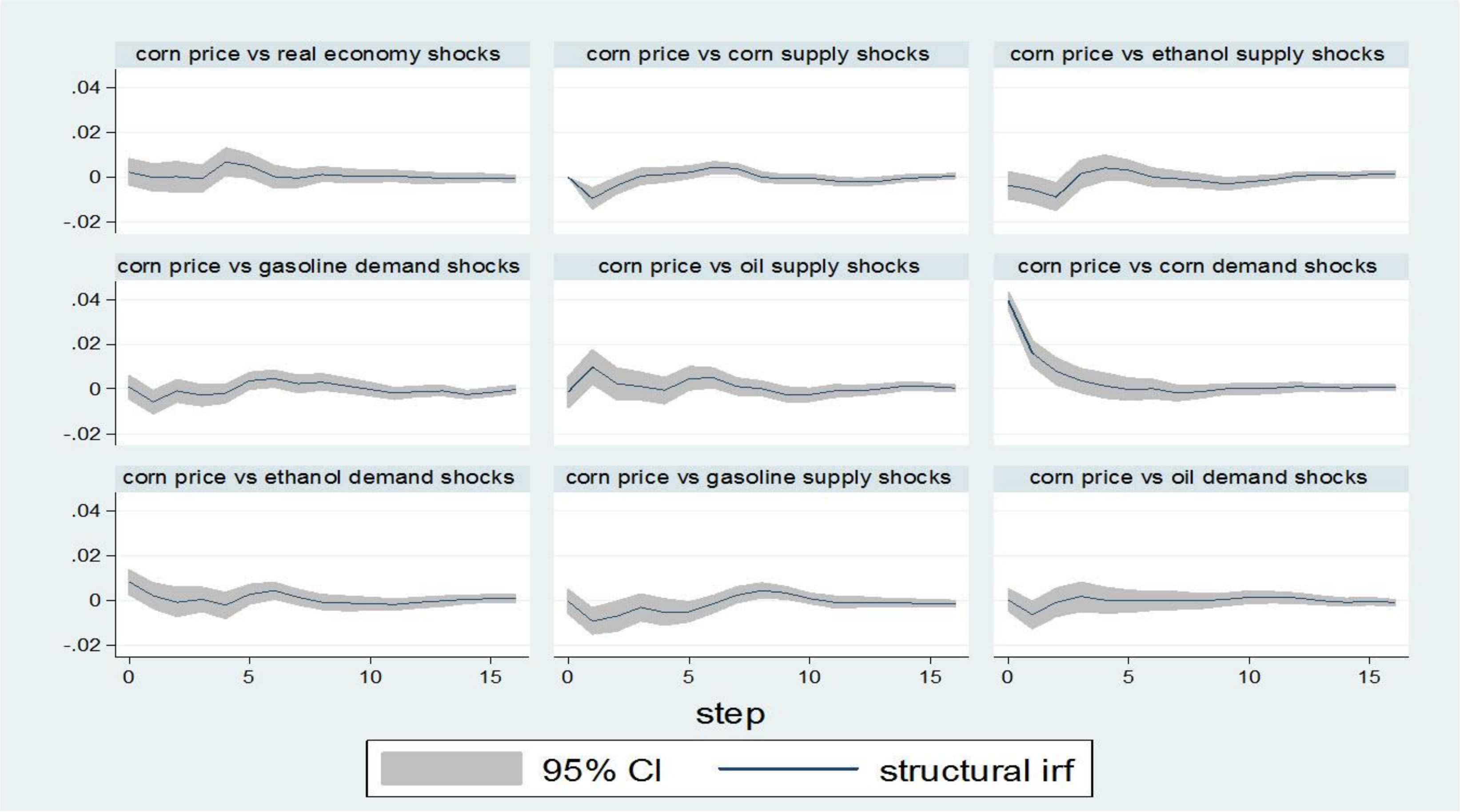

Figure 4.2. Structural Impulse Responses of Corn Prices

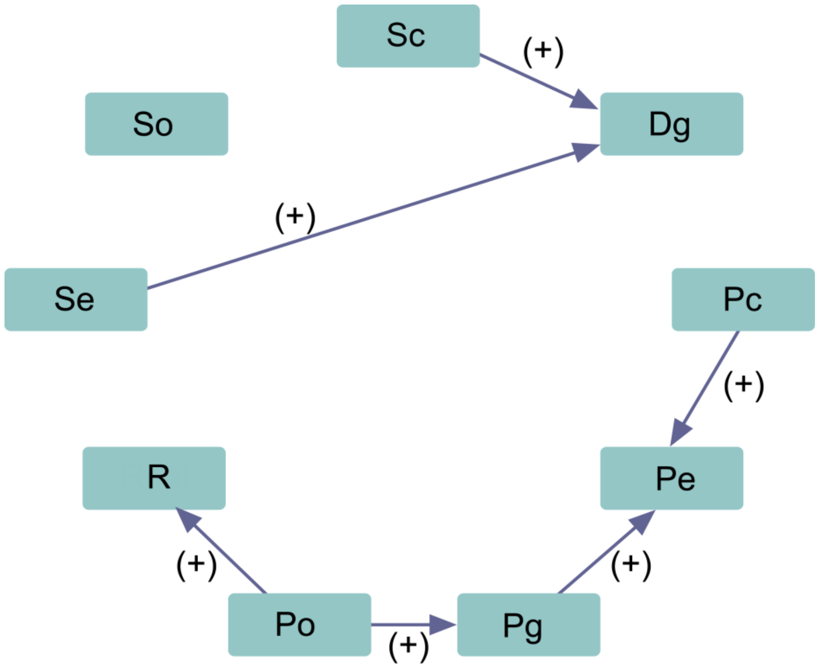

Figure 4.3. Directed Acyclic Graph

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1. Summary of Conclusions

This study investigates three related issues on U.S. corn-based fuel ethanol markets. The primary objectives involve measuring economic consequences of relaxating the blend wall, building a theoretical framework for the inter-linkage between the fuel and food markets, analyzing the food vs. fuel literature, methodologies and policies for the food before fuel nexus, and addressing the food before fuel debate by empirical studies.

As a renewable biofuel, ethanol has been used in the U.S. for more than one hundred years. Especially during the past thirty years, government policies such as U.S. Energy Tax Act, Volumetric Ethanol Exercise Tax Credit, Clean Air Act Amendments, the ban of MTBE, Renewable Fuels Standards enhanced and promoted the development of the ethanol industry. Among these government incentives and regulations, of particular concern is the relaxation of the blend wall. In October 2010, EPA partially increased the blend wall from 10% to 15% to post 2007 vehicles. Although it is not questionable that an increase of the blend wall will foster ethanol production, whether the blend wall will hinder or assist the petroleum gasoline consumption is still under debate. In a pure ceteris paribus framework, the most popular predictions and economics theories projected that with a relaxation of the blend wall, less petroleum gasoline will be consumed leading to a greater energy security. Yet in our research, considering the interplay with different blends, we argued that relaxing the U.S. blend wall might lead to an anomaly-more U.S. petroleum gasoline might be consumed under plausible conditions. Based on the theoretical model built in a companion paper published in Energy Policy (2010), empirical investigations including both benchmark values calculations and Monte Carlo simulations are conducted. Consistent with the comparative statics results in the theoretical model, both benchmark and Monte Carlo calculations indicate that an increase in the blend wall is prone to result in an increase in the price of ethanol, E85, while lowering the price of low ethanol blends. These price effects attribute to a higher demand of ethanol, an increased supply of low ethanol blends, and a lower supply of E85. A price wedge between low ethanol blends and E85 will be profound with a relaxation of the blend wall, leading to a potentially retarding the adoption of flex-fuel vehicles. In the benchmark calculations, 74% ethanol is found as a cutting off level, under which any increase of the blend wall will result in an increase of the petroleum gasoline consumptions rather than a decrease.

Under the current blend wall cap, this result of a positive shift of the blend wall will likely elicit more petroleum gasoline consumptions, indicating theoretically the expansion effect offsets the substitution effect, and gasoline and ethanol are complementary rather than substitute. This is counter to the popular prediction that a relaxation of the blend wall will likely enhance energy security through consuming less imported petroleum gasoline. Instead, our results forecast greater prominent energy insecurity problems in the future. Monte Carlo simulated probabilities for a shift in the blend wall to increase total gasoline consumption conform to the benchmark calculation results. The results indicate that when the blend wall is greater than 70%, the possibility of a positive value for the elasticity of petroleum gasoline with respect a blend wall shift overwhelms the corresponding possibility of negative values.

Food before fuel issue is another potential external cost of the expansion of the ethanol industry. Different from the most popular statement that the food price spikes during 2007-2008 are attributed to the direct competition between biofuel production and foodstuff supply, we conduct analysis in a supply-demand framework, and lay out evidence to support the hypothesis that 2007-2008 agricultural commodity price spikes were the consequences of the fundamental market powers of demand and supply. In the short-run, the agricultural commodities prices increase from the agricultural demand or other demand shocks (such as biofuel demand shocks). While in the long-run, global competitive agricultural commodities markets will adjust, restoring prices to their long-run trends. But there might be a lag time in such response.

How supply and demand as well as other factors (such as macroeconomic activities) affecting the ethanol price volatilities in previous literatures are summarized and compared. Considering the restrictions of the exogenous determined elasticities in the widely used Computable General Equilibrium (CGE) models, time-serious econometrics models are less restrictive and will provide empirical results addressing the food vs. food issue.

Based on a supply/demand framework and the hypothesis above, a Structural Vector Autoregression (SVAR) model is employed to capture the inter-linkage between the food and fuel market in the short- and long-run. With a consideration of the fossil fuel market (crude oil, gasoline), biofuel market (ethanol), macroeconomic activities and the food market, SVAR models with identified shocks are established. With the dominance of corn-ethanol production in the U.S., corn is used as a proxy of agricultural commodities. Structural impulse response (SIRF) functions basically support the hypothesis that in the short-run positive demand shocks tend to elicit instant increases in the corn prices, while those price effects are not persistent, fading out in the long-run. Structural error forecast variance decompositions (SEFVD) indicate that although proportions of the corn price variations explained by each structural supply/demand shock varies in the short-and long-run, corn demand shocks governed the most. This indicates that although the current U.S. government choices and incentives are more tilted to biofuels rather than foodstuff, ethanol demand shocks only yield fairly small impacts on the corn price volatilities. Thus the direct competition between food and fuel might be marginal or even questionable.

Directed Acyclic Graphs (DAGs) capture causal flows between the food and fuel markets strengthen our findings in the SIRFs and SEFVDs, and support the existence of “pass-through” effects between the food and fuel markets. A complementary relationship between ethanol and gasoline is detected as a byproduct, conforming to the theoretical and empirical results in the ‘blend wall’ analysis.

In conclusion, this dissertation makes three primary contributions to the energy economics research:

First, it provides both theoretical and empirical investigations on how the relaxation of the blend wall affects the related fuel markets. Rather than a simple “YES” or “NO” choice, this study provides new insights into the economic consequences of the U.S. ethanol regulations : with a consideration of the interplay between different blends, we propose theoretically that, an increase of the blend wall will lead to either more or less petroleum gasoline consumptions under different plausible conditions. An anomaly that a relaxation of the blend wall results in more petroleum gasoline consumptions might take place under the current blend wall cap. Therefore, a critical concern is addressed: care should be taken by EPA in considering the potential effects of the U.S. ethanol regulations, and an increase of the blend wall cap from 10% to 15% might not be a sustainable choice for the energy sector.

Second, this study builds a theoretical framework to capture the inter-linkage between the food and fuel markets, and extends SVAR model to capture the dynamic interactions to the corresponding empirical studies. So far, the most dominant method used in addressing the food before fuel issues is CGE models. However, CGE models usually fail to precisely illustrate the time trends and price volatility, and can not be directly applied to the estimation at a particular point in time (Ignaciuk and Dellink, 2006). Furthermore, CGE models rely on exogenously determined elasticities, which might bring more challenges to distinguish the short- and long-run impacts. VECM and VAR models are employed as well in some literatures, but it is generally difficult to distinguish contemporaneous supply-demand linkages and isolate macroeconomic impacts in these models. SVAR models could mitigate these shortcomings, and are efficient in capturing unpredictable changes in supply/demand within the food and fuel markets, as well as macroeconomic indicators.

Third, DAG is used as a new tool for the causality analysis in food before fuel issue. Compared to the Granger causality test that is only valid within a two-dimensional system, DAG pictures contemporaneous causality flows (including both direct and indirect causality relationships) within the food market-macroeconomic activities-fuel market system.

5.2. Policy Implications

Based on the results, there are multiple implications that government policy makers may want to consider. Both theoretical models and empirical studies indicate that under the current U.S. blend wall cap, a relaxation of the blend wall is prone to increase rather than decrease U.S. petroleum consumption, leading to greater insecurity risks and potentially retarding the U.S.

flex-fuel vehicle adoptions. Therefore, in the long-run, strategies might be taken to retain the current blend-wall blend wall restrictions on conventional non-flex fuel vehicles and thus reduce any comparative advantage conventional vehicles have over flex-fuel vehicles. Current market forces show that E85 is not price competitive with gasoline. Policies should then be directed toward discouraging the driving of conventional vehicles and providing incentives for increased availability and consumer willingness to use alternative fuels (such as subsidies). For a continued viable renewable fuels sector, the ethanol industry should direct their efforts toward policies that discourage conventional fueled vehicles and encourage alternative fuels.

For the food before fuel nexus, our results indicate that although decentralized competitive markets respond to the structural demand shocks instantly, these price effects fade out gradually in a long-run. Decentralized competitive markets restore the price to the long-run equilibrium level although a time lag usually takes place. Therefore, within the supply-demand framework, the issue is how rapid the supply responses and what is its magnitude. If supply is able to rapidly respond to a demand shift, then there is no food before fuel issue. If not, then there is cause for concern. The underlying driver of the 2007-2008 food price spikes was the lack of sufficient food stocks to rapidly buffer the price spike and avoid a food before fuel issue. Thus in a short-run, it is very important to ensure the food availability to all, especially to the poor who spend a larger share of income on food. Although in the long-run, market will adjust, in cases of global supply shortfalls, such adjustments come at a high price. Public policies such as increasing food stocks should be considered and designed as a tool to reduce food price volatilities. Furthermore, technologies targeting increases in agricultural commodity supplies (such as reduced tillage technology, improved drying and irrigation systems, and efficient application and timing of fertilizers) should be encouraged and promoted.

5.3. Suggestions for Future Research

More work could be improved or conducted in several directions.

First, although mandated quota and RINS are considered in the theoretical model, they are excluded in the empirical analysis, indicating that a representative blender just produces at the mandated quota. This might be not necessarily satisfied in the real productions.

Second, all parameter elasticities used in this study are based on previous literature. In this study, monthly data of quantities and prices are from May, 1989 to February, 2011, and we use values observed in February, 2011 as the corresponding benchmark values. However, parameter elasticities collected from previous literature were estimated within different time ranges along with some specific assumptions or conditions that might not generally necessarily held. Thus, all the parameter elasticities employed could just be considered as the “second-best” choice. For more accurate estimates, updates of those parameter elasticities are desirable and necessary.

Third, an extension from the U.S. food and food market to the global economy is meaningful and warranted. In this study, empirical analysis on inter-linkages between the food and fuel markets is only conducted within the U.S. market, while results might differ in other countries or world as a whole. In the U.S., most of the ethanol is corn-based, while in Brazil and globally, ethanol is mainly refined from sugar. Thus an extension to different countries and conducting a relevant comparison would enhance our understanding of the relationship between the food and fuel markets as well as provide more valuable policy implications for policy makers.

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