ESSAYS ON AGRICULTURAL ADAPTATION TO CLIMATE CHANGE AND ETHANOL MARKET INTEGRATION IN THE U.S.

A Dissertation

by

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Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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December 2012

Major Subject: Agricultural Economics

ABSTRACT

Climate factors like precipitation and temperature, being closely intertwined with agriculture, make a changing climate a big concern for the entire human race and its basic survival. Adaptation to climate is a long-running characteristic of agriculture evidenced by the varying types and forms of agricultural enterprises associated with differing climatic conditions. Nevertheless climate change poses a substantial, additional adaptation challenge for agriculture. Mitigation encompasses efforts to reduce the current and future extent of climate change. Biofuels production, for instance, expands agriculture's role in climate change mitigation.

This dissertation encompasses adaptation and mitigation strategies as a response to climate change in the U.S. by examining comprehensively scientific findings on agricultural adaptation to climate change; developing information on the costs and benefits of select adaptations to examine what adaptations are most desirable, for which society can further devote its resources; and studying how ethanol prices are interrelated across, and transmitted within the U.S., and the markets that play an important role in these dynamics.

Quantitative analysis using the Forestry and Agricultural Sector Optimization Model (FASOM) shows adaptation to be highly beneficial to agriculture. On-farm varietal and other adaptations contributions outweigh a mix shift northwards significantly, implying progressive technical change and significant returns to adaptation research and investment focused on farm management and varietal adaptations could be quite beneficial over time. Northward shift of corn-acre weighted centroids observed indicates that substantial production potential may shift across regions with the possibility of less production in the South, and more in the North, and thereby, potential redistribution of income. Time series techniques employed to study ethanol price dynamics show that the markets studied are co-integrated and strongly related, with the observable high levels of interaction between all nine cities. Information is transmitted rapidly between these markets. Price seems to be discovered (where shocks originate from) in regions of high demand and perhaps shortages, like Los Angeles and Chicago (metropolitan population centers). The Maximum Likelihood approach following Spiller and Huang's model however shows cities may not belong to the same economic market and the possibility of arbitrage does not exist between all markets.

DEDICATION

To the one whom I complete, Fortune,

and to the offspring the Lord has blessed us with, Ofure and Omose.

> “So then it is not of him that wills, nor of him that runs,
> but of God that shows mercy” (Romans 9:16).

ACKNOWLEDGEMENTS

First and foremost, I am most grateful to Dr. Bruce McCarl, the chair of my PhD advisory committee, who first introduced me to the major ideas and methods that enabled this research. The opportunity to work on a number of projects and his consistent guidance, mentoring, and financial assistance made a big difference in my stay at Texas A&M University. I am particularly grateful for his prompt feedback and constructive criticism on my manuscript along the way. Clearly, the outcome of this dissertation has largely been as a result of his support, resourcefulness and encouragement. I would like to thank specially Dr. David Bessler for serving on my committee, his very helpful comments and corrections on Time Series analysis, for making every visit to his office meaningful, and for the honor of hooding me at the graduation ceremony. Many thanks also to Drs. Jianbang Gan and Ximing Wu for agreeing to serve on my committee, and being available to provide guidance whenever needed.

The Schlumberger Faculty for the Future fellowship thankfully provided funding for four years, without which I would not have carried on with the PhD program, and to the Schlumberger Foundation I remain indebted. Many thanks go to Paul Conant for his advice and help with editing and formatting this document, and Dr. Samiran Sinha as well as Juan Monge for research support. I also want to extend my gratitude to Jean

Claude Bizimana, Yuquan Zhang, Mark Musumba, Rajorshi Sen Gupta and Padmaja Pancharatnam, not just for their friendship, but for their collaboration and contributions to my research. Thanks also go to my friends and close colleagues (Witsanu Attanavich, Yasser Bhoulal, Rafael Costa, Randi Hughes-Fraire, Somali Ghosh, Zafarbek Ahmedov), office mates (Jun Cao and Layla Shiva), and the Agricultural Economics department faculty and staff (especially Dr. Jerry Cornforth, Dr. Shelly Peacock, Dee Cochran and Suzy Pryor) for making my time at Texas A&M University a great experience. I'm grateful for friends like Funmi, Ignacie, Ololade, Adannaya, Nadine, Sade, Nwanneka, Edward, Chioma, and Unoma, among others, for the various degrees of inspiration and sacrifice made to help me along the way. I appreciate the friendship and encouragement of several other friends and relatives in Nigeria, the U.K. and also all over the U.S., who cared to call, write or pray for me.

Copious thanks to my amazing parents, Dr. Isaac and Professor Elizabeth Amuta for their prayers, encouragement and immense support during my PhD journey. Thanks for continuing to mentor me towards greatness. Also, special thanks go to my siblings: Joshua, Joy, Paul and Ann, for praying and cheering me on. Finally, I would like to thank my husband Fortune, for his remarkable patience, love and the countless sacrifices he and our kids have had to make; the emotional support, companionship and joy they bring to my life everyday keeps me going. Thank you!

NOMENCLATURE

ADF	Augmented Dickey-Fuller
CB	Corn Belt
CC	Canadian Global Circulation Model
CV	Coefficient of Variation
CSIRO	Commonwealth Scientific and Industrial Research Organization
DAG	Directed Acyclic Graph
DOE	Department of Energy
ECM	Error Correction Model
FASOM	Forestry and Agricultural Sector Optimization Model
FEVD	Forecast Error Variance Decomposition
FTC	Federal Trade Commission
FULL	Sum Total of Physical Adaptations
GCM	Global Circulation Model
GHG	Greenhouse Gas
GP	Great Plains
HC	Hadley Global Circulation Model
HQ	Hannan and Quinn’s Measure
IPCC	Intergovernmental Panel on Climate Change
LS	Lake States
MGT	On-farm Management and Varietal Adaptations

MIX	Crop Mix Migration
MLE	Maximum Likelihood Estimation
MTBE	Methyl Tertiary Butyl Ether
NE	Northeast
OPIS	Oil Price Information Service
PAL	Price in Albuquerque
PC	Peter and Clark
PCH	Price in Chicago
PCR	Price in Cedar Rapids
PDV	Price in Denver
PHO	Price in Houston
PIN	Price in Indianapolis
PLA	Price in Los Angeles
PMN	Price in Minneapolis
PNWE	Pacific Northwest
PNWW	Pacific Northwest
PSE	Price in Seattle
PSW	Pacific Southwest
REGCM	Regional Climate Model
RFS	Renewable Fuel Standard
RM	Rocky Mountains
SC	South Central

SD	Standard Deviation
SE	Southeast
SEPTC	Small Ethanol Producer Tax Credit
SL	Schwartz Loss
SW	Southwest
UNFCCC	United Nations Framework Convention on Climate Change
U.S.	United States
USGCRP	U.S. Global Climatic Change Research Program
VAR	Vector Auto Regression
VEETC	Volumetric Ethanol Excise Tax Credit

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Climate factors such as precipitation and temperature, being closely intertwined with agriculture, make a changing climate a big concern for the entire human race and its basic survival. There is a scientific consensus that human greenhouse gas (GHG) emitting activities are changing our climate (IPCC WG I 2007). There is a need to explore the many options and opportunities to adapt to such a changing climate (adaptation) plus reduce current and future GHG net emissions (mitigation).

Adaptation, the process of adjusting to a changing climate, encompasses a broad set of activities designed to reduce human and ecosystem vulnerability to the potential short and long-term impacts of a changing climate (Vajjhala 2009). Adaptation to climate is a long-running characteristic of agriculture evidenced by the varying types and forms of agricultural enterprises associated with differing climatic conditions. Nevertheless climate change poses a substantial, additional adaptation challenge for agriculture perhaps at an unprecedented pace.

Mitigation encompasses efforts to reduce the current and future extent of climate change. Biofuels, for example, have become increasingly important as a possible mitigation alternative since they replace GHG emitting fossil fuel use. The market for one biofuel, ethanol, has expanded rapidly in the U.S. within the last decade. Indeed, expanding demand, increasing oil prices, and instability in oil-exporting countries plus heightened concerns about climate change, have led to considerable efforts to promote biofuels as an alternative to fossil fuels.

This dissertation which will address economic aspects of the adaptation and mitigation issues, with a specific focus on: (1) economic aspects of agricultural adaptation to climate change, (2) modeling and valuing of agricultural adaptation alternatives, and (3) characteristics of the U.S. ethanol market. This section briefly introduces the essays and the objectives of each.

Essay 1 examines and synthesizes the literature on economic aspects of agricultural adaptation in terms of needs for adaptation, evidence on observed adaptation practices, approaches to quantitative analysis of adaptation, and findings from quantitative analysis of adaptation. Essay 2 is closely tied to Essay 1. Essay 2 expands on essay 1 by carrying out quantitative analysis on the costs and benefits of select adaptations. These adaptation possibilities will be examined in using a partial equilibrium model for the U.S. agricultural sector in which climate-change scenarios are taken into account. Results highlighting changes in welfare, production, prices, land use changes, etc., will be presented.

Essay 3 is a study that aims to measure market integration, characterize dynamic price information flows, and establish the ways the market for ethanol differs between producing and consuming states. Market extent measurement gives a snapshot of how integrated markets are, which is very important. The arbitrage-cost approach following

Spiller and Huang (1996) will be used. In addition, time-series techniques will also be carried out to measure market integration and thereby substantiate or refute results obtained from using the Spiller and Huang model.

The main objectives for this thesis include the following:

- Examine comprehensively scientific findings on agricultural adaptation to climate change. This will be accomplished by synthesizing the literature on agricultural adaptation to assess what has been investigated and what research needs are;
- Develop information on the costs and benefits of select adaptations to examine (by quantitative analysis) what adaptations are most desirable, for which society can further devote its resources;
- Study how ethanol prices are interrelated across, and transmitted within the U.S., and the markets that play an important role in these dynamics. This will be accomplished by analyzing in terms of the extent, integration and dynamic price information flows, the market for ethanol in select U.S. cities.

2. AGRICULTURAL ADAPTATION TO CLIMATE CHANGE*

The total burden of climate change consists of three elements: the costs of mitigation (reducing the extent of climate change), the costs of adaptation (reducing the impact of change), and the residual impacts that can be neither mitigated nor adapted to (Parry et al. 2009)

Climate change and issues arising from its impacts and the ability to adapt to and mitigate these impacts in different sectors of any economy continue to be significant globally, especially with regards to quantifying costs, residual damages, investment decisions and the policy implications resultant. The uncertainties that surround climatic predictions and the need for more robust results highlight the sustained need for further research in this field of study.

Adaptation to climate is a long-running characteristic of agriculture evidenced by the varying types and forms of agricultural enterprises associated with differing climatic conditions. Climate change, however, poses a substantial, additional adaptation challenge for agriculture (broadly defined here to include forestry) which will likely stimulate further shifts in location of production and processing, changes in management

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*This section is an extended version of: Aisabokhae, R.A., B.A. McCarl, and Y.W. Zhang. 2012. "Agricultural Adaptation: Needs, Findings and Effects", in *Handbook on Climate Change and Agriculture*, Edited by Robert Mendelsohn and Ariel Dinar, Edward Elgar, 2012.

and altered research needs, along with other influences (McCarl 2007; Antle 2009). Adaptation has been defined as an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects which moderates harm or exploits beneficial opportunities (IPCC WGI 2001). Adaptation may include reducing and transferring climate risks, as well as building the capacity to make changes in the future (Patt et al. 2010). Adaptation can be anticipatory or reactive, in addition to being planned or autonomous, among other characterizations as discussed subsequently.

Adaptation is rapidly evolving and there is a need to assess what has been investigated and what needs to be done. An improved understanding of the potential implications of climate change and adaptation options for U.S. agriculture will assist policy makers and farmers alike, in facing the adaptation challenge and developing strategies to reduce the vulnerability of the sector to climate change. Knowledge from scientific research and practice with regards to adaptation is crucial for planning and decision-making, particularly within the context of realized and anticipated climate change impacts, and associated uncertainties. Hence this essay as its main objective, examines comprehensively scientific findings on agricultural adaptation to climate change in terms of (a) needs for adaptation, (b) evidence on observed adaptation practices, (c) approaches to quantitative analysis of adaptation, and (d) findings from quantitative analysis of adaptation.

This work also sets the background for essay 2 in Section 3.

2.1 Background and Literature Review

Impacts of climate change on agriculture can be partially addressed through adaptation. Understanding the background on climate change and the basis of adaptation, by reviewing literature focused on the agricultural sector is the goal of this section. In this manner, relevant information for interested parties and decision makers concerned with timely and efficient climate change adaptation policy and implementation is provided.

2.1.1 The Inevitability of Adaptation

A substantial degree of climate change appears inevitable. Efforts to limit greenhouse gas (GHG) emissions are emerging slowly while emissions continue to rise rapidly; besides, it appears that given projected socioeconomic growth and lags in shifting the energy system, it is almost certain that emissions will continue to grow for some time to come, causing substantial climate change (see IPCC WGIII 2007 or Rose and McCarl 2008). Furthermore even if net emissions fell to zero it would take a substantial time for the climate and atmospheric system to reach equilibrium (Stern 2006). The IPCC WGI (2007) report contains projections indicating that if concentrations stabilize at 2000 levels, then global average temperatures would increase by 0.3 to 0.9 degrees Celsius in 2090–2099 relative to 1980–1999, but emissions continue to grow while the 2010 NRC report shows stabilization takes a reduction of emissions to quite low levels and is likely to take considerable time. As a consequence, it is likely that concentrations will reach a high level causing considerable realized climate change (IPCC WGIII, 2007). Thus it is apparent that the need for agricultural adaptation is inevitable (as argued in Rose and McCarl 2008).

Actions to adapt to climate change can be viewed as a response by economic decision-makers to incentives created by climate change, and the net benefits to those actions can be expressed as follows:

$$\text{Net expected benefits of adaptation} = \text{perceived gains from adaptation} - \text{costs of adaptation.}$$

The simple logic of rational decision makers taking adaptive actions when net expected benefits of adaptation are positive underlies the quantitative analysis of impact and adaptation (Antle 2009). This also goes to show that although adaptation reduces the damages due to climate change, there are also costs involved that are usually greater than zero.

2.1.2 Adaptation Nomenclature and Characterization in Literature

Figure 1 illustrates the taxonomy and understandings of adaptation found commonly in literature. The rest of this section provides brief explanations of adaptation classifications which typically overlap between categories. Each of these categories will be discussed below:

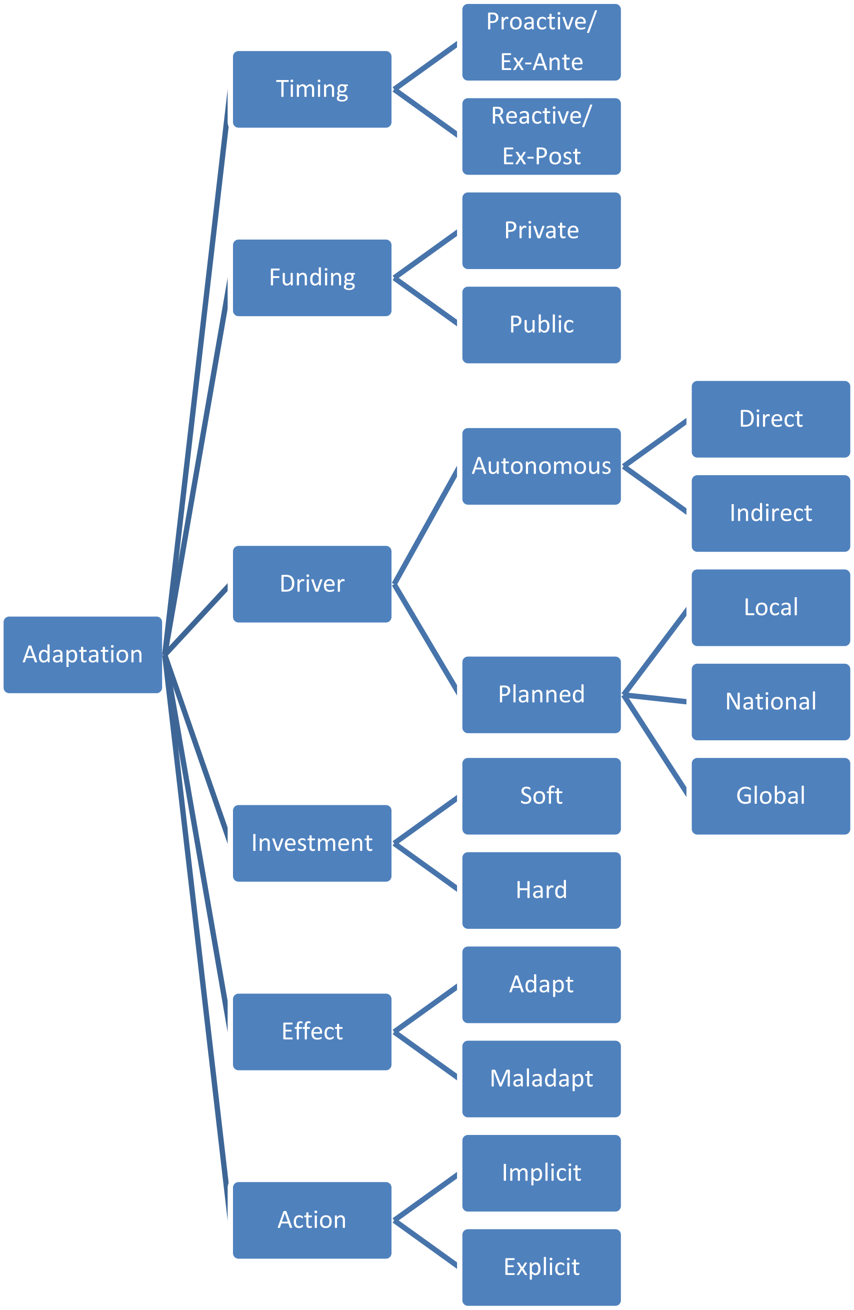

Figure 1. Characterization of adaptation

2.1.2.1 Timing

Adaptive action taken before climate change in anticipation of its negative effects is referred to as proactive or anticipatory adaptation, whereas reactive adaptation is in response to climate change impacts. Reactive adaptation options according to de Bruin et al. (2011) includes such actions as using more water (where irrigation systems are in place), changing crop varieties of types to other more heat-resistant ones, or changing the planting times of the crops. Examples of proactive adaptation measures include investments in irrigation systems or investments in the development of different more heat-resistant crop types. Burton, Diringer and Smith (2006) state that, since reactive adaptation is informed by direct experience, resources can thereby be targeted to known risks. They add that in dealing with future risks "uncertainties in the extent, timing, and distribution of impacts make it harder to determine the appropriate level of investment, exactly what measures are needed, and when."

2.1.2.2 Funding

According to IPCC (2001), adaptation that is initiated and implemented by individuals, households or private companies is private adaptation, while there is also public adaptation that is initiated and implemented by governments at all levels. Whereas private adaptation is usually in the actor's rational self-interest, public adaptation is usually directed at collective needs (IPCC 2001).

2.1.2.3 Drivers

Private adaptation is also often referred to as autonomous or spontaneous adaptation undertaken by individuals or species in response to climatic stimuli, often triggered by ecological changes in natural systems and by market or welfare changes in human systems (IPCC 2007). Public or planned adaptation is typically the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain or achieve a desired state (IPCC 2007). The distinction between autonomous direct adaptation and autonomous indirect adaptation, according to Aaheim and Aasen (2008) is as follows: while the former can be described as changes that market participants or individuals make as part of their economic behavior when confronted with climate change, the latter is a result of the market effects spurred by climate change (for example, knock-on effect of climate change impacts in one sector on other sectors, thereby affecting prices and consequently production). Planned adaptation which operates within public policy frameworks could be on a local or national scale as regards individual countries; however, international effort such as the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) Adaptation Fund is an international or global effort at enhancing adaptation to climate change impacts.

2.1.2.4 Investment

The World Bank's "Adaptation Guidance Notes—Key Words and Definitions" (World Bank, 2010) discusses investment items in terms of hard and soft items. They indicate hard adaptation measures usually imply the use of specific technologies and actions involving capital goods, such as dikes, seawalls and reinforced buildings, whereas soft adaptation measures focus on information, capacity building, policy and strategy development, and institutional arrangements. Hard adaptation is often irreversible and typically entails heavy capital outlay (capital intensive) when compared with soft adaptation. Sedjo (2010) discussing forestry indicates soft adaptation might include policies and regulation to facilitate the "natural" migration and regeneration of the forest and this could include fire control. Although soft adaptation is harder to quantify, both approaches, according to the World Bank's economics of adaptation to climate change synthesis report (World Bank, 2010), are needed. The report states that "good policies, planning, and institutions are essential to ensure that more capital-intensive measures are used in the right circumstances and yield the expected benefits."

2.1.2.5 Effects

The effect or implication of adaptation activities on a system is initially somewhat uncertain—it could be positive, negative or neutral. A system is said to have adapted when changes occur in natural or human systems in response to tangible or anticipated climatic stimuli, or their effects result in ameliorating damage or exploiting beneficial opportunities (IPCC WGI, 2001). An action or process, however, which increases vulnerability to climate change-related hazards, is called maladaptation (World Bank, 2010). Government intervention, for instance in relief efforts, such as the capping of insurance rates in certain U.S. states and similar adaptation policies, although may provide immediate gains, do not serve to reduce climate change vulnerability in the long run.

2.1.2.6 Actions

Direct purposeful action targeted at reducing the impact of climate change or indirect adaptation where the ultimate purpose is concerned with reducing an impact of climate change is referred to as explicit adaptation, whereas, implicit adaptation comprises other actions that are likely to moderate harm or exploit opportunities from climate change without considering the issue of climate change directly (Stecker et al. 2011).

2.1.3 **Why Adapt: Climate Change Drivers and Effects on Agriculture**

Climate change drivers that affect agriculture can be roughly grouped into six categories:

- Temperature alterations that directly affect crop growth rates, livestock performance and appetite, pest incidence, plant evapotranspiration, soil moisture and reservoir evaporation, among other influences;
- Precipitation alterations that directly affect the water available to crops, the drought stress crops are placed under, the supply of forage for animals, irrigation water supplies, river flows supporting barge transport and pest populations, among other items;
- Changes in atmospheric CO2 as it influences the growth of plants by altering the basic fuel for photosynthesis as well as the water that plants need as they grow. It also alters the growth rates of weeds;

- Extreme events as they influence production conditions, destroy trees or crops, drown livestock, yield extended droughts, alter water supplies and influence waterborne transport and ports;
- Sea level rise as it influences the suitability of ports and waterborne transport, and inundates producing lands;
- Production changes due to climate change-motivated greenhouse gas (GHG) net emissions reduction efforts as they would influence resources available for adaptation and the costs of inputs plus add new opportunities for adaptation, for example, use of alternative sources of biofuels or wind energy.

Agriculture will need to adapt to these forces. IPCC WGII (2001) identified six determinants that will influence the degree of adaptation: (a) economic resources, (b) technology availability, (c) information and skills, (d) infrastructure, (e) institutions and (f) equity. Also relevant are degree of realized climate change, the amount of public and private investment undertaken, asset obsolescence, generated research findings, information availability and producer flexibility. As climate change becomes more apparent, laws and regulations that affect agriculture's ability to adapt may also change. The implementation of the GHG cap and trade policy for instance, although currently stalled in the U.S., has the potential to use land for afforestation and thus impact agricultural adaptation strategies that need land.

There are vast differences around the world in the availability of the aforementioned factors. For example, in the agricultural arena, differences can be observed in investment rates in agricultural technology research and diffusion despite a large need in terms of fundamental food supply (Pardey et al. 2006a; Pardey et al. 2006b; Roseboom 2004).

2.1.4 **Exploring Agricultural Adaptation**

2.1.4.1 Ongoing Adaptation

Agricultural adaptive management is fundamental and ongoing, potentially contributing to sustaining the livelihood of millions of people worldwide. Examples in this regard are:

- Crop production and the climate it faces vary substantially from year to year with, for example, the U.S. total corn production varying by 20-30 percent. This requires adaptations which are manifest in harvesting, fertilization, pest control, irrigation and other management practices;
- Beef production practices vary substantially from year to year with locally adequate sources of feed in some years and the need for large quantities of imported feed in others with consequent management alterations in diet composition and animal selling practices and/or regional migration;
- Forests are at much greater risk of fire in some years than others with adjustments possible through management and prevention practices;
- Pest populations become resistant to treatment practices with pest-treatment practices managed to slow growth of resistance and adapt as resistance emerges;

- Farmers have increasingly engaged in water markets as non-agricultural water scarcity has emerged with permanent sale and leasing markets arising;
- Income and health concerns have shifted dietary preferences with agriculture adapting in terms of livestock species composition and feeding practices plus the share of organic production;
- Increased energy cost and falling water tables have caused many farmers to adapt by using water conserving technologies;
- Changing climate conditions have led to northern expansions in corn and other crop production;
- Nomadic activities among livestock owners have increased especially in African countries bordering the Sahara desert as dryer and harsher climates have emerged.

As inherent in the above examples, sectoral management regularly adapts to:

- Long-run forces such as development of pest resistance to treatment methods, invasive species, consumer diet preferences, income effects on dietary choices, competition for water from municipal and industrial forces, early onset of climate change and changes in government policies;
- Short-run forces such as pest and disease outbreaks, El Niño Southern Oscillation events, drought and flood cycles and extreme event cycles, among numerous other forces.

2.1.4.2 Adaptation Activities and Roles

The influences of the climate change drivers above include the following adaptation possibilities:

- Climate change-induced autonomous reduction in crop and livestock yields and altered yield growth rates may cause alterations in crop and livestock mixes;
- Planned research investment devoted to creating practices and genetic stocks that maintain or enhance productivity at a site under altered climatic conditions;
- Investments in capital intensive agricultural practices that deal with a rise in temperature and/or decreased rainfall;
- Relocation of processing and transport facilities as a reaction to migrating cropping and livestock patterns;
- Extension activities that provide educational outreach and dissemination of adaptation strategies;
- Land use change that alter mix between cropping, livestock, forests, other natural areas and abandoned lands either to expand or contract current forms of agriculture.

These challenges are likely to be greater for developing countries where agriculture may be more susceptible to temperature and other climate changes, and where there is a lack of institutions to support adaptation. They will also place increased demands on producers, agricultural research, extension and infrastructure (McCarl 2007; Antle 2009; McCarl et al. 2010).

Some of the basic forms of adaptation and activities pursued within these structures are presented in figure 2. Climate change is expected to change price signals besides the yield effects, hence managers carrying out these adjustments indirectly respond to climate-induced price changes.

Activities to facilitate adaptation to changing climatic conditions can be undertaken by different parties at different levels of operation and take on diverse forms, the characteristics of which have implications for investment needs. Many of these adaptation possibilities would proceed without need for direct capital investment but several would require some mix of capital and research investments with almost all requiring information and technology dissemination. How much agriculture will need to adapt depends on the level of mitigation, anticipated potential local climate change, capacity to adapt and relative impacts on other regions (Rose and McCarl 2008).

2.1.5 **Magnitude of Adaptation Costs**

As outlined in Parry et al. (2009), several groups have endeavored to estimate the magnitude of needed costs (Oxfam 2007; Stern 2006; UNDP 2007; UNFCCC 2007; World Bank 2006) with the UNFCCC focusing on this most directly, including an agricultural estimate developed by McCarl (2007). Parry et al. (2009) reviewed these studies and had further developed the cost estimate, but concluded that these estimates were probably under-valued and that much more study was needed.

Agriculture Operators/ Fundamental Actors: involved in direct production/management and thereby make changes that facilitate adaptation to a changing climate

- Crop, forage and tree species/varieties and management
- Livestock species/breeds and management
- Moisture management/irrigation
- Pest and disease management
- Management of natural areas
- Fire management
- Land use or enterprise choice change

Industry-Level Private Adaptation: profit-seeking firms requiring minimal public investments to pursue various adaptation possibilities

- Input supply
- Processing
- Product transport
- Market trading

Public Facilitation of Private Adaptation: public-oriented investment by governments, international organizations, NGOs and international donors

- Research
- Extension and training
- Transitional assistance
- Trade policy
- Infrastructure development
- New laws and regulations

Figure 2. Possible adaptation actions

Unfortunately these costs are quite difficult to estimate as is the ability of regions to implement them due to the reasons listed in Parry et al. (2009) and IPCC WGII (2001):

- Adaptive capacity in terms of human and physical capital as well as resource base varies among regions and countries;

- Uncertainty in the link between investment and adaptation;
- Competing investment needs for food supply increases in support of growth and economic development versus adaptation;
- Non-exclusiveness- adaptations are typically not to climate change alone, with other environmental matters, food needs, pest evolution and other factors contributing. Unraveling the climate change component is virtually impossible.

To illustrate the magnitude of such costs we briefly review the investment cost estimates generated by McCarl (2007) which indicate that global agriculture, forestry and fisheries investment in research, extension and infrastructure needs to:

- Increase in total by 47.2 percent by 2030 to match the no-climate-change baseline caused by one third more people. This amounts to U.S. $520 billion or $260 in 2030 per new person;
- Increase by an added U.S. $12.9 billion without GHG mitigation to adapt to anticipated climate change;
- Increase by an added U.S. $11.3 billion when GHG emissions are mitigated to adapt to climate change, considered relative to the no-climate-change baseline.

It is also worth pointing out that the magnitude of these investments is large compared to the value of climate impacts and may turn some of the positive 'with adaptation' findings (such as those in McCarl 2006) to negative after considering the cost of developing and adopting adaptation (IPCC WGII 2007).

The cost of adaptation in developing countries is expected to be higher than studies have shown because of the limited capital, research and extension funding, investment in infrastructure and institutional capacity. These factors (amongst others) needed to bridge the ‘development deficit’ greatly impact the ability of developing countries to adapt to climate change compared with high-income countries (Parry et al. 2009; McCarl 2007).

2.2 Sources of Adaptation Funding for Agriculture

International donor funding, largely for research and extension, is expected to arise through the CGIAR system, donor agencies and the World Bank while private sources of financing could come from multinational seed, chemical companies (and other input companies), domestic producers and processing firms as well as through emissions permits revenues (McCarl 2007). The requisite balancing of public funding due to the need to allocate diverted resources towards a climate policy portfolio could result in synergies or tradeoffs within and with other sectors of the economy.

2.3 Approaches to and Findings from Quantitative Analysis of Adaptation

Early impact studies largely ignored adaptation, and though it was soon recognized that adaptation is a critical factor in determining impacts, quantifying adaptation remains a major challenge for modeling studies. Most recently, studies have begun to incorporate adaptation by simulating the effects of climate change without and with some form of adaptation, and comparing the results (Antle 2009). These studies have looked at various issues. For instance, the impact of market feedbacks, adaptation choices, and other modeling assumptions has been studied by Adams et al. (1999), Schneider and McCarl (2006) and Schneider et al. (2007).

Adaptation investigations in an agricultural context have taken on several different forms. Generally these are investigations based on:

- Observed data looking at the types of adaptation observed as climate varies;
- Biophysical simulators looking at how management options influence performance under climate change;
- Economic models that allow adaptation by including alternative production possibilities.

Each will be reviewed below with principal findings mentioned.

2.3.1 Adaptation Based on Observed Behavior

Adaptation behavior has been examined by looking at the way that observed farming practices vary over space and time as climate conditions differ using a spatial-analogue approach. The basic assumption is that one gains insight into how agriculture might adapt to climatic variations in a region by examining the ways certain factors vary over alternative locations with varying climatic conditions (Mendelson, Nordhaus and Shaw 1994; Chen and McCarl 2001; Seo and Mendelsohn 2008a, 2008b; Seo et al. 2009a; Seo et al. 2009b). A large number of studies based on real world observations have used this approach and some that have argued items related to adaptation include:

- Mendelsohn and Dinar (2003) who argue that observed behavior in Brazil and India shows smaller observed yield changes under climate change than agronomic results suggest, indicating that adaptation is present and effective;
- Chen and McCarl (2001) who find increased pesticide costs incurred as climate warms indicating adaptation to climate induced increased pest populations;
- Seo and Mendelsohn (2008b, c) who find that the mix of animals grown in Africa is climate sensitive with farmers adapting the livestock species that they raise in accordance with the climate they face. They also find an effect on crop choice (Seo and Mendelsohn 2008a);
- Seo et al. (2009a, b) who find that total livestock population increases as temperature and rainfall increase, but that the population declines when the weather is too wet. Further, they find a conversion from crops to livestock as temperature increases;
- Mu (2010) who finds that climate change influences choice of livestock species and allocation of land between pasture and crops and stocking rates;
- Tubiello et al. (2000) who find there are adaptations of varieties and planting times that avoid drought and heat stress during the hotter and drier summer months in Italy. Furthermore they estimate that these adaptations have avoided significant negative impacts on sorghum (-48 to -58 percent), moderating them to neutral and even marginally increasing positive impacts (0 to +12 percent). Figure 3 summarizes the effect of adaptation techniques on projected yield;

- IPCC WGII (2007) which finds from a review of evidence on the benefits of adaptation that adaptation can provide approximately a 10 percent yield benefit when compared with yields without adaptation, but that these benefits vary with crops and across regions;
- Other spatial and temporal examinations, while not explicitly examining adaptations, argue that their underlying models incorporate the effects of full farmers' adaptation (Deschênes and Greenstone 2007; McCarl et al. 2008; Dixon and Segerson 1999; Mendelsohn et al. 1994; Schlenker et al. 2005, 2006).

2.3.2 **Adaptation Modeling—Alternative Management**

A wide range of potential adaptations exist within agricultural systems that would help maintain or increase crop yields under climate change. Studies have been performed largely on cropping system management regarding the value of altered planting dates, harvest dates, varieties and so forth (e.g., Adams et al. 1995; Adams et al. 1999a; Easterling et al. 1993; and Tubiello et al. 2000).

The U.S. National Assessment study (Reilly et al. 2001; Tubiello et al. 2002) examined a fairly comprehensive adaptation set using crop models to test the effects of early planting, cultivars better adapted to warmer climates and irrigation strategies. These results indicate that crop yield reductions can be reduced or increases enhanced by adopting adaptation strategies.

Other findings that emerge are that:

- Howden et al. (2007) argue that marine fishery adaptation is limited, except for management changes in catch size and efforts. However it is possible that most fishing communities have developed coping capacity in accordance with fluctuating stocks caused by annual and decadal climatic variability (Brander 2005; IPCC WGII 2007; King 2005);
- Many studies have discussed the necessity of adaptation in water management systems but have not fully appraised the cost or feasibility of the adaptation options (Hayhoe et al. 2004; Hurd et al. 2004; Mote et al. 2003; Roy et al. 2001);
- Adaptive strategies to deal with climate change are beginning to be considered in conservation of ecosystems (Chopra et al. 2005; Lemieux and Scott 2005) and have emphasized the importance of planning guided by future climate scenarios (IPCC WGII 2007);
- Porter and Gawith (1999) and Wheeler et al. (2000) argue that variability in climate can have important and dramatic impacts on the productivity of cropping systems meriting additional adaptation efforts.

2.3.3 Adaptation—Economic Modeling

Economic decision-making models have been used to simulate possible adaptations. This approach, often referred to as structural, typically starts with climate-change-sensitivity estimates from field or individual plant-level crop-simulation models as well as estimates on livestock sensitivity and irrigation water supply from other models or experts. In turn, the estimated effects are incorporated as shifts in the production possibilities in an economic, possibly agricultural sector model which also contains adaptation options through changes in acreage, livestock numbers, livestock feeding, commodity supply, international trade and activity calendars. The economic models simulate behavior which seeks to maximize net farm income or, in national analyses, consumers' and producers' welfare such as illustrated in McCarl (2006). This approach has been applied to look at adaptation at the state (Kaiser et al. 1993), regional (Easterling et al. 1993) and national levels (Adams et al. 1995; Adams et al. 1998; Adams et al. 1999b; Adams et al. 1988; Adams et al. 1990; Butt et al. 2005; Butt et al. 2006; McCarl 1999, 2006; Reilly et al. 2001). In this case adaptation can only employ possibilities portrayed in the model, so it is important to have an augmented set of production possibilities that can be used in the face of climate change. A challenge is to identify and incorporate the range of adaptations which farmers might employ. This is further complicated given that innovations continue to arise as induced by price changes, and the fact that most studies have yet to incorporate the costs of investments in alternative strategies.

A number of findings have arisen from such studies:

- Adams et al. (1998) considered the impact of adaptations considering varietal-planting date-harvest date adaptations along with trade, crop mix, irrigation, and consumption. Their results indicate that adaptations to climate change can play an important role in mitigating adverse effects of climate change;

- Crop mixes and management practices have been found to shift in adjustment to direct and indirect climate change impacts (for example, northward migrations in crop mixes, or altered pest management regimes as discussed in Adams et al. 1998, Adams et al. 1999a, or Reilly et al. 2002);
- Adaptation can in certain cases switch yield and income effects from negative to positive in addition to greatly reducing the risk of hunger effects (Adams et al. 1995; Adams et al. 1999a; Butt et al. 2005; Butt et al. 2006; Easterling et al. 1993; Fischer et al. 2005; Kaiser et al. 1993; Reilly et al. 2001);
- Butt et al. (2006) examined adaptation through crop mix, international trade and technology (in the form of adapted crop varieties) in Mali, showing as depicted in figure 4 that up to 38 percent of the negative effects on welfare could be avoided;
- Producers in low-mid latitude forests have been found capable of adapting with more productive short-rotation plantings, driving down timber prices (Shugart et al. 2003; Sohngen et al. 2001; Spittlehouse and Stewart 2003; Weih 2004).

2.4 Strengths and Weaknesses of Basic Economic Approaches in Climate Change Studies

Most of the climate change impact studies have used biophysical and economic models in their assessments, while some have relied on differences in the observed climate in different regions as the basis of their impact assessment. Estimation of the potential economic vulnerability along with mitigation and adaptation responses, for instance, has been the subject of several economic studies employing a number of economic approaches (for example Mendelsohn et al. 1994; Adams et al. 1999). It is therefore important to classify and briefly discuss the foundations of these approaches highlighting their key strengths and weaknesses. Table 1 is a snapshot of the features of two basic economic approaches: the spatial analogue and the structural.

2.5 **Conclusions**

Essay 1 examined and synthesized the economic literature on agricultural adaptation in terms of needs for adaptation, evidence on observed adaptation practices, approaches to quantitative analysis of adaptation, and findings from quantitative analysis of adaptation. Literature shows the evidence of climate change and the need to adapt. Taxonomy and understandings of adaptation found commonly in literature are centered on timing, funding sources, drivers, investment needs, outcomes and range of actions. More specifically, the wide range of realized and possible adaptations found to exist within agricultural systems, goes to show that agricultural adaptive management is fundamental and ongoing, potentially benefitting millions of people globally. The majority of the studies reviewed show agricultural adaptation to be beneficial. It should be noted that adaptation investigations in an agricultural context have taken on several different forms including observed data looking at the types of adaptation observed as climate varies; biophysical simulators looking at how management options influence performance under climate change; and economic models that allow adaptation by including alternative

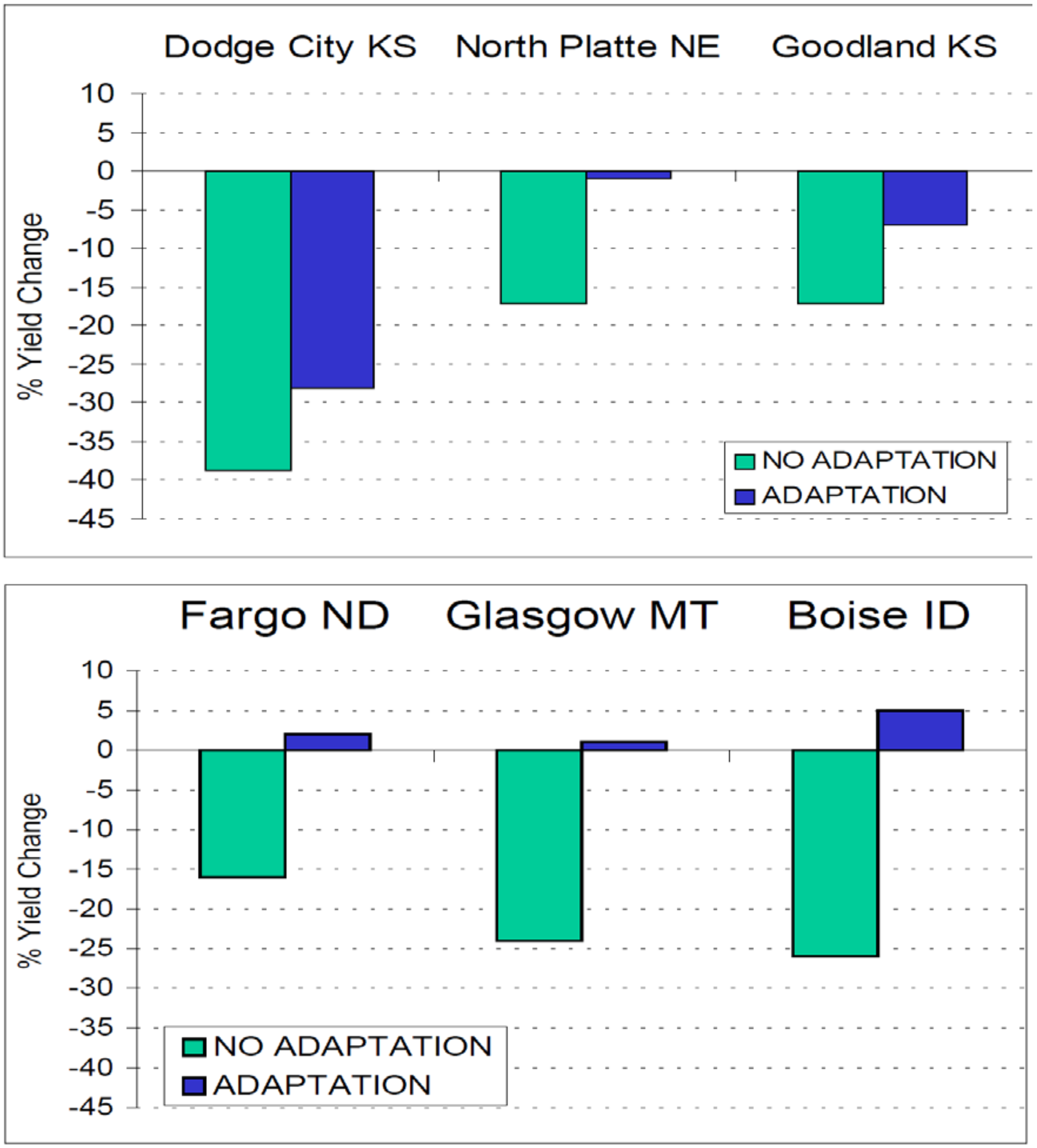

Figure 3. Examples of adaptation techniques and their effects on projected yields: adaptation for winter wheat (top figure) was a change of cultivar; for spring (bottom figure) was early planting

Source: Tubiello et al. (2000)

Table 1. Strengths and weaknesses of the spatial-analogue and structural approaches

	Spatial-Analogue	Structural
Strengths	• Based on observed behavior and as such relies on actual adjustments, changes in resource values and other systematic management/response attributes. • Incorporates adaptation to climate change to the extent to which climate change has been adapted to across space and time.	• Can depict adaptation and mitigation adjustments outside of historical observations as induced by climate change and market price responses. Also may be able to look at issues for which historical data are unavailable. • As far as accurate simulations come from crop and livestock productivity models, implications of adjustments to CO2 can be represented. • Market reactions are easily accommodated and can typically estimate changes in market conditions under climate change.
Weaknesses	• Cannot fully account for items which are expected to fall significantly outside the range of historic observation. • A key foundation is that farming practices, crop varieties, and cropping practices in warmer regions are transferable. • Largely assumes costless structural adjustment and full adaptation which may be infeasible. • Data availability can be an issue. • Market prices limit the amount of the production possibilities observed and large changes in prices may induce heretofore unobserved behaviors.	• Model structure fundamentally assumes the nature of behavioral responses. • A key assumption is that the full applicable range of actors' responses is included in the model. • Simulated climate effects often inaccurate. • Usually associated with higher cost implications. • Model size and complexity could be a limiting factor.

Source: Authors Illustration adapted from Aisabokhae et al. (2012)

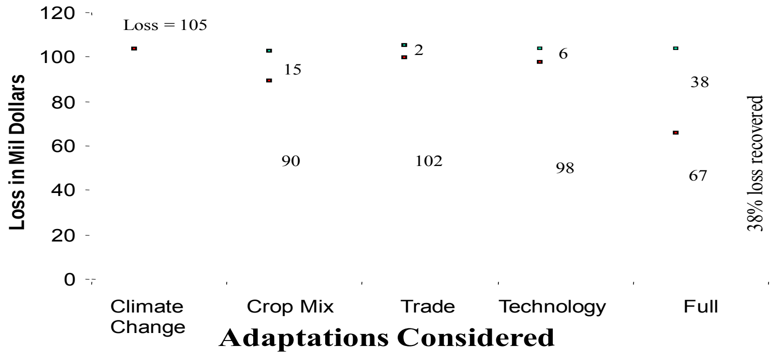

Figure 4. Value of adaptation ($ Million) in Mali

Source: Butt et al. (2006)

production possibilities. Finally, strengths and weaknesses of both the spatial-analogue, and structural approaches discussed, go to show that further work on modeling agricultural adaptation is needed.

The range of possible climate change adaptations as well as the elements of climate change which stimulate adaptation, besides the continued evolution of knowledge, raises a variety of research needs which include the following. On a broad scale, research needs, as gathered from literature, are that studies are needed which:

- Include the cost of adaptation in economic evaluations, as well as work on practical adaptation potential (IPCC WGII 2007);
- Examine the uneven distribution of climate change effects across the world and over time, developing localized and time-specific adaptation strategies;
- Examine adaptation costs (especially aspects of adaptation strategy development, investments in research), burden sharing with respect to adaptation investment that includes the funding of relevant research, and possible diminishing marginal returns;
- Address optimal degrees of adaptation and practical levels of the extent to which climate change vulnerability can be addressed;
- Address means for adapting existing crops and livestock, move varieties of heat-tolerant crops and livestock breeds into regions and alter management (McCarl 2007; Antle 2009);
- Examine new adaptation options through benefit-cost analysis and judge effectiveness using appropriate tools and approaches—not as an add-on, but as a potentially important factor in shaping adaptation decisions.
- Develop understanding of the process in which adaptation is taking place and will occur in the future (IPCC WGII, 2007);

- Examine means of adaptation to altered variability and the effects thereof which could be unpredictable. Parry et al. (2009) argue that this is a big challenge;

- Consider strategies to deal with climate change for unmanaged or passively managed production systems;

- Deal with resource and funds competition for food, energy, adaptation and mitigation;

- Examine levels of investment needed to insure a sufficient food supply given the factor productivity implications of climate change as found by McCarl et al. (2009);

- On a final note, estimations considering only mitigation or effects/adaptation options have a huge possibility of a bias because of the inter-connection between climate change impacts, adaptation and mitigation, motivating therefore the need to investigate the interplay between these policy elements.

Models of the cause-and-effect chain of climate change, often analyze long-time horizons—typically over 100 years—to suggest decisions to be made and strategies to be developed now (Patt et al. 2009). One challenge for modeling, and interpreting the results of models, is the great deal of uncertainty with respect to the costs of mitigation, climate damages, and climate adaptation (IPCC 2007; Parry et al. 2007). The uncertainties surrounding the science of climate change and the possible climate futures further compounds this problem.

Two major reasons nonetheless why more information on the value of adaptation strategies is required include:

- The need to design successful adaptation strategies to maximize the greatest net benefit.
- The need to provide relevant information to guide policy-making.

3. MODELING AND VALUING OF AGRICULTURAL ADAPTATION ACTIONS*

Policy makers according to Patt et al. (2009) need to know what the range of potential climate impacts will be at the scale that they are working, what actors (private and other public actors) might try to do to adapt, and given these potential futures, what the possible costs and benefits of their own policy options could be. To serve decisions being made at the global scale, for example, there are estimates being made of the adaptation financing requirements for developing countries, which necessarily identify particular adaptations as appropriate or feasible (UNFCCC 2007).

Adams et al. (1998) carried out a study that extended previous work by considering the impacts of farmer adaptations to climate change (amongst other objectives) and including more adaptation possibilities than used in previous climate-change assessments. Their uniform change assessment featured two "central case" scenarios to first illustrate in detail the range of economic effects arising from climate change: a benign (and perhaps optimistic) case and a more negative or adverse climate case; and secondly to employ in a series of sensitivity analyses relating to the role of farmer adaptations and export (world food production) assumptions. The magnitude of welfare changes for the optimistic case indicated welfare gains of $14.7 and $46 billion

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*This section was also developed alongside: Aisabokhae, R.A., B.A. McCarl, and Y.W. Zhang. 2012. "Agricultural Adaptation: Needs, Findings and Effects", in *Handbook on Climate Change and Agriculture*, Edited by Robert Mendelsohn and Ariel Dinar, Edward Elgar, 2012.

predicted for 1990 and 2060, respectively, whereas, the adverse case showed a loss of \$7.4 billion for 1990 and a gain of \$0.15 billion for 2060. The gains from favorable climate change were reported to be larger due to the more comprehensive treatment of adjustment possibilities such as the inclusion of new crops and migration possibilities in their analysis. Sensitivity analyses, based on historical evidence regarding farmers' behavior, indicated that potential farmer adaptations to climate change can play a role in mitigating adverse effects of climate change. This finding they conclude, coupled with the importance of technology and related assumptions, supports inclusion of such features in future economic assessments.

As mentioned above, the need to design successful adaptation strategies to maximize the greatest net benefit and to provide relevant information to guide policy-making is crucial. The necessity in examining what adaptations are most desirable behooves the undertaking of this study. The main objective of this essay is to develop information on the costs and benefits of select adaptations to examine (by quantitative analysis) what adaptations are most desirable, for which society can further devote its resources. To this end, an empirical study on the value of various types of adaptations following Adams et al. (1998) and Butt et al. (2006) will be conducted.

3.1 **Model Setup**

The Forestry and Agricultural Sector Optimization Model (FASOM) is a dynamic, non-linear, programming, price-endogenous model that depicts the resource transfers in the U.S. forestry and agricultural sector over a 70-to-100-year period (McCarl 2008). The

FASOM uses budgets to maximize the net present value of producer and consumer welfare across the agricultural and forestry sectors with inter-sectoral transfers and GHG modeling. The economic model output includes the production, processing, consumption, prices, trade, environmental and other economic indicators (McCarl and Spreen 2002). This model has the advantage of being flexible besides its capacity to incorporate more variables and equations.

To develop empirical estimates, the agricultural component of FASOM (Adams et al. 2005) was used to investigate climate change impacts on the U.S. crop-livestock sector with and without selected adaptation strategies. The specific adaptation strategies studied were (a) Shifts in crop varieties and planting schedules, (b) altered management practices such as irrigation water use, and (c) A 200-mile northward migration of crop mixes.

FASOM simulates the allocation of land over time to competing uses in the forest and agricultural sectors in the U.S. in addition to export markets, providing estimates of resultant consequences for the markets of commodities supplied by these lands (Adams et al. 2005). In doing so, outcomes resulting from both climate change and market forces are expected. The basic conceptual framework of the agricultural sector in FASOM is presented in figure 5.

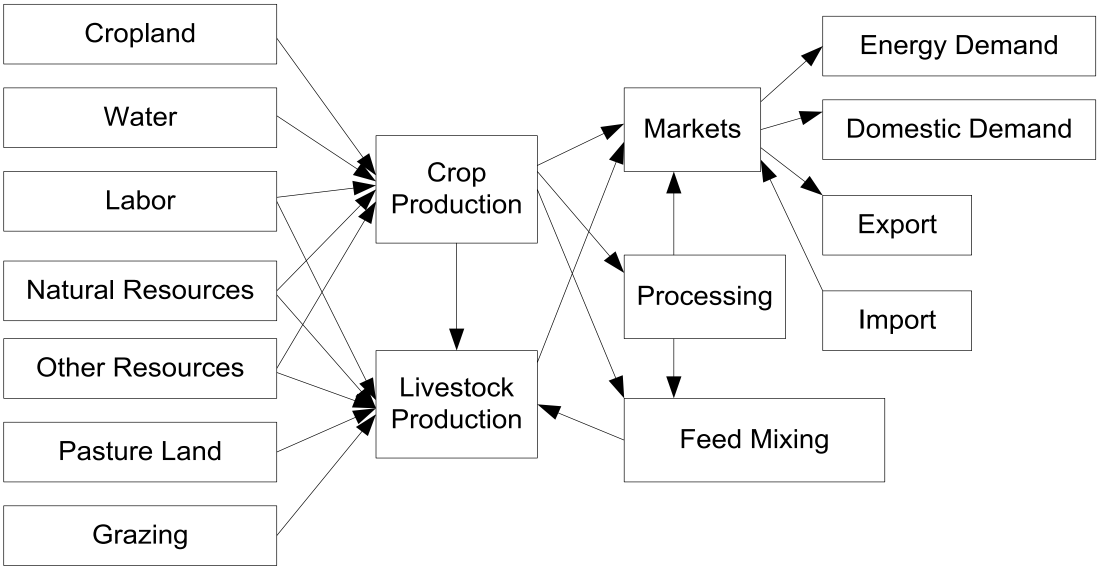


Figure 5. FASOM agricultural sector modeling structure

Source: Beach and McCarl (2010)

Following McCarl (2006), four GCM projections were employed: specifically, the Hadley and Canadian scenarios used in the U.S. Global Climatic Change Research Program (USGCRP) U.S. National Assessment (Reilly et al. 2001; Reilly et al. 2002; Reilly et al. 2003) as well as the CSIRO and REGCM (Mearns et al. 2003) scenarios were utilized in this study.

As summarized in McCarl (2006), the Hadley and Canadian scenarios fall in the middle and high end, respectively, of the 2001 IPCC projections of warming by the year 2100; the CSIRO model performs a reasonably good simulation of present-day climate over North America compared to other GCMs available (Mearns et al. 2003); and the REGCM model has the advantage of greater regional detail. The U.S. National

Assessment data on climate change effects (McCarl 1999; Reilly et al. 2001; Reilly et al. 2002) were used and included climate change effects on crop yield, irrigated crop water use, irrigation water supply, livestock productivity, grazing/pasture supply, grazing land usage, international trade and pesticide usage. Adaptations in the cropping system are considered using data of adaptation-adjusted performances simulated by crop models (Reilly et al. 2002; Tubiello et al. 2000; Tubiello et al. 2002). The specific scenarios run for this study are listed in table 2.

Table 2. Scenarios run

	Global Circulation Model Used	On-farm Management and Varietal adaptations	Crop Mix Migration
Base	None	None	None
cc_no_adapt	Canadian	None	None
hc_no_adapt	Hadley	None	None
regcm_no_adapt	REGCM	None	None
csiro_no_adapt	CSIRO	None	None
cc_adapt_crop	Canadian	Yes	None
hc_adapt_crop	Hadley	Yes	None
regcm_adapt_crop	REGCM	Yes	None
csiro_adapt_crop	CSIRO	Yes	None
cc_adapt_full	Canadian	Yes	Yes
hc_adapt_full	Hadley	Yes	Yes
regcm_adapt_full	REGCM	Yes	Yes
csiro_adapt_full	CSIRO	Yes	Yes

As detailed in table 2, under the base scenario, no climate change occurs. In scenarios without adaptation, water availability, yield rates, livestock performance and other factors change while in scenarios with adaptation, the yields and irrigation water use as well as the planting time, harvest time and varieties are adaptation adjusted. Notice that the term “MGT” refers to the crop management strategies mentioned earlier and the term “MIX” refers to the 200-mile northward movement.

3.2 Results and Implications

In the results below in this section, the term “market forces” refers to autonomous socioeconomic adjustments. Adaptation occurring endogenously within the model as a result of intertemporal economic forces elicited by market or welfare changes is autonomous. In other words, autonomous adaptation is that which is implicitly generated within the system, as the outcome of competitive market forces and market adjustments. “Physical” or planned adaptation encompasses on-farm endeavors- cropping management timing and varietal adaptations (MGT) and crop mix migration (MIX) with “Subtotal” as a sum of values added from “physical” adaptations. MGT is separated from MIX to highlight the contribution of both adaptation opportunities. “FULL” refers to a combination of MIX and MGT.

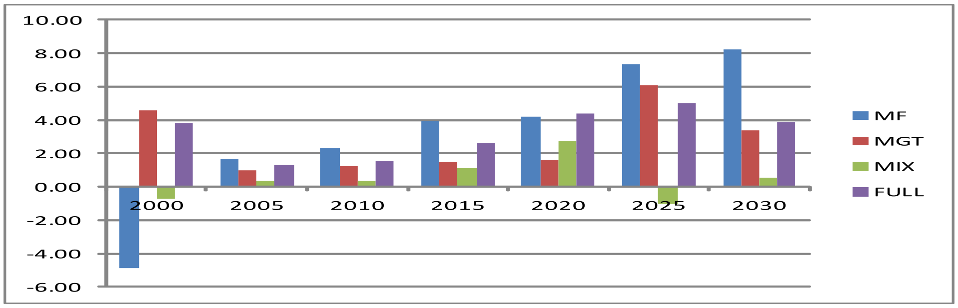
3.2.1 Welfare

Table 3 depicts the changes in aggregate welfare for all scenarios relative to the base. The value of adaptation is significant, especially in the Canadian and Hadley GCM scenarios with welfare increasing by up to $16 billion in the latter. Market forces can generate more than twice the value that MGT and MIX create together in some scenarios. In addition, irrespective of the scenarios examined, MGT contributions outweigh that of MIX. Also significant is the $12.47 billion increase due solely to socioeconomic adjustment, which is over 75 percent of the grand total of value-added welfare for the Hadley scenario. Finally, it is important to note that there might be important implications for inter-temporal as well as inter-regional income distribution that would require research and planning, regardless of the path climate change follows.

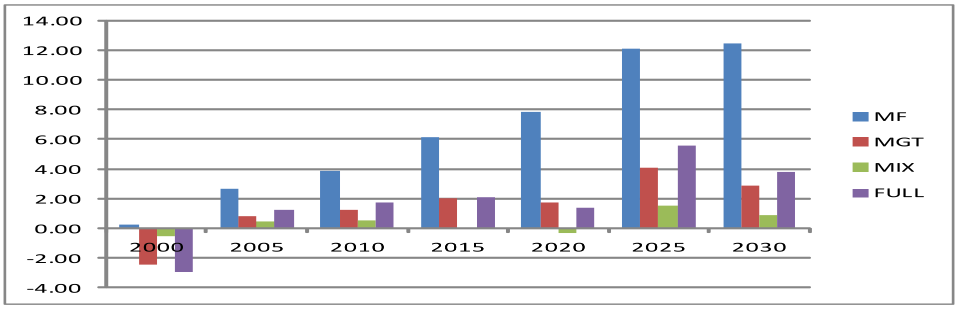
Table 3. Aggregate welfare changes in billions of 2004 dollars for 2030

GCM	Human	Physical			Total
	Market Force	MGT	MIX	Subtotal	
Canadian	8.24	3.35	0.52	3.87	12.11
Hadley	12.47	2.89	0.89	3.78	16.25
REGCM	1.70	1.47	0.91	2.38	4.09
CSIRO	1.13	1.44	1.06	2.50	3.62

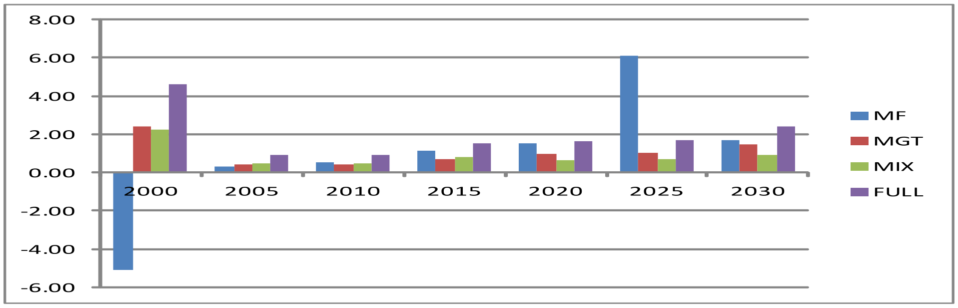
In the Hadley and Canadian model scenarios, as seen in figure 6, the peak of returns to physical adaptation (or FULL) is evident in 2025; however, this is the case for the REGCM and CSIRO scenarios in 2000. Figure 7 tells the same story by highlighting proportions of yearly contributions to a whole. It would appear for all scenarios between 2005 and 2020 that the value of adaptation increased at a diminishing rate.



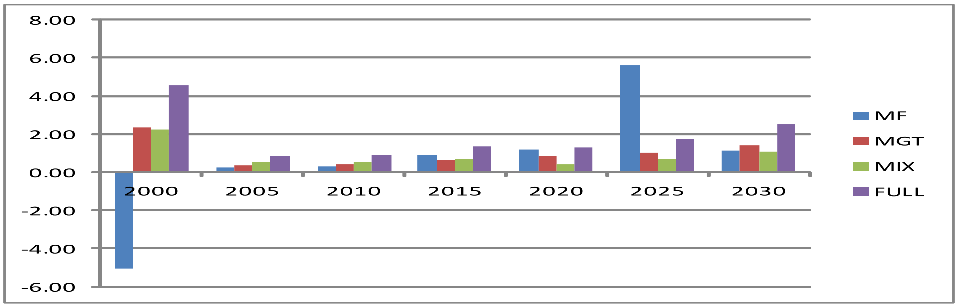
Canadian



Hardley



REGCM



CSIRO

Figure 6. Distribution of the value of adaptation strategies across different scenarios

Although market forces as observed in both table 3 and figure 6 play the biggest role on average in the requisite adjustment to climate change effects, the significant value and contribution of MGT as a component of physical adaptation cannot be overemphasized.

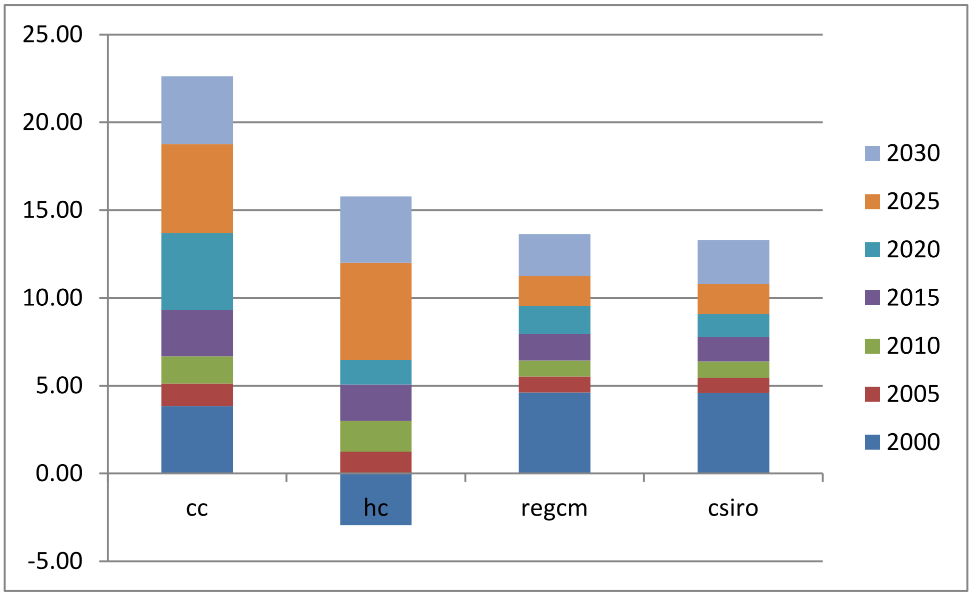


Figure 7. Proportion of physical adaptation value over time under different scenarios

3.2.2 **Production**

Relative to the base scenario, in table 4, crop production for all scenarios is higher when autonomous and the subtotal of physical adaptations are taken into account independently and jointly. Except for the Canadian scenario, all others show at least about twice the return for physical adaptation than for autonomous adaptation. Crop varieties, planting schedules and management regimes are important determinants of production and these items are contained within the MGT. A significantly higher percentage of increase is associated with MGT when compared to the MIX type of adaptation. Adaptation gains are pronounced but it is worth noting that the cost of investments required to adopt certain adaptation practices are not included.

Table 4. Crop production (Fisher index for 2030)

GCM	Human	Physical			Total
	Market Forces	MGT	MIX	Subtotal	
Canadian	6.63	6.06	0.69	6.75	13.37
Hadley	12.15	3.64	-0.29	3.35	15.51
REGCM	5.26	1.87	1.02	2.88	8.14
CSIRO	5.70	1.14	1.21	2.36	8.05

The trend in returns to crop production due to adaption in figure 8 indicates an initial sharp increase, a subsequent diminishing increase and then a decrease compared to the base.

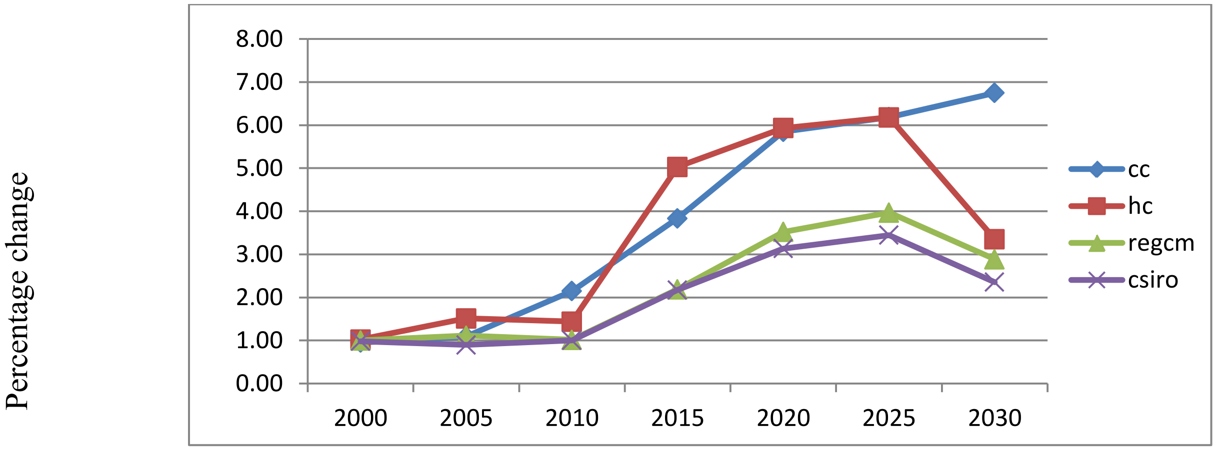


Figure 8. Distribution of crop production under physical adaptation over time

For livestock production as shown in table 5, REGCM and CSIRO scenarios show slight increases with MIX and MGT adaptations but decreased output relative to the base overall as well as without “physical” adaptation. For the other two scenarios (Canadian and Hadley), only MIX demonstrates minor losses in production. However in all scenarios, MGT and total physical adaptation show some increases albeit insignificant. Adaptation showing even greater initial losses can be explained by the possible start-up costs and/or investments required in adopting certain adaptation practices. Beyond the investment phase nevertheless, evidence of returns to adaptation could become apparent through marked increase in production.

Table 5. Livestock production (Fisher index for 2030)

GCM	Human	Physical			Total
	Market Forces	MGT	MIX	Subtotal	
Canadian	0.70	1.26	-0.19	1.07	1.76
Hadley	1.65	0.45	-0.01	0.44	2.10
REGCM	-1.11	0.28	0.07	0.35	-0.76
CSIRO	-1.14	0.25	0.00	0.25	-0.89

Figure 9 shows livestock production changes in the Canadian GCM scenario relative to the base scenario under MIX, MGT and FULL. The sharp decline in MIX after 2025 could be indicative of unfavorable consequences stemming from the northward shift in crop mixes; however this supposition has not been investigated in this study. MGT continues to rise as is expected.

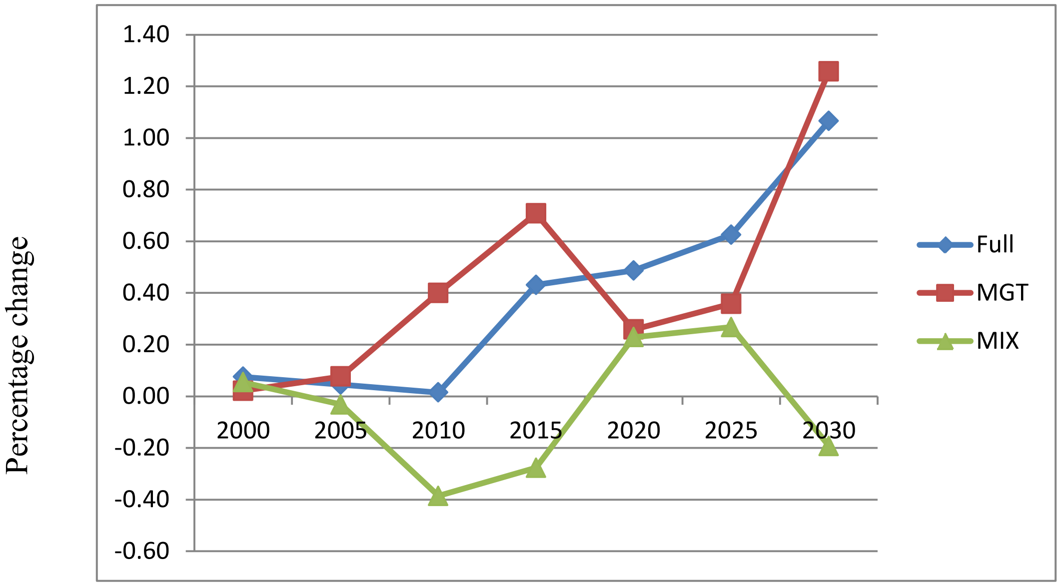


Figure 9. Distribution of livestock production under physical adaptation—Canadian GCM

3.2.3 **Prices**

Comparing crop and livestock price changes under MIX and MGT in 2030 (see figures 10 and 11), the tendency, where crop prices decrease more significantly than livestock prices do compared to the base, is identical under virtually all scenarios. The only exception is the Hadley model scenario under MIX. It should be noted that prices falling does not indicate a loss in welfare although it could mean that consumer surplus increased relative to producer gains.

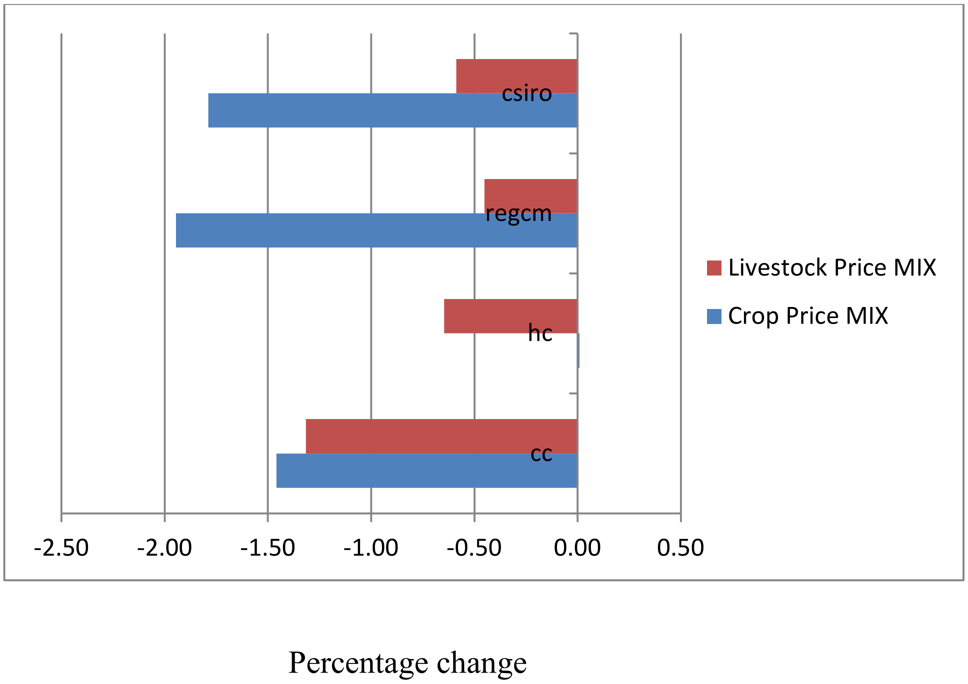
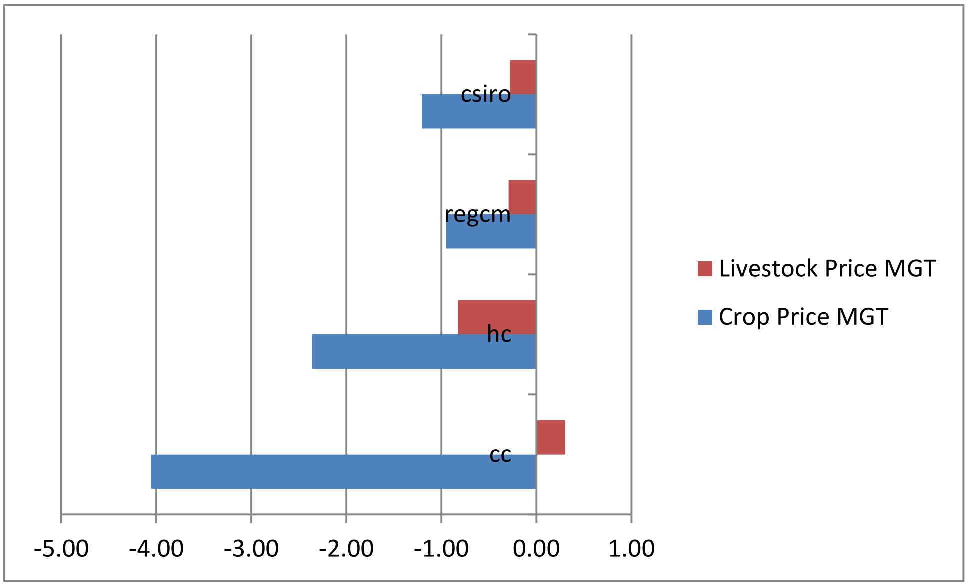


Figure 10. Livestock and crop price changes under MIX in 2030

3.2.4 **Exports**

Finally, table 6 demonstrates that climate change with or without adaptation supports an increase in crop exports, with physical adaptation resulting in greater gains for REGCM and CSIRO scenarios than autonomous adaptation. This possible expansion could lead to a higher comparative advantage and increased income from international trade for the U.S., especially with up to a 20 percent increase. International trade in itself has been shown to be a climate change adaptation option for many countries, but this alternative has not been explored in this study.



Percentage change

Figure 11. Livestock and crop price changes under MGT in 2030

Table 6. Crop exports (Fisher index for 2030)

GCM	Human	Physical			Total
	Market Force	MGT	MIX	Subtotal	
Canadian	11.03	7.88	1.75	9.64	20.67
Hadley	15.04	5.14	1.23	6.37	21.41
REGCM	2.60	3.45	3.39	6.84	9.45
CSIRO	3.12	2.14	3.76	5.90	9.02

Crop exports increased between 2015 and 2030 under both autonomous and physical adaptation as seen in figure 12 in all four scenarios, however the proportion of change across these scenarios varies, albeit slightly. It can be presumed that substantial adaptation in the U.S. will create more avenues for international trade with the rest of the world especially where climate change effects have negative consequences. Also noteworthy in figure 12 whilst comparing physical to autonomous adaptation over the years there are two contrasting results split evenly between the four scenarios. The Canadian and Hadley models show higher exports due to autonomous adaptation when compared with physical adaptation in both 2015 and 2030. On the other hand, for both the CSIRO and REGCM model scenarios, the reverse is the case. By taking into consideration demand growth due to population expansion, the tendency to agree with the former can be substantiated; nonetheless, progressive technical change and significant returns to adaptation research and investment could result in physical adaptation being the mainstay.

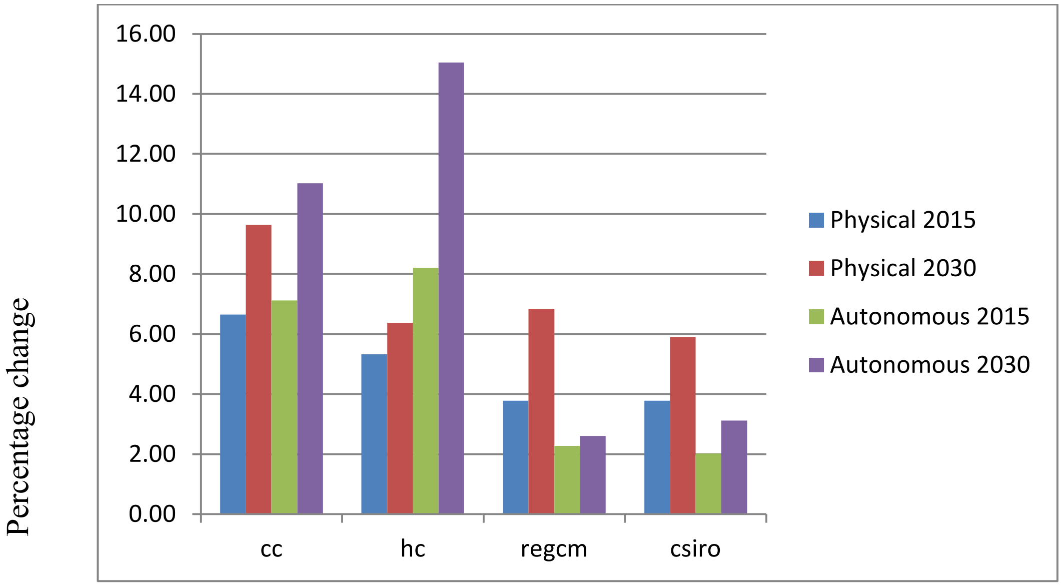


Figure 12. Crop exports under autonomous and physical adaptation in 2015 and 2030

3.2.5 **Regional Effects**

FASOM uses historical crop-mix data to avoid regional specialization, the outcome being a convex combination of historical cropping patterns. The 200-mile mix migration mentioned earlier is to enlarge the possibility space that goes beyond historical crop mix. FASOM can choose to incorporate this "new" crop mix into the convex combination if it turns out to be optimal. In this section however, only results based on on-farm adaptation (MGT) compared to the base of no climate change would be highlighted. Table 7 shows regional, as well as sub-regional classifications under FASOM.

Since land use can be shifted among crops, pasture, grazing and forests, land use management can also be used to adapt climate change. Examples of climate change induced alteration of spatial and temporal distribution have been overviewed in essay 1; however, it is worth mentioning two key studies that have examined shifts in production systems.

Reilly et al. (2003) examine how crops have shifted over time, constructing the geographic centroid of production for corn and soybeans and plotting its historical movements. Their results indicate that both U.S. maize and soybean production shift northward by about 120 miles. Attavanich et al. (2011) also find that U.S. corn and soybean production shifted northward ranging from 100–150 miles during 1950–2010.

Table 7. Definitions of 11 market regions in FASOM

Key	Region	States/Subregions
NE	Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
LS	Lake States	Michigan, Minnesota, Wisconsin
CB	Corn Belt	All regions in Illinois, Indiana, Iowa, Missouri, Ohio (IllinoisN, IllinoisS, IndianaN, IndianaS, IowaW, IowaCent, IowaNE, IowaS, OhioNW, OhioS, OhioNE)
GP	Great Plains	Kansas, Nebraska, North Dakota, South Dakota
SE	Southeast	Virginia, North Carolina, South Carolina, Georgia, Florida
SC	South Central	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee, Eastern Texas
SW	Southwest (agriculture only)	Oklahoma, All of Texas but the Eastern Part (Texas High Plains, Texas Rolling Plains, Texas Central Blacklands, Texas Edwards Plateau, Texas Coastal Bend, Texas South, Texas Trans Pecos)
RM	Rocky Mountains	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
PSW	Pacific Southwest	All regions in California (CaliforniaN, CaliforniaS)
PNWE	Pacific Northwest—East side (agriculture only)	Oregon and Washington, east of the Cascade mountain range (agriculture only)
PNWW	Pacific Northwest—West side (forestry only)	Oregon and Washington, west of the Cascade mountain range (forestry only)

Under CC, HC, REGCM, and CSIRO scenarios, crop production (measured by Fisher Index) in 2030 declines in the Corn Belt but increases in Lake States (see tables 8 and 9), indicating crop production may have moved northward. These results agree with studies earlier discussed.

Table 8. Crop production index (change from Base=100) for Corn Belt

Scenario	2000	2005	2010	2015	2020	2025	2030
CC	-1.4874	-8.7441	-28.2026	25.2868	51.6109	-14.3939	-74.0944
HC	1.3764	14.9567	-20.5166	58.8796	92.2956	51.7946	-62.8915
REGCM	-1.4804	-16.1828	-40.5408	-45.9935	-52.5477	-59.6515	-33.4906
CSIRO	-0.3336	-15.7509	-42.2277	-41.9573	-47.3282	-50.5279	-48.2931

Table 9. Crop production index (change from Base=100) for Lake States

Scenario	2000	2005	2010	2015	2020	2025	2030
CC	3.0464	-5.9002	-25.6839	-9.7493	-16.0434	23.3932	69.197
HC	0.8451	18.2426	-13.1476	-17.0958	-17.225	-32.5805	97.6142
REGCM	1.2445	22.9064	28.8217	62.8454	67.738	73.4569	132.3613
CSIRO	0.8225	0.3063	-0.9874	51.4623	51.7295	55.3208	80.1436

In FASOM, for each crop, production budgets are differentiated by region, tillage choice, irrigated/dryland and cropland type. There are three tillage choices: conventional tillage (Vent), conservation tillage (Cons), or no-tillage (Zero). Conservation agriculture and organic agriculture that combine zero or low tillage and permanent soil cover are promising adaptation options for their ability to increase soil organic carbon, reduce mineral fertilizer use and reduce on-farm energy costs (FAO 2007). Table 10 highlights land use patterns across regions in the U.S. Conservative and zero tillage appear to decrease in the Corn Belt in 2030 (22% and 14%, respectively), but conservative tillage increases in the Lake States (20%) under the CC scenario. Cropland diminishes under all scenarios for the South Central, Southeast, and Southwest regions, as did conventional tillage. This is possibly another indication of less production in the south and substantial production potential shifts that may occur across regions.

By calculating the X and Y coordinates which are a representation of longitude (East-West), and latitude (North-South) respectively, “spatial movement” may be observed. Weighting of the centroids is done using corn acreage, an important measure of production especially in the Corn Belt. Table 11 illustrates how weighting is carried out, however Tables 12 and 13 provide a better picture across time horizons and among scenarios.

The average of X across all Corn Belt regions is -88.81, and average Y is 40.46. Thus weighted X (-90.2661) is below average X. Weighted Y (40.7636) however is greater than average Y, except for the HC scenario. Under CSIRO and REGCM, corn planting appears to move northward in the Corn Belt because of the larger weighted Ys than the base. Under HC, the weighted X is -90.04, greater than the Base, indicating an eastward movement, however corn acreage moves West under CC (Base is -90.26 compared to weighted X under CC as -90.98).

In general, for Base, from 2000 to 2030, corn acreage is moving West (-90.26 less than -90.01) and moving South (40.76 less than 40.88). This southward move may not be surprising given that the Base scenario does not take climate change into account. Under the REGCM scenario where climate change effects and adaptation are considered however, northward movement in terms of latitude is observed. This result agrees with previous studies.

Table 10. Land use pattern in 2030: Percentage change from Base

CATEGORY	ITEM	REGION	CC	HC	REGCM	CSIRO
LandUse	Pasture	CB	0%	0%	0%	0%
LandUse	Pasture	GP	1%	1%	0%	0%
LandUse	Pasture	LS	11%	10%	1%	1%
LandUse	Pasture	NE	-23%	-21%	-35%	-40%
LandUse	Pasture	RM	0%	-5%	0%	0%
LandUse	Pasture	PSW	709%	709%	522%	512%
LandUse	Pasture	PNWE	-87%	-100%	-81%	
LandUse	Pasture	SC	68%	115%	111%	92%
LandUse	Pasture	SE	-10%	-11%	2%	12%
LandUse	Pasture	SW	-5%	1%	3%	2%
LandUse	Pasture	National	3%	3%	4%	4%
LandUse	Cropped	CB	-1%	-2%	-1%	0%
LandUse	Cropped	GP	8%	-1%	-1%	-1%
LandUse	Cropped	LS	-3%	-4%	-1%	-1%
LandUse	Cropped	NE	-39%	-35%	-19%	-18%
LandUse	Cropped	RM	5%	2%	6%	6%
LandUse	Cropped	PSW	0%	0%	0%	0%
LandUse	Cropped	PNWE	2%	1%	1%	0%
LandUse	Cropped	SC	-7%	-9%	-7%	-7%
LandUse	Cropped	SE	-40%	-48%	-22%	-22%
LandUse	Cropped	SW	-22%	-34%	-13%	-7%
LandUse	Cropped	National	-4%	-9%	-4%	-3%
Tillage	Vent	CB	11%	7%	0%	0%
Tillage	Vent	GP	-6%	-5%	-5%	-5%
Tillage	Vent	LS	-5%	-5%	-4%	-6%
Tillage	Vent	NE	-45%	-43%	-25%	-24%
Tillage	Vent	RM	13%	8%	8%	8%
Tillage	Vent	PSW	1%	1%	2%	1%
Tillage	Vent	PNWE	7%	3%	3%	1%
Tillage	Vent	SC	-9%	-11%	-9%	-8%
Tillage	Vent	SE	-42%	-53%	-26%	-26%
Tillage	Vent	SW	-27%	-38%	-11%	-11%
Tillage	Vent	National	-5%	-8%	-5%	-5%

Table 10. Continued

CATEGORY	ITEM	REGION	CC	HC	REGCM	CSIRO
Tillage	Cons	CB	-22%	-32%	-3%	-3%
Tillage	Cons	GP	-4%	-5%	19%	22%
Tillage	Cons	LS	20%	20%	27%	31%
Tillage	Cons	NE	0%	-25%	0%	0%
Tillage	Cons	RM	-15%	-22%	3%	4%
Tillage	Cons	PSW	361%	347%	312%	322%
Tillage	Cons	PNWE	-20%	-19%	-7%	-4%
Tillage	Cons	SC	-14%	9%	21%	18%
Tillage	Cons	SE	-48%	-48%	18%	20%
Tillage	Cons	SW	16%	6%	3%	5%
Tillage	Cons	National	-7%	-12%	10%	11%
Tillage	Zero	CB	-14%	1%	0%	0%
Tillage	Zero	GP	23%	23%	-8%	-11%
Tillage	Zero	LS	-42%	-42%	-26%	-24%
Tillage	Zero	NE	-24%	0%	0%	0%
Tillage	Zero	RM	-3%	18%	-7%	-7%
Tillage	Zero	PSW	-30%	-30%	-32%	-31%
Tillage	Zero	PNWE	0%	36%	0%	0%
Tillage	Zero	SC	-2%	-2%	-3%	-3%
Tillage	Zero	SE	-25%	-25%	-8%	-8%
Tillage	Zero	SW	-44%	-40%	-26%	-5%
Tillage	Zero	National	-9%	-1%	-7%	-5%

Table 11. Longitude and latitude coordinates and Corn Belt corn acres by region in 2030

	Longitude (X) coordinates	Latitude (Y) coordinates	Base	CC	HC	CSIRO	REGCM
IowaCent	-92.8789	42.160508	4.5964	2.555	0.0003	4.5138	4.5138
IowaS	-93.5177	41.033751	1.4395	1.3959	1.0218	1.4327	1.5886
IowaNE	-92.1731	42.953796	0.8849	0.0003	0.0003	0.7202	1.3361
IllinoisN	-89.2734	40.828832	6.752	6.5607	6.9034	6.9486	6.5607
IllinoisS	-89.0434	38.485283	3.7172	3.7113	3.6887	3.2498	1.9008
OhioNE	-83.8403	40.511097	0.342	0.3181	0.2572	0.2686	0.2709
OhioS	-82.7064	39.182547	0.2902	0.3046	0.4123	0.4142	0.4123
OhioNW	-81.6774	40.715743	1.5264	0.9033	1.1816	1.8576	2.2443
IndianaN	-86.1271	40.569763	3.8786	0	2.6275	2.2553	2.2052
IndianaS	-86.5373	38.740533	0.647	0	0.647	0.4365	0.4542
Missouri	-92.4772	38.367494	1.7525	2.0477	2.7061	1.7474	1.9337
IowaW	-95.5766	42.073816	4.7007	4.3906	4.689	4.3777	4.3777
		weighted X	-90.2661	-90.9829	-90.044	-90.3473	-90.3826
		weighted Y	40.7636	40.59054	40.32405	40.78968	40.93219

Table 12. Weighted longitude across scenarios (using corn acres)

	2000	2005	2010	2015	2020	2025	2030
Base	-90.0185	-90.143	-90.2889	-90.4741	-90.5072	-90.4268	-90.2661
CC	-90.1386	-90.2844	-90.479	-90.6559	-90.6952	-90.9881	-90.9829
HC	-90.1218	-89.8244	-90.0418	-89.8491	-89.6674	-89.547	-90.044
REGCM	-89.9736	-90.2165	-90.3413	-90.3427	-90.3233	-90.3333	-90.3826
CSIRO	-90.0073	-90.1921	-90.2812	-90.2998	-90.2709	-90.3466	-90.3473

Note: Positive change implies an eastward move; if negative, then westward.

Table 13. Weighted latitude across scenarios (using corn acres)

	2000	2005	2010	2015	2020	2025	2030
Base	40.88558	40.74811	40.84302	40.65159	40.66883	40.66799	40.7636
CC	40.8659	40.71611	40.75183	40.80227	40.79102	40.76553	40.59054
HC	40.86614	40.62573	40.64083	40.46659	40.4652	40.33322	40.32405
REGCM	40.8865	40.74711	40.90315	40.84439	40.84521	40.85678	40.93219
CSIRO	40.88999	40.7064	40.82503	40.74793	40.74076	40.739	40.78968

Note: Positive change implies a northward move; if negative, then southward.

3.3 **Conclusions**

This essay attempted to value an array of possible agricultural adaptations to climate change. Specific adaptation strategies studied were: shifts in crop varieties and planting schedules, altered management practices such as irrigation water use, and a 200-mile northward migration of crop mixes. Important outcomes are summarily discussed below.

Adaptation is found to be highly beneficial to agriculture, increasing welfare by up to $16 billion. Interestingly, climate change is beneficial even without planned adaptation. Autonomous adaptation, the outcome of competitive market forces and market adjustments, is capable of generating more than twice the value that physical or planned adaptations (on-farm and mix-migration) generate. In terms of ranking of the two major types of physical adaptations studied, on-farm adaptation contributions outweigh that of a 200-mile crop-mix shift northwards significantly. This finding implies that progressive technical change and significant returns to adaptation research and investment focused on farm management and varietal adaptations may prove to be quite beneficial over time.

Crop production increases with adaptation. Significantly higher percentage of increase is associated with the on-farm varietal and other adaptations when compared to the mix-migration adaptation. Adapting management onsite is more valuable because action is taken where crops are located, compared with mix shifts which have much less returns.

A northward shifting of the corn-acre weighted centroids observed indicates that substantial production potential may shift across regions with the possibility of less production in the South, and more in the North, and thereby, potential redistribution of income. This finding further implies a possible need for regional changes in infrastructure, farmers in the North needing more information on adaptation possibilities, etc.

Climate change with or without adaptation is found to support an increase in crop exports, with physical adaptation resulting in greater gains than autonomous adaptation. This possible expansion could lead to a higher comparative advantage and increased income from international trade for the U.S., especially with up to the observed 20% increase. International trade in itself has been shown to be a climate change adaptation option for many countries, but this alternative has not been explored in this study.

Finally, while adaptation gains are pronounced, it is worth noting that the cost of investments required to adopt certain adaptation practices is not included. An implication of this exclusion is the possibility of greater initial losses due possible start-up costs and/or investments required in adopting certain adaptation practices. Beyond the investment phase, nevertheless, the expectation is that returns to adaptation would become more apparent.

3.4 Limitations and Future Research

Itemized below are limitations associated with this study and avenues for future research:

- No costs of adaptation are included in the study. Costs associated with the social burden of society adapting to a changing climate, scientific or research costs, etc. are important and being excluded presents a bias for this study.
- Although FASOM is solves at 5-year time steps, the model is assumes that producers have full information/perfect foreknowledge about climate change effects on crop yields. This may not be true, and there may perhaps be some inertia preventing taking the adaptation measures timely.
- For crop mix migration, the information costs or to what extent the producers are willing to embrace new cropping patterns is not considered. Nonetheless, FASOM provides the possibility of 200 mile northward migration although it remains up to the producers who make cropping decisions.
- The forest sector not modeled in this study although it is closely related to the agricultural sector.
- FASOM does not provide confidence intervals on the calculations for the welfare effects of the adaptation strategies studied. Specifically, employing the deterministic version of optimization models such as FASOM yield results as

only point estimations, and these outcomes may not fully account for uncertainties linked with future climate change.

- Finally, the extreme dependence of mathematical programming models like FASOM on model parameters, sometimes taken as given from literature or simply assumed, make results somewhat sensitive to the choice of parameters.

Possibilities for future research abound. In general, with the availability of more data and regional details, the model can be refined. FASOM has the property of being flexible and capable of expansion to incorporate more variables and equations. A natural extension of this work would be to expand the model to include more varietal adaptations or new adaptation strategies, and perhaps observe interactions with other sectors. One may also be able to calibrate the model to investigate how adaptation options interact with mitigation alternatives, and whether an optimal mix of both responses is realizable. Future research could use the stochastic version of FASOM to better reflect possible uncertainties.

4. MARKET INTEGRATION AND EXTENT FOR ETHANOL

Biofuels have generated a great deal of interest among developed and developing countries as a way to simultaneously reduce imports of petroleum while reducing air pollution and greenhouse gas emissions. Heightened concerns about global climate change, expanding demand and increasing oil prices, and instability in oil-exporting countries have led to considerable efforts in many nations to promote biofuels as an alternative to fossil fuels. In the U.S., where 52% of global ethanol output was produced in 2008 (Renewable Fuels Association 2009), attention has focused principally on ethanol derived from corn (Saitone, et al. 2007), although in recent years, "2nd-generation biofuels" produced from crop and forest residues and from non-food energy crops are gaining importance, even though very little of the latter being produced. Federal and state energy policies have also contributed considerably to the expansion of the biofuels industry in the U.S. A snapshot of the history of ethanol subsidy legislation including mandates, tax incentives, and blending subsidies can be seen in table 14.

Ethanol is derived from renewable feedstocks and is produced mostly in the Midwestern states—the Corn Belt and in California (Entrix 2010). Most ethanol is consumed in blended form in conventional gasoline engines (as an oxygenate, octane booster and gasoline extender), at about a 10-percent ethanol blend (E10), with the possibility of blending in higher concentrations, such as E85 (85 percent ethanol, 15 percent gasoline).

Interestingly, the value of ethanol is said to vary depending on how it is blended with gasoline (Dipardo 2000), yet this claim is unsubstantiated. Ethanol can also be used in higher concentrations as an alternative to gasoline in vehicles designed for its use. Unlike oil though, ethanol is not easily transferred through petroleum pipelines, and therefore must be splash-blended near end-market locations. Physical properties of ethanol such as its affinity to water, and corrosive nature, posing damage to existing pipelines and storage tanks, prevent it from being shipped in existing U.S. pipeline infrastructure (American Petroleum Institute 2006). Hence, ethanol in the U.S. is transported typically by tanker trucks, train, and barge, modes of transport that lead to higher prices than for pipeline (Schnepf and Yacobucci 2012). Ethanol also has less energy per gallon.

Transportation considerations make producing ethanol close to the feedstock supply less expensive than transporting the feedstock, then producing the ethanol elsewhere, thus, it is not unexpected that the top five corn-producing states in the U.S. (Iowa, Illinois, Nebraska, Minnesota and South Dakota as shown in USDA, 2012) are also among the top ethanol-producers (see table 15 below). Up to 25% of ethanol use is in the metropolitan centers of the Midwest, where it is produced. When ethanol is used in other regions, shipping costs tend to be high, since ethanol-blended gasoline cannot travel through petroleum pipelines. This geographic concentration, and the issue of corn

Table 14. History of U.S. energy policy initiatives: ethanol subsidy legislation

Year	Legislation	Description
1978	Energy Tax Act of 1978	$0.40 per gallon of ethanol tax exemption on the $0.04 gasoline excise tax.
1980	Crude Oil Windfall Profit Tax Act and the Energy Security Act	Promoted energy conservation and domestic fuel development.
1982	Surface Transportation Assistance Act	Increased tax exemption to $0.50 per gallon of ethanol and increased the gasoline excise tax to $0.09 per gallon.
1984	Tax Reform Act	Increased tax exemption to $0.60 per gallon.
1988	Alternative Motor Fuels Act	Created research and development programs and provided fuel economy credits to automakers.
1990	Omnibus Budget Reconciliation Act	Ethanol tax incentive extended to 2000 but decreased to $0.54 per gallon of ethanol.
1990	Clean Air Act amendments	Acknowledged contribution of motor fuels to air pollution—oxygen requirements for motor fuels.
1992	Energy Policy Act	Tax deductions allowed on vehicles that could run on E85.
1998	Transportation Efficiency Act of the 21st Century	Ethanol subsidies extended through 2007 but reduced to $0.51 per gallon of ethanol by 2005.
2004	Jobs Creation Act	Changed the mechanism of the ethanol subsidy to a blender tax credit (the Volumetric Ethanol Excise Tax Credit, or VEETC) instead of the previous excise tax exemption. Also extended the ethanol tax exemption to 2010.
2005	Energy Policy Act	Established the renewable fuel standard (RFS) starting at 4 billion gallons in 2006 and rising to 7.5 billion in 2012. Eliminated the oxygen requirement for gasoline, but failed to provide MTBE legal immunity/ protection. MTBE use in gasoline banned in 20 states by 2006.
2007	Energy Independence and Security Act of 2007	Expanded the RFS requiring 36 billion gallons (1 billion biodiesel) by 2022. Capped the use of conventional ethanol produced from corn starch at 15 billion gallons in 2015 and required the remaining 21 billion gallons to be produced from advanced biofuels, including at least 16 billion gallons from cellulosic feedstocks.
2008	Farm Bill	Reduced VEETC from $0.51 to $0.45 per gallon regardless of the feedstock. Small Ethanol Producer Tax Credit (SEPTC) created to provide producers with capacity 60 million or less and an additional $0.10 on the first 15 million U.S. gallons produced; and Cellulosic Biofuel Producer Tax Credit (CBPTC) for producers of ethanol from cellulosic feedstocks income tax credit of up to $1.01 for each gallon of cellulosic ethanol produced. The CBPTC (set to expire December 2012) includes, and must be reduced by, the amount of the VEETC and the SEPTC.

Source: Adapted and expanded using North Dakota Chamber of Commerce 2006, Tyner 2007, Tyner 2008, U.S. Department of Energy 2010, O'Brien 2011.

ethanol shipments being in the opposite direction of existing pipeline transportation (which moves gasoline from refiners along the coast to other coastal cities and into the interior of the country) are obstacles to the use of ethanol on the East and West Coasts (Yacobucci and Womach 2004, Schnepf and Yacobucci 2012), yet mandates—blenders credits requires its use at a rate of 10 percent.

Table 15. Ethanol and corn production by state

	Online Capacity (9/1/2010) (MGY)	Share (%)	Corn production 2009 (Mil Bu)	Share (%)
IA	3,183.0	24.6%	2,438.8	18.5%
IL	1,350.0	10.4%	2,065.0	15.7%
NE	1,454.0	11.2%	1,575.3	12.0%
MN	1,112.6	8.6%	1,251.3	9.5%
SD	1,016.0	7.9%	933.7	7.1%
IN	706.0	5.5%	719.1	5.5%
WI	498.0	3.9%	598.3	4.5%
KS	436.5	3.4%	546.4	4.2%
OH	314.5	2.4%	448.3	3.4%
TX	250.0	1.9%	254.8	1.9%
All Others	2,614.0	20.2%	2,320.2	17.6%
TOTAL	**12,934.1**	**100.0%**	**13,151.1**	**100.0%**

Source: U. S. Department of Energy 2010

Operational issues, distributional challenges and logistical limitations associated with the U.S. ethanol market influence transaction costs, and are major price-setting issues that could impede a comparable level of integration obtainable in oil markets, especially with the possibility of arbitrage (taking advantage of a price differential beyond transaction costs between two or more markets) due to market inefficiencies arising. Also, with the extensive intervention of the government in the ethanol industry, there is increased potential for inefficient allocation of resources, and perhaps market inefficiency. Thus studies on the “immature” ethanol market structure and pricing remain relevant.

This study focusing on the ethanol market structure, examines how supply centers interact with metropolitan or demand zones, and investigates leadership in the market in an effort to provide more information, essentially on which cities price shocks or signals originate from. Providing information on the dynamics of prices allows for a better understanding of price information flows among markets (Mjelde and Bessler 2009). Rashid et al. (2010) argue that the main goal of analyzing market integration is to have a better understanding of the implementation of short and long term policy interventions. An efficient and competitive ethanol market is one which is highly integrated, with no market power or distortions in pricing. One may therefore ask: Are ethanol markets efficient in the U.S.? If so, then the theory of arbitrage holds and the markets are integrated, at least regionally.

The objective of this research is to study how ethanol prices are interrelated across, and transmitted within the U.S., and the markets that play an important role in these dynamics. The procedure will be to measure market integration, characterize dynamic price information flows and establish the ways the market for ethanol differs (or the possibility of a single economic market) between major ethanol producing areas and in more distant major consuming states. In conducting this study, the arbitrage cost approach following Spiller and Huang (1996) will be used. In addition, time series techniques will also be carried out to measure market integration and thereby substantiate or refute results obtained from using the Spiller and Huang model.

Given the increasing importance of ethanol industry in the energy market, and its highly regulated nature, it is vital to understand how different markets for ethanol interact, and important for policy makers to understand the price discovery process between different markets. In particular, information on how price innovations in one market affect the other markets in the ethanol industry is relevant. Important implications for planning, strategizing, decision making, risk mitigation, etc., for relevant players in the ethanol industry, particularly policy makers, and others concerned with the future of ethanol pricing, such as suppliers, retailers and large-scale consumers are conceivably imminent from this research. Market efficiency is enhanced by more information, which is beneficial for price forecasting for instance.

Organization of the essay is as follows: Section 4.1 presents a brief literature review; Section 4.2 introduces the theoretical framework and models to be employed; Section 4.3 presents the data and preliminary data analysis. The estimation results and discussion are contained in Section 4.4. Section 4.5 summarizes and concludes the study.

4.1 **Brief Literature Review**

Potentially, biofuels remain an attractive alternative in the U.S., according to McCarl (2007) for the following reasons: higher fossil-fuel prices, cap on GHG emissions, the specter of value to GHG offsets, market development and penetration, conversion efficiency, identification of relative advantage given the diversity of the landscape, capital availability, and existing industrial capacity and technological development. In terms of market development and penetration, the biofuel of choice is currently ethanol, especially with the rapid expansion of ethanol plants and corresponding production over the last decade, in addition to the resulting prospect of more ethanol in energy markets across the U.S. Li et al. (2009) attribute this growth in the ethanol industry primarily to available production infrastructure and experience with fuel blending. Zhang et al. (2007) show that while tax credits and subsidies played a modest role, government bans and mandates (especially state bans on Methyl Tertiary Butyl Ether—MTBE) have caused the ethanol industry to become a major supplier of fuel additives in the U.S. In addition, the increased price of crude oil in recent years has significantly contributed to biofuel expansion (Taheripour and Tyner 2008). The following paragraphs review some recent studies on the ethanol market, and also highlight work on energy markets that have used methods similar to the one adopted in this study.

Federal Trade Commission's (FTC) 2011 report on ethanol market concentration indicates a low level of concentration and a large number of market participants in the U.S. ethanol production industry. The report concludes that these dynamics make it extremely unlikely that a single ethanol producer or marketer or a group of such firms could exercise market power to set prices or coordinate on price or output levels. Potential entry by new firms and the possibility of ethanol imports they add, provide further additional constraints on the exercise of market power by current industry participants. This is a strong indication of the competitiveness of ethanol markets.

Historically, ethanol prices have been higher than gasoline prices because of its additive value (more oxygen and a much higher octane level) and because of the federal and state subsidies (Tyner 2007). The U.S. Department of Energy (DOE 2010) argue that "mandates often increase demand for ethanol in the regions of the U.S. in which transportation fuel demand is large, such as highly populated areas, thereby shaping the geography of demand for ethanol to areas outside of states where ethanol production is high." Yacobucci and Womach (2004) in support state that without the current regulatory requirements and incentives, much of ethanol's market would likely disappear.

Tyner (2008) however, by examining the impacts of a wide range of policies for subsidies and renewable fuels standards, states that policy choices will be absolutely critical in determining the extent to which biofuel targets are achieved and at what cost, and, that biofuels will continue to be produced even without government interventions if the price of oil remains above $100 per barrel. He finds that future prospects for corn ethanol depend on a number of factors: the crude oil price, the price of corn and distillers' grains, the market value of ethanol, plant capital and operating costs, and federal ethanol and biofuel policies. He concludes that it is likely that the rapid growth of corn ethanol will cease, and under most assumptions, corn ethanol will peak around

57 billion liters (15 billion gallons), beyond which the price of corn high enough to choke off further growth in the industry is likely.

More studies on the effect of mandates on markets include Schnepf and Yacobucci (2012), and Tyner and Vitee (2010). Schnepf and Yacobucci (2012) make interesting conclusions on the issues associated with the expanded RFS including: the presence of considerable uncertainty regarding potential spillover effects in other markets and on other important policy goals; effects on energy prices being uncertain, unless wholesale biofuels prices are higher than gasoline prices (after all economic incentives are taken into account), which would mean mandating higher levels of biofuels, likely leading to higher gasoline pump prices; expanding ethanol production likely straining the existing supply infrastructure requiring investment in entirely new infrastructure. Tyner and Vitee (2010) study the implications of blending limits on the U.S. ethanol and biofuels markets, and determine that "The bottom line is that ethanol cannot be the only biofuel in the U.S. market given current and possible future blend levels and the low level of penetration of flex-fuel vehicles."

Energy and food prices have been strongly linked in literature. Many of these studies have employed time-series econometric techniques, in particular cointegration, to test the joint movement of energy and agricultural commodity prices (Beckman et al 2011). Establishing whether fuel markets are econometrically cointegrated according to Ma and Oxley (2010) is potentially important for economists and researchers, as the results of such estimation and testing can inform a range of analytical and policy issues. If agricultural and energy prices are closely linked, rising energy prices imply the potential for higher commodity prices and a direct compensation for rising input prices for farmers (Tyner and Taheripour 2007). Taheripour and Tyner (2008), for example, state that since ethanol is a near perfect substitute for gasoline, higher gasoline prices mean higher demand for ethanol, which induces investment in ethanol plants. More ethanol plants and production, they conclude, imply more demand for corn, which, in turn, means higher corn prices.

Higgins et al. (2006) use a time series cointegration approach to reveal historical ethanol price behavior and relationships, and show a linkage between ethanol prices and corn prices, as well as confirm historical linkages between ethanol and gasoline prices.

Similarly, Serra et al. (2010) use nonlinear time series models to assess price relationships within the U.S. ethanol industry using daily ethanol, corn, and crude oil futures prices. Their results suggest the existence of an equilibrium relationship between the three prices studied with only ethanol prices found to adjust to deviations from this relationship. They conclude that the evolution of ethanol prices in relation to corn and crude oil prices may have important implications for the long-run competitiveness of the U.S. ethanol industry.

Research on energy markets in the U.S and internationally have also been insightful for this research.

Mjelde and Bessler (2009) investigate dynamic price information flows among U.S. electricity wholesale spot prices and the prices of the major electricity generation fuel sources- natural gas, uranium, coal, and crude oil using multivariate time series methods applied to weekly price data. Their results show that in the long run, price is discovered in the fuel-sources market (except uranium).

Ma and Oxley (2010) also test for energy price co-movement in China as part of a strategy to identify the existence of a national energy market using panel cointegration tests, with results suggesting that not all energy commodities are spatially homogenous in prices, and the processes of energy price cointegration are different over time and over fuel sources.

Li et al. (2010) examine the hypothesis that there is a single economic market for the international steam-coal industry and investigate the degree of steam-coal market integration over time. Also using cointegration analysis, they find that the international steam-coal market is generally integrated.

Serra et al. (2010b) assessed volatility spillovers in Brazilian ethanol markets using a maximum likelihood estimator (on weekly international crude oil prices, and Brazilian ethanol and sugar prices), that allows for joint estimation of the cointegration relationship between the price series investigated and the multivariate generalized autoregressive conditional heteroscedasticity process. The advantage of this methodology was that it allowed for the responses of both food price levels and volatility to unanticipated shocks to be considered together. A strong link between food and energy markets, both in terms of price levels and volatility, was found.

Busch et al. (2012) examine the relationship between diesel and biodiesel prices, and between rapeseed oil, soy oil, and biodiesel prices between 2002 and 2008, using a regime-dependent Markov-switching vector error-correction model due to pronounced changes in market conditions and the policy framework. They conclude that frequent switches between the regimes of the price dynamics which they find during this period indicate a high extent of uncertainty and instability in the market.

None of the afore mentioned studies have looked at, using fairly recent data, market interactions and integration between markets in different U.S. states, using solely ethanol prices to characterize pricing dynamics like this study does. The rationale and usefulness of this study have already been discussed in the proceeding section.

4.2 Theoretical Framework and Models

Competitive market equilibrium, according to the first theorem of welfare, ensures efficient allocation of resources, hence defining market extent economically or geographically, and investigating market integration helps in measuring market efficiency and in providing a better understanding of market dynamics.

The definition of markets by Alfred Marshall (1961), “a market for a good is the area within which the price of a good tends to uniformity, allowance being made for transportation,” is related to the economic market where differences in prices of the same commodity observed at different places are due to transaction costs. Therefore, according to the definition of a market, in the same geographic region, it is almost impossible that prices of the same commodity display a greater difference than the transaction costs over a long period of time. If a single price exists over several spatially separate markets, it implies that these markets are integrated as a single market (Yang, Bessler and Leatham 2000). In other words, assuming market integration, prices of a commodity observed in different locations simultaneously will differ by the amount up to the transaction costs (referred to as the law of one price). This law is the basis for defining spatial price relations and market extent (Dawson and Dey 2002; FAO 2004). The reason is that arbitrage will always occur when the price differences in different geographic regions exceed the transaction costs (Egbendewe-Mondzozo 2009). When markets are efficient, arbitrage opportunities will be sought until prices are equalized between markets.

One way of finding empirical evidence of price linkages has been achieved through testing the law of one price (Ardeni 1989; Dawson and Dey 2002; Bukenya and Labys 2005). The concept of market integration has also been used in defining market boundaries in antitrust cases (see, for example, Horowitz 1981; Slade 1986; Spiller and Huang 1986; Kleit 2001) and international trade conflicts (e.g., Asche et al. 1999). It has been suggested, for example, that a greater degree of integration leads to more transmission of price signals, which, in turn, encourages producers to specialize according to comparative advantage (Baulch 1997). Studies on market extent and the degree of market integration have developed, and used a myriad of methods. According to Fackler and Tastan (2008), economists commonly study measures of market integration by analyzing correlations of prices (given that prices are often the only available data), which entails significant difficulty in estimating structural models capable of isolating the effect of regional demand shocks. The lack of complete data and the consequent presence of latent variables they add, further compounds this difficulty. The arbitrage cost approach has been shown in literature to have many advantages over the correlation approach; in particular, its ability to generate a precise number for arbitrage costs between markets, and how those arbitrage costs can change with changes in exogenous factors (Spiller and Huang 1986).

4.2.1 Spiller and Huang Methodology

The first studies of arbitrage outcomes examined whether two locations were in the same economic market by estimating the probability that their prices differed by the transaction costs, (Spiller and Huang 1986; Spiller and Wood 1988). Prices in the two locations either differ by the transaction cost (successful arbitrage), or by less than the transaction cost (autarky). This paper follows the method used by Spiller and Huang (1986). It is assumed that all regions of a state are within the same market and so one city in each state is used as a representative data point. The methodology involves the estimation of a switching-regimes model. One regime is characterized by ethanol prices in two cities differing by the arbitrage (or transaction) costs. In the other, when there is no (explicit or implicit) arbitrage between the two products, their prices differ by less than the transaction costs. This regime is statistically identified by a truncation in its error structure, similar to the stochastic frontier models estimated elsewhere in the literature (Spiller and Huang 1986).

Now to the model itself:

Assume that the autarky prices for two markets in a given period, P_t^{1A} and P_t^{2A}, can be defined by the following reduced form equations:

(1a) $P^{1A}{}_t = \pi^1 + \varepsilon_t^1$

(1b) $P^{2A}{}_t = \pi^2 + \varepsilon_t^2$

Where π^1 and π^2 are nonstochastic elements of prices determined by supply and demand conditions in local markets, and ε_t^1 and ε_t^2 are zero mean stochastic disturbances (shocks) in each region. Next, define a transaction cost T_t, of moving the commodity from location A to B. In the absence of legal trading barriers but with finite transaction costs, the observed prices P_t^1 and P_t^2 may diverge from the autarky prices. Arbitrage opportunities arise if the autarky prices differ by more than T_t and do not arise if the reverse is the case. For simplicity, it is assumed that $P_t^{1A} < P_t^{2A}$. Then if

(2) $0 < P_t^{2A} - P_t^{1A} < T_t$ where $P_t^1 = P_t^{1A}$ and $P_t^2 = P_t^{2A}$, this implies that

(3) $0 < P_t^2 - P_t^1 < T_t$

Where arbitrage arises, the observed equilibrium prices in the two regions differ only by T_t, therefore implying that a shock in one region translates to the other (as long as the autarky price difference does not fall below T_t). Thus, if

(4) $0<T_t< P_t^{2A} - P_t^{1A}$, then

(5) $0< P_t^2 - P_t^1 = T_t$

Now suppose that the transaction costs T_t are distributed geometrically with mean $T_t= Te^{Vt}$, where V_t is normally distributed with zero mean and constant variance σ_v^2. The probability of no arbitrage opportunities and hence the probability of observing (3), is a constant λ.

(6) $\text{Prob } [0< P_t^2 - P_t^1<T_t] = \text{Prob } [0< P_t^{2A} - P_t^{1A}<Te^{vt}]$

$= \text{Prob } \{\log[(\pi^2 - \pi^1)+ (\varepsilon_t^2 - \varepsilon_t^1)- V_t< \log T)\} = \lambda$

The probability of arbitrage and hence the probability of observing that the prices are separated by the transport costs (5) is (1-λ). This probability measures how integrated the two areas are. If (1-λ) is very close to one, then the two areas are almost always in the same economic market. On the other hand, when it equals zero, the markets are unrelated. The value λ is, in other words, the probability that prices in region B do not constrain prices in A. Thus, (1-λ) is the probability that the two regions are directly "connected," that is that prices in region B act to constrain prices in region A.

Next, define a positive random variable U_t, and B = log T. It can be seen that the observed price equations in (3) and (5) are in fact a switching-regressions system, where

(7) $\log (P_t^2 - P_t^1) = B + V_t - U_t$ with probability λ and

(8) $\log (P_t^2 - P_t^1) = B + V_t$ with probability (1-λ)

These two equations represent the two market integration states. Equation (7) corresponds to the regime of no arbitrage opportunities or the autarky state, and (8) corresponds to the arbitrage state. Equation (7) is in fact a composite error regression with a positive component U_t. While the parameter λ measures the probability of being in autarky, the positive error U_t is a conditional measure of propensity to trade. The smaller the positive value of U_t, the higher is the propensity to trade.

U_t is assumed to be distributed independently of V_t, with a one-sided half-normal distribution, i.e., the distribution is derived from a normal distribution $N(0, \sigma_u^2)$ truncated from below at zero. Denote $\theta = (B, \sigma_u^2, \sigma_v^2, \lambda)$ as the parameter vector for the regressions (7) and (8); then the likelihood function for the n observations is given by:

(9) $$L = \prod_{t=1}^{n} [\lambda f_t^1 + (1-\lambda) f_t^2]$$

where f_t^1 and f_t^2 are the density functions of (7) and (8), respectively.

Let $Y_t = \log(P_t^1 - P_t^2)$, then the density functions are

(10) $$f_t^1 = \left(\frac{2}{\sqrt{(\sigma_u^2+\sigma_v^2)}}\right) \phi\left(\frac{Y_t-B}{\sqrt{(\sigma_u^2+\sigma_v^2)}}\right)\left[1-\Phi\left(\frac{(Y_t-B)\frac{\sigma_u}{\sigma_v}}{\sqrt{(\sigma_u^2+\sigma_v^2)}}\right)\right]$$

(11) $$f_t^2 = \frac{1}{\sigma_v} \phi\left(\frac{Y_t-B}{\sigma_v}\right)$$

where ϕ and Φ are the standard normal density and distribution functions, respectively. In this context, the goal of the maximum likelihood estimation is to maximize the value of L in (9) over the parameters θ.

4.2.2 Time Series Techniques

As time series techniques will be used to supplement the arbitrage-cost approach, the associated theoretical framework will only be overviewed here with references provided to more detailed discussions. Restating this information provided in detail elsewhere, is redundant. Observing how the two approaches tie together—similar results on the extent of ethanol market—is of interest.

4.2.2.1 The Error Correction Model (ECM)

Cointegration implies that two price series cannot wander off in opposite directions for very long without coming back to a mean distance eventually (Chan 2006). The expectation of observing market integration in the form of cointegration in a set of ethanol price series leads to the data-generating process of P_t (price at time t) being appropriately modeled in an error correction model (ECM) with k-1 lags following from Stockton et al. (2010). The ECM for the 9 markets is:

$$\Delta P_t = \Pi P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \mu + e_t \text{ where } t = 1,\ldots, T;\ \ e_t \sim \text{Niid}\,(0, \Sigma) \tag{12}$$

where Δ is the difference operator ($\Delta P_t = P_t - P_{t-1}$), P_t is an (n x 1) vector of weekly prices at time t = 1,…, T; Γ_i is an (n x k) matrix of parameters to be estimated, reflecting the short-run relationships between past and current differences in prices (price changes lagged i period to current changes in prices); $\Pi = \alpha\beta'$ is an (n x n) matrix of parameters reflecting the relationship between lagged levels of prices to current changes in prices

(or n x n+1 if a constant is in the cointegration space); μ is a constant and ε_t is an (n x 1) vector of white noise innovations. The co-movement of prices can exhibit long-run and short-run relationships. The matrix β' reflects the long-run relationships between levels of price series, and α is a matrix of adjustment parameters summarizing how each series adjusts to perturbations in each of the long-run relationships summarized in β' (Stockton et al. 2010).

The number of cointegrating vectors, r, obtained from the rank of Π (i.e. row rank of β) can bring enlightenment on the long-run structure of market interdependence. To determine this number, trace tests on the eigenvalues of Π are used (Enders, 2010), and employed in this study likewise.

To provide a better understanding of the dynamic relationship among prices in the ethanol market, innovation accounting techniques of forecast error variance decomposition and impulse response functions are presented. Innovation accounting according to Enders (2010) may be the best description of such a dynamic structure.

4.2.2.2 Directed Acyclic Graph

The ECM models cointegration but does not indicate the direction of influence or causation between variables. So DAG comes to the rescue by showing the causal flows. Detailed development and discussion of DAGs can be found in literature (Pearl 2000; Spirtes, Glymour, and Scheines 2000).The principal idea of DAGs is to determine the causal relationship or flow among a set of variables, then portray it using an arrow graph or picture (Vitale and Bessler 2006). DAGs can and have been used to sort out the causal path in what are otherwise complicated pricing networks (Bessler and Kergna 2003; Vitale and Bessler 2006). In Spirtes et al. (2000), the PC algorithm, one of the search algorithms associated with DAGs and employed in this study, is described as a sequential algorithm that begins with an assumption that every variable is connected with every other variable and proceeds step-wise to remove connections between variables to discover "causal flow.” Although shortcomings of the PC algorithm have been documented in the literature, its advantages and extensive usage have also been emphasized (see Spirtes et al. 2000 and Demeralp and Hoover 2003). Following Stockton et al. (2010), contemporaneous information flows are studied in a DAG structure using estimated innovations, and their estimated co-variances, using a PC algorithm.

In the graphs, given two variables X and Y, there are five possibilities between the variables: (1) no causal relationship when edges are removed, (2) Y causes X($Y \rightarrow X$) (3) X causes Y($X \rightarrow Y$), (4) Y and X simultaneously cause each other($X \leftrightarrow Y$), and (5) the causal flow cannot be determined given the information contained in the sample ($X - Y$).

With reference to findings from the use of DAGs (in sorting out causal paths in pricing networks), price discovery tends to reflect both regions of excess demand and supply, as indicated in results from Park, Mjelde, and Bessler (2008). Price innovations arising in regions of scarcity signal shortages to regions of excess supply (Bessler and Krenga 2002); however, Vitale and Bessler (2006) find price signals from an excess supply market (large central market with storage facilities) leading prices in all local “neighborhood markets”. These studies have set the stage with regards to expectations from this work.

4.3 Description of Data and Preliminary Data Analysis

The data employed consists of weekly consumer prices of ethanol per gallon from Oil Price Information Service (OPIS) as reported in Hart's Oxy Fuel News. The assumption is that all regions of a state are within the same market and so one city in each state is used as a representative point. The data spans 20 years (1989–2008 with 1036 observations) for nine cities: Los Angeles (PLA); Denver (PDV); Cedar Rapids (PCR); Chicago (PCH); Indianapolis (PIN); Minneapolis (PMN); Albuquerque (PAL); Houston (PHO); Seattle (PSE). The selection of cities was based on production capacity/utilization (Midwest), consumption (Los Angeles, Houston) and distance from major hubs (Seattle and Albuquerque).

Table 16. Summary statistics on ethanol prices (per gallon) in nine U.S cities, 1989–2008

City	Mean	SD	CV
Los Angeles	1.479631	0.503409	34.02261
Denver	1.469731	0.472928	32.17784
Cedar Rapids	1.415084	0.452329	31.96481
Chicago	1.421886	0.463686	32.61061
Indianapolis	1.408526	0.471286	33.45953
Minneapolis	1.439699	0.461545	32.05845
Albuquerque	1.489171	0.483881	32.49332
Houston	1.441413	0.529681	36.74736
Seattle	1.502976	0.491658	32.7123

Table 16 showcases descriptive statistics: the mean, standard deviation (SD), and coefficient of variation (CV) for the nine ethanol markets from January 1989 to February 2008. Seattle has the average highest price followed by Albuquerque. This agrees with the expectation that mean prices are most likely higher in consuming regions or regions far from production hotspots like the Midwest. A market such as Houston with a greater price CV indicates high variability (volatility) or possible susceptibility to shocks from other markets; however, this supposition will be tested later in the study.

Tests to check for structural breaks in each data series were carried out, but no break points in the data were observed.

Correlation and cointegration are both used to model dynamics in a price system; however, while correlation measures interdependence in the short term, cointegration measures common trends in prices in the longer term. Looking at the correlation matrix in table 17, as expected, all prices are highly correlated. By differencing the data to remove trends or eliminate the possibility of a common cause, however, one observes that price correlations are not as high with correlation coefficients ranging from 0.96 to 0.99 in levels, and from 0.35 to 0.85 in first differences. The lowest correlations are between Denver and Houston, Denver and Albuquerque, and Los Angeles and Houston. Spiller and Huang in their paper suggest however that price correlations are not the proper statistic to infer whether two regions are usually in the same market. The results anticipated by using their model may therefore provide substantially different implications than those of simple correlation coefficients.

Table 17. Simple correlation coefficients—levels/first difference of ethanol prices for nine U.S. cities

	Denver	**Cedar Rapids**	**Chicago**	**Indianapolis**	**Minneapolis**	**Albuquerque**	**Houston**	**Seattle**
Los Angeles	0.98/0.58	0.98/0.63	0.98/0.68	0.98/0.71	0.98/0.61	0.98/0.65	0.99/0.46	0.99/0.74
Denver		0.96/0.50	0.97/0.54	0.97/0.54	0.97/0.61	0.96/0.44	0.97/0.35	0.98/0.52
Cedar Rapids			0.99/0.85	0.99/0.78	0.99/0.53	0.98/0.64	0.98/0.51	0.98/0.59
Chicago				0.99/0.79	0.98/0.68	0.97/0.64	0.98/0.52	0.98/0.60
Indianapolis					0.99/0.73	0.97/0.62	0.99/0.50	0.98/0.63
Minneapolis						0.97/0.73	0.98/0.62	0.99/0.75
Albuquerque							0.98/0.71	0.98/0.77
Houston								0.98/0.63

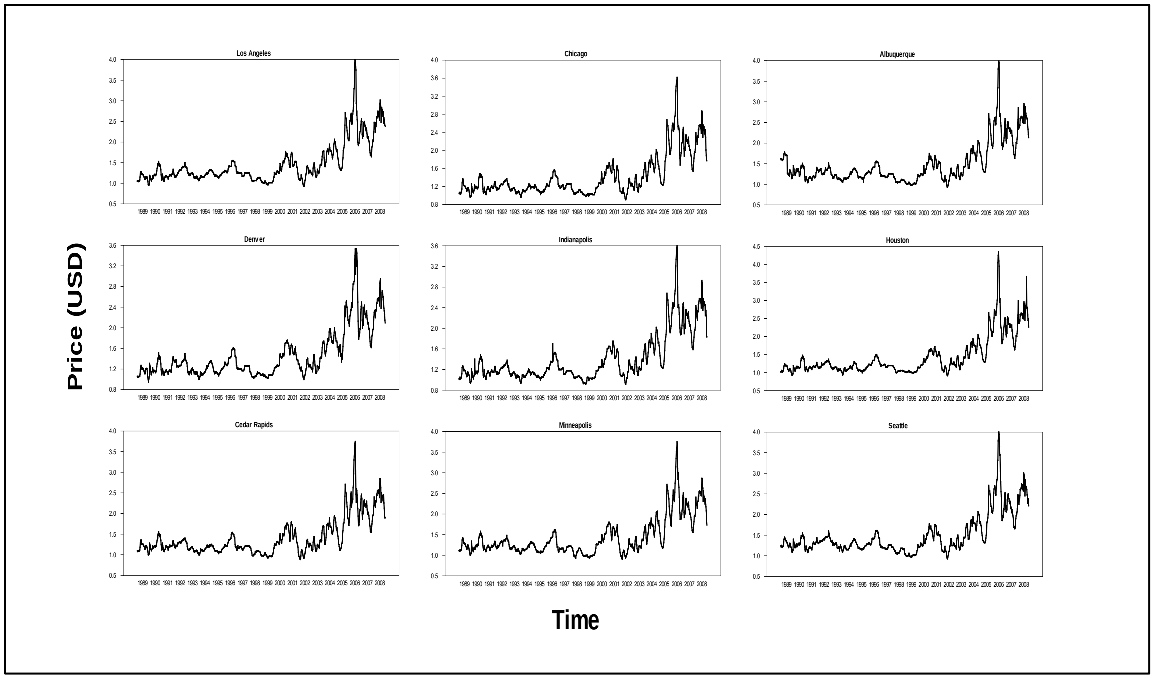


Figure 13. Graphs of price series in levels of ethanol in nine U.S. cities, 1989–2008

The prices of ethanol in the 9 markets (in figure 13) seem to move together, showing possible cointegration. These prices show almost the same variation in terms of magnitude and amplitude (flat, peak) during the course of the period of study. This is an indication of the law of one price with good price signal transmission between the ethanol markets. Prices begin trending upward from late 2005 and peaks observed in mid-late 2006 onwards could be attributed to the oil price boom, the increased food prices triggered in part by the increase in corn demand for ethanol fuel production and the requirements of the 2005 Energy Act. A quote from the New York Times in January, 2006, reads “High oil prices are dragging corn prices up with them, as the value of ethanol is pushed up by the value of the fuel it replaces” (Wald 2006). During that period, there was also reported rising demand for animal feed in China, which helped push global grain prices to levels higher than had been observed in at least a decade.

As mentioned earlier, prices tend to be lower in the Midwest region where most of the ethanol is produced and tends to be greater in more distant regions. That being said, it appears that the price range across all cities is rather small. Considering only the major producing states in the Midwest for instance, it is anticipated that all will be found to be in the same market in terms of the market integration findings, however for major consumers like California, Texas, Illinois and Iowa, results with regards to transactions costs estimates and the possibility of being in different markets are expected.

It is expected that California would be a key player in U.S. ethanol market structuring and pricing. California in 1999 was the first state to ban MTBE, phase it out of its reformulated gasoline program in 2003, and opt to use ethanol in the minimum amount (5.7 percent), although rules in 2010 were passed allowing E10 to be used (Brekke 2010). California is a very important ethanol market in the U.S. for a number of reasons: (a) it is the largest consumer of ethanol, and its market share continues to grow especially with the recent blend increase to 10 percent; (b) California agriculture exhibits, on average, a higher valued specialty crop mix than the commodity products grown in the Midwest, making feedstocks, and thus inputs for ethanol, more expensive (AGMRC 2004); and (c) California has been a forerunner with regards to the formulation and implementation of environmental policies (as illustrated above). Ethanol fuel or corn feedstock is largely imported from Midwest states creating interstate transport challenges (Lin et al. 2009) that could affect pricing for end-users; and ethanol's increasing consumption in California supports, according to Brekke (2010), a couple of key public policies—the RFS2 which requires greater use of fuels like ethanol through 2022; and California's relatively new low carbon fuel standard (LCFS), which mandates a reduction in the state's GHG emissions (10% reduction in carbon intensity of transportation fuels is one policy goal) by 2020.

It is important to recall nonetheless that the U.S. ethanol market is growing and thus may still be in a price-discovery state, especially with increasing federal and state subsidies and mandates encouraging production and utilization of biofuels.

4.4 **Results and Discussion**

To test for non-stationarity of the ethanol price series, the Augmented Dickey-Fuller (ADF) test is used. Results of the ADF (testing the null hypothesis that each series is nonstationary) on levels and first differences are presented in table 18. All series were found to be nonstationary in levels and stationary in first differences, indicating each class series integrated of order one (denoted as I(1)).

Table 18. Unit root test on prices of ethanol in nine U.S. cities, 1989–2008

Augmented Dickey-Fuller (levels)				Augmented Dickey-Fuller (1st diff)		
Market	t-test	k	Q (p-value)	t-test	k	Q (p-value)
Los Angeles	-1.1091	2	586.07(0.00)	-6.2621	2	592.71 (0.00)
Denver	-1.1437	2	500.07 (0.00)	-6.2465	3	508.48 (0.00)
Cedar Rapids	-1.4061	1	579.86 (0.00)	-7.3843	2	589.71 (0.00)
Chicago	-1.47704	1	536.89 (0.00)	-8.0506	2	544.42 (0.00)
Indianapolis	-1.56612	2	412.41 (0.00)	-6.7885	2	418.05 (0.00)
Minnesota	-1.5302	2	487.09 (0.00)	-7.1065	2	501.25 (0.00)
Albuquerque	-1.32504	2	541.21 (0.00)	-6.10331	2	537.91 (0.00)
Houston	-0.98951	3	783.13 (0.00)	-4.47482	2	751.04 (0.00)
Seattle	-1.52972	3	567.28 (0.00)	-6.84231	2	579.85 (0.00)

The critical value (t-stat) to reject the null hypothesis (at 5% significance level) of non-stationarity is -2.89. The column named “k” indicates the number of lags of the dependent variable used to produce “white noise” residuals. The value of k results from the minimization of the Schwarz loss metric on values of k ranging from 1 to 3. The column labeled “Q (p-value)” refers to the Ljung-Box statistic (Portmanteau test) test of white noise residuals from ADF regression.

Loss metrics and trace tests (further discussed below) are used to determine the number of cointegrating vectors, first by finding out the appropriate lag length (“best” model), and then determining how many price vectors are in the cointegrating space.

Table 19. Loss metrics (SL and HQ) on lag length from VARs in nine U.S. ethanol markets, 1989–2008

Lag length	SL	HQ
7	-59.8292	-60.7749
6	-59.7008	-60.5130
5	**-59.7319**	-60.4106
4	-59.7250	-60.2705
3	-59.5831	-59.9957
2	-59.3943	-59.6741
1	-58.9758	-59.1229

Metrics considered are Schwarz-loss (SL) and Hannan and Quinn's (HQ) measure on lag length (k) of a levels VAR: SL = log(|Σ|) + (6k) (log T)/T; HQ = log(|Σ|) + (2.00) (6k) log(log T))/T where Σ is the error covariance matrix and T is the total number of observations on each series. The symbol "| |" denotes the determinant operator and log is the natural logarithm. The single asterisk "*" indicates minimum of the SL metric and HQ measure.

A lag length test determines the maximum number of lags for a model. The lag length for the ECM is established from the specification derived from an unrestricted VAR. Schwartz Loss (SL) and Hannan Quinn (HQ) tests were performed (see table 19) to determine the maximum number of lags for the model, and the SL metric which is implemented subsequently shows a minimum of five lags are appropriate for the VAR model.

Table 20 displays results on the number of cointegrating vectors using the trace test. Failure to reject is at r=8, indicating that there are 8 cointegrating vectors with a constant in the cointegrating space, implying that the series is highly cointegrated. This is not surprising given high correlations observed; however, while high correlations may indicate cointegration, it is not sufficient to point to the presence of a long-run relationship. Recall that cointegration is a sign that markets are well behaved, implying efficiency.

Table 20. Trace test (lag = 5) on ethanol prices from nine U.S. cities, 1989–2008

r	Trace	P-Value	D	Trace*	P-Value*	D*
=0	757.299	0	R	734.679	0	R
≤1	504.508	0	R	491.81	0	R
≤2	366.628	0	R	358.179	0	R
≤3	248.03	0	R	242.962	0	R
≤4	180.135	0	R	176.39	0	R
≤5	119.443	0	R	117.25	0	R
≤6	68.4	0	R	67.273	0	R
≤7	31.661	0.001	R	31.026	0.001	R
≤8	4.447	0.361	F	4.329	0.377	F

The test statistic (T) is the trace test corresponding to the number of cointegrating vectors (r) presented in the far left-hand column and a p-value. Entries associated with an asterisk have a constant within the cointegrating vectors. Entries without an asterisk have no constant in the cointegrating vector but instead have the constant outside the cointegrating vector. The column labeled "D" indicates the decision to reject (R) or fail to reject (F) at a 5% percent level of significance the null hypothesis Ho that the number of cointegrating vectors r=0, r≤1, …, r≤8.

Innovation accounting discusses current and lag-time dynamic relations. Exploring how each series responds to innovations in every other series and the relative importance of each series in explaining (accounting for) the variation in the other series helps provide additional insight into the dynamic structure of ethanol prices in these nine cities. Based on the contemporaneous innovation correlation matrix, created from the correlation matrix of the residuals associated with the estimated ECM (table 21), the contemporaneous causal structure between price innovations were analyzed using the DAG and the results of this analysis (based on ECM and PC algorithms) are presented below in figure 14. The arrows and edges illustrate the flow of information, or as stated by Stockton et al. (2010), show the causal structure of the contemporaneous innovations. The number of edges indicates a great deal of flow of information and interaction between the markets. While Albuquerque, Houston, Seattle and Indianapolis show up to be price sinks, price signals originate primarily from Los Angeles, a chief consumer (demand pull). Chicago also provides price signals, and though Illinois may well be the key production state in the Midwest, most of its corn and ethanol production is carried on outside Chicago in less densely populated areas like Peoria. Price seems to be discovered in regions of high demand and perhaps scarcity, like Los Angeles and Chicago (metropolitan population centers).

Table 21. Correlation matrix of the residuals from the ECM on ethanol prices of nine U.S. cities, 1989–2008

	DPLA	DPDV	DPCR	DPCH	DPIN	DPMN	DPAL	DPHO	DPSE
Residuals	0.047445	0.051643	0.051834	0.05004529	0.048554	0.047681	0.052161	0.062675	0.046841
DPLA	1								
DPDV	0.604	1							
DPCR	0.656	0.55	1						
DPCH	0.696	0.602	0.826	1					
DPIN	0.708	0.596	0.765	0.786	1				
DPMN	0.598	0.57	0.729	0.665	0.661	1			
DPAL	0.616	0.47	0.605	0.602	0.585	0.658	1		
DPHO	0.444	0.395	0.524	0.518	0.51	0.557	0.671	1	
DPSE	0.77	0.548	0.62	0.61	0.63	0.716	0.748	0.595	1

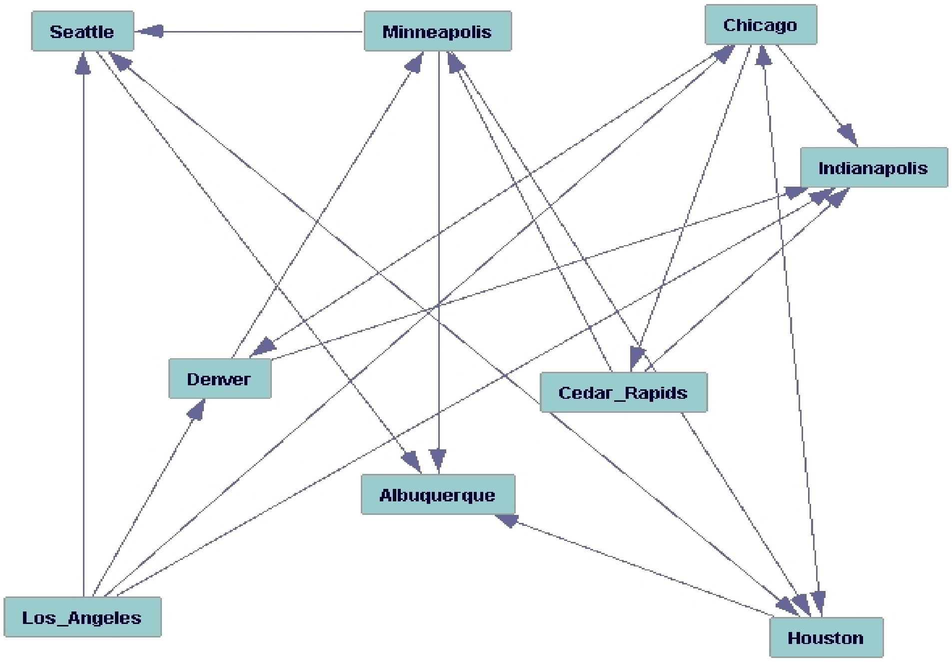


Figure 14. Causal flows found with PC algorithm at 5% significance level, on innovations from an ECM on ethanol prices from nine U.S. markets, 1989–2008

The functions graphed in (figure 15) show how different markets (listed at the beginning of each row) respond over a certain period of time (8 weeks) to a one-time-only shock or innovation from other markets (listed at the heading of each column) in the form of an impulse response function. The impulse response function displays the dynamic responses to adjustment of each price to a shock in the series. If the figure is read vertically, it shows how the innovation or shock (new information) from each market (listed at the heading of each column) affects prices in every market listed at the beginning of each row. The objective of conducting the impulse response function is to examine the hypothetical scenario of having a shock in one market and the consequent effect of that shock on the other markets. For example, take a Midwestern state like Iowa experiencing an exogenous shock that can affect ethanol production, and very likely its prices. From figure 15, price innovations from Los Angeles are transmitted to all other markets over a period of 8 weeks (see spikes). Price leadership from Los Angeles and Chicago is further substantiated.

From the results obtained and preceding discussion, it is extremely likely that new information is being transmitted within these markets rapidly.

Table 22 captures the price dynamics among the different markets in terms of the forecast error variance decomposition (FEVD), and provides a clearer picture of price dynamics. The FEVD was analyzed to see how much change in the future (uncertainty or error variance) of one market price is caused by shocks in other markets. It tells us what proportion of the variance of the forecast error in predicting a price in one market can be attributed to the other markets. Some percentages reported in the table 22 would be discussed side by side with results from the arbitrage cost approach presented in table 23 later in the discussion of results.

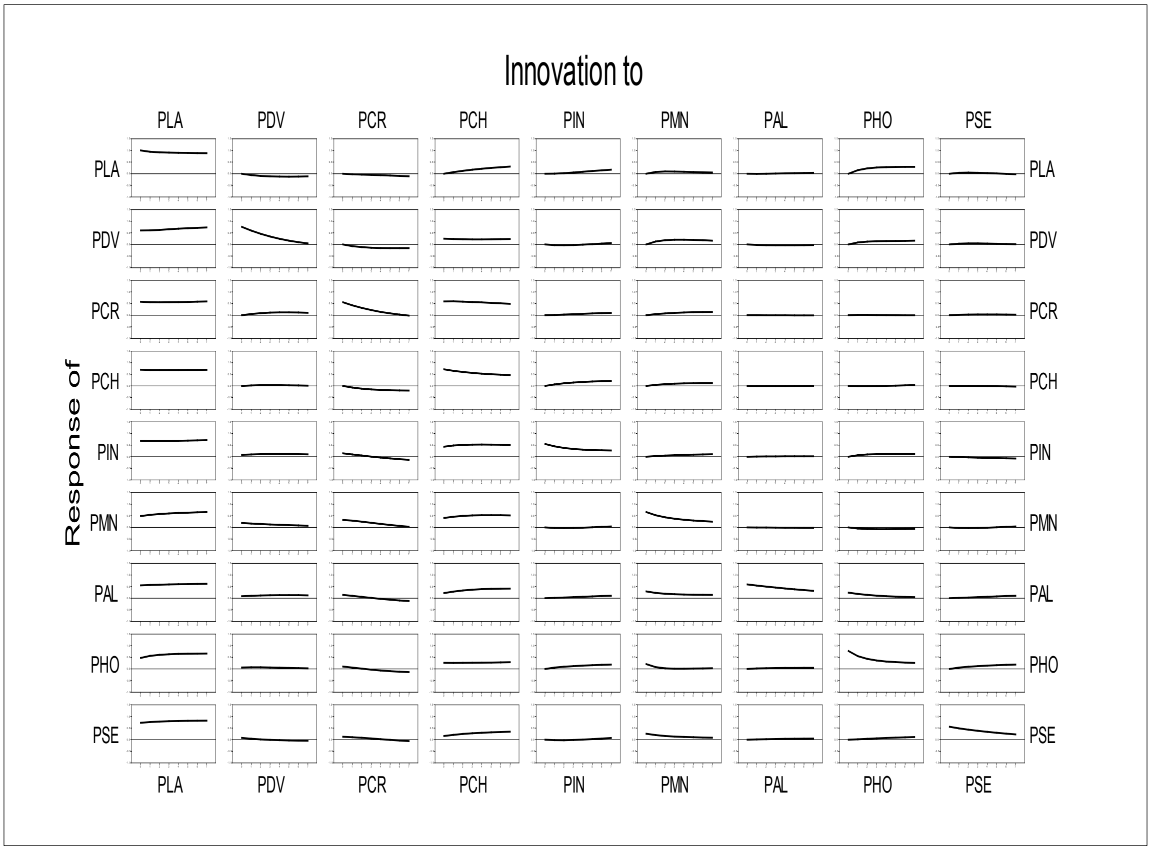


Figure 15. Response of each market to a one-time-only shock (innovation) in each series

Table 22. Forecast Error Variance Decompositions

Horizon	PLA	PDV	PCR	PCH	PIN	PMN	PAL	PHO	PSE
Responses to Shock in PLA									
1	100	0	0	0	0	0	0	0	0
2	97.95	0.178	0.023	0.246	0	0.304	0.001	1.224	0.075
4	93.198	0.672	0.108	1.314	0.083	0.633	0.002	3.856	0.135
8	86.354	1.102	0.445	4.219	0.971	0.541	0.042	6.243	0.083
Responses to Shock in PDV									
1	36.24	57.525	0	6.235	0	0	0	0	0
2	40.308	51.507	0.287	6.49	0.039	0.869	0.022	0.411	0.066
4	48.388	39.281	1.184	6.702	0.067	2.837	0.081	1.295	0.163
8	60.629	23.169	2.336	7.165	0.129	3.975	0.114	2.343	0.139
Responses to Shock in PCR									
1	33.482	0	31.276	35.242	0	0	0	0	0
2	35.001	0.155	26.661	38.026	0.009	0.116	0	0.012	0.02
4	38.158	0.697	19.284	41.147	0.089	0.544	0.002	0.015	0.066
8	43.987	1.296	11.298	41.336	0.502	1.472	0.005	0.009	0.094
Responses to Shock in PCH									
1	48.72	0	0	51.28	0	0	0	0	0
2	50.327	0.025	0.243	49.044	0.239	0.118	0	0.002	0.002
4	52.608	0.075	1.098	44.609	1.106	0.5	0	0.002	0.002
8	55.493	0.075	2.598	37.895	2.83	1.059	0.001	0.033	0.017
Responses to Shock in PIN									
1	47.745	0.635	2.102	18.921	30.598	0	0	0	0
2	48.856	0.826	1.603	22.045	26.396	0.042	0.002	0.221	0.009
4	50.422	1.137	0.904	25.917	20.664	0.192	0.008	0.685	0.072
8	52.794	1.268	0.958	28.033	15.008	0.579	0.019	1.066	0.276
Responses to Shock in PMN									
1	24.136	3.809	10.57	16.757	0	44.728	0	0	0
2	28.24	3.473	10.056	20.063	0.023	38.02	0	0.122	0.002
4	34.376	2.891	8.154	24.901	0.045	29.271	0.002	0.358	0.003
8	42.618	2.055	4.908	29.396	0.061	20.443	0.01	0.47	0.038
Responses to Shock in PAL									
1	31.419	0.741	2.057	4.966	0	8.706	36.335	5.966	9.81
2	33.806	0.948	1.615	6.962	0.008	7.293	34.845	4.887	9.638
4	37.305	1.325	0.945	10.595	0.081	5.68	31.319	3.478	9.272
8	42.079	1.683	0.933	15.418	0.488	4.347	24.703	2.089	8.26

Table 22. Continued

Horizon	PLA	PDV	PCR	PCH	PIN	PMN	PAL	PHO	PSE
Responses to Shock in PHO									
1	22.666	0.38	1.054	6.965	0	4.461	0	60.619	3.855
2	31.737	0.52	0.811	7.996	0.19	2.952	0.026	52.986	2.782
4	44.202	0.606	0.499	9.26	0.904	1.722	0.097	41.058	1.653
8	55.091	0.448	1.096	10.637	2.535	0.958	0.191	28.025	1.019
Responses to Shock in PSE									
1	55.584	0.592	1.642	2.603	0	6.949	0	0	32.63
2	59.315	0.384	1.453	3.669	0.023	5.665	0.007	0.018	29.466
4	64.58	0.202	0.998	5.66	0.032	4.113	0.038	0.138	24.239
8	70.142	0.172	0.583	8.727	0.135	2.664	0.124	0.582	16.871

Note: The forecast error variance decompositions are partitions on observed innovations from the ECM. Each row entry sums to 100.

Table 23. Parameter estimates (Log T, λ and Log L) for selected pairs of cities

	PLA-PDV	**PLA-PCR**	**PMN-PCH**	**PLA-PCH**	**PLA-PHO**	**PHO-PSE**	**PLA-PAL**	**PCH-PAL**	**PHO-PCR**
Log T	-0.59	-2.97	-2.75	-2.57	-2.53	-2.79	-3.56	-3.52	-3.56
λ	0.01	0.82	0.43	0.49	0.74	0.01	0.01	0.01	0.01
Log L	1670.03	214.28	720.63	978.73	955.35	351.07	660.59	201.25	660.59

Log T represents log of transactions costs, λ is the probability of no binding arbitrage and Log L is the value of the likelihood function. The cutoff point chosen (similar to that employed by Spiller and Huang) would be such that any λ less than approximately 0.30 would be indicative of a high probability arbitrage and thus of being in the same market (1- λ).

Conjectures based on the parameter estimates (results in table 23) would be that: city pairs with high λ are most likely not in the same market, and are thus less integrated. From table 23, it can be inferred that at least 4 pairs of cities seem to be less integrated (LA, CR), (MN, CH), (LA, CH) and (LA, HO), as the probability of arbitrage is low. Recall that a low λ is indicative of a high probability of being in the same market, and therefore high possibility of arbitrage when the opportunity arises. Recall that an arbitrage opportunity arises where it is possible to take advantage of price differentials between two markets, usually risk-free. Among these pairs, it is surprising that MN and CH do not have a high prospect of arbitrage, in spite of their geographic proximity. The magnitude of λ (0.82) indicates that the probability of arbitrage is very low (18%) between (LA, CR) which is expected, given the distance between these cities.

As observed in table 23, 5 pairs of cities seem to be more integrated. These pairs are (LA, DV), (HO, SE), (LA, AL), (CH, AL) and (HO, CR). Since the probability of these pairs to be in the same market is very high, it is interesting to examine what percentage of variation in the forecast error is explained by the other market in each pair. Towards that end, refer to table 22 above where the forecast error variance decompositions are used. Take one pair, (LA, DV), for example. LA market price seems to account for 36% of DV price in the short horizon of 1 week and 60% in the long horizon of 8 weeks. Next, let us consider the (LA, AL) pair, which also seems to be integrated according to the MLE analysis. In this case, a shock in LA seems to explain 31% (in the short horizon) to 42% (in the long horizon) of the forecast error variance in AL price. On the other hand, for pairs that the MLE analysis show to be less integrated, such as (CR, LA), the FEVD analysis suggests that 33% of the variation in ethanol price forecast in CR is attributed to LA in the short run (1 week) to 44% in the long run (8 weeks). Likewise, for the (LA, CH), the error decomposition analysis suggests that LA explains 48% of the forecast error variance in CH price in the short run and 55% in the long run. Consequently, one can conclude that LA plays an important role in the price dynamics of the ethanol market. Thus the Spiller and Huang methodology along with time series analysis together gives a more complete picture of the extent of ethanol market and the nature of price dynamics especially for pairs of integrated markets.

One also notes that the transactions cost estimated by the model, and also reported in table 23 is highest between the pair (LA, DV) in spite of the fact that the probability of arbitrage is very high between these cities. Among other pairs that have high arbitrage probability, transaction costs are relatively low between (HO, SE), which is surprising given the actual distance between the cities.

To dig a little deeper as to what drives ethanol price formation, Ruppel (1987) may throw some light. According to Ruppel, export shipments better characterized as a logistic variable, depend on such factors as transportation costs, weather constraints, and desired delivery dates, as contrasted with export sales, an economic variable, which responds to commodity prices, exchange rates, and world income levels. Ethanol prices therefore, may well be determined months or up to a year in advance through futures or forward sales rather than by spot trading, especially since corn (from which nearly all U.S. ethanol is made) is a storable commodity usually contracted in advance. This is a plausible explanation for price establishment in the ethanol industry.

4.5 Summary, Conclusion and Further Research

Spatial price determination and discovery, the focus of this essay, is pertinent for the ethanol market as it emerges for a number of reasons. Firstly, the afore-mentioned factors affecting the energy sector such as environmental concerns and federal and state energy policies in addition to unstable energy prices and pressures for oil independence, have strong effects on the market for renewable energy, hence conducting analyses in this growing market is relevant. Secondly, since increased demand and supply of ethanol is expected to have a significant effect on its pricing, and the cost of transportation would influence the spatial price pattern, spatial price determination and discovery is therefore pertinent for the ethanol market as it emerges.

This research to the best of my knowledge is unique because although several papers have been written on testing the extent of different markets, and studies on ethanol that investigate relationships between food and fuel, energy markets integration, direct and indirect land use changes due to ethanol production and utilization, implications of the RFS mandates, etc. exist, this study employs more recent data and ventures into the emerging ethanol market for which no similar study has been found.

This study aimed to measure market integration and establishes the extent of the market for ethanol with regards to cities in major producing states as well as major consuming states. Maximum Likelihood Estimation (MLE) following Spiller and Huang (1996) to estimate the probability of arbitrage between pairs of cities in the burgeoning ethanol market was applied to weekly ethanol price data spanning 20 years (1989–2008 with 1036 observations). In addition, time series techniques (ECM, DAG, impulse response analysis and FEVD) were carried out to measure market integration and investigate price discovery.

Time series techniques show that the markets under study are cointegrated and strongly related, with the observable high levels of interaction between all nine cities. Information is shown to be transmitted rapidly between these markets. Price seems to be discovered (where shocks originate from) in regions of high demand and perhaps shortages, like Los Angeles and Chicago (metropolitan population centers).

The MLE approach on the other hand shows that all the nine cities may not belong to the same economic market and that the possibility of arbitrage does not exist between all the markets. The knowledge of which cities have a high probability of being in the same market is important, as this information can be used to form expectations on price movement and the possibility of arbitraging between two markets.

Information from this study should prove beneficial in terms of planning, strategizing, decision making, risk mitigation, etc., for relevant players in the ethanol industry, particularly policy makers, and others concerned with the future of ethanol pricing, such as suppliers, retailers and large-scale consumers.

Issues that have not been addressed in this research, such as the inclusion of other cities (East Coast states) and countries (Brazil), could provide additional insights into the dynamics of the ethanol market. States which receive large ethanol imports for instance, are also expected to receive price signals from international markets. Transportation costs which have fluctuated over time are not controlled for in this study. Also, by taking into account individual market characteristics, such as the different policies in different states which could make their markets distinct, these results could be improved. Further work would include carrying out exclusion and weak exogeneity tests to determine which markets are not parts of the cointegrating space and which markets are unlikely to respond to shocks, respectively. Using the same or a modified MLE framework, more city-pairs could also be investigated for the probability of being in the same market or of arbitrage taking place. It would be interesting to investigate whether ethanol and its alternatives (such as the now largely banned MTBE) are in the same market or whether ethanol-blended gasoline and regular/premium gasoline are in the same market.

5. CONCLUSIONS, LIMITATIONS AND FURTHER RESEARCH

5.1 **Conclusions**

This dissertation encompasses adaptation and mitigation strategies as a response to climate change. In particular:

- Agricultural adaptation to climate change is comprehensively reviewed to assess what has been investigated and what needs to be done;
- Quantitative analysis is performed on the costs and benefits of select adaptations to examine what adaptations are most desirable;
- The emerging ethanol market is analyzed in terms of market extent, integration and dynamic price information flows.

The following sections present the results and conclusions of these studies (essays).

Essay 1 examined and synthesized the economic literature on agricultural adaptation in terms of needs for adaptation, evidence on observed adaptation practices, approaches to quantitative analysis of adaptation, and findings from quantitative analysis of adaptation. Literature shows the evidence of climate change and the need to adapt. Taxonomy and understandings of adaptation found commonly in literature are centered on timing, funding sources, drivers, investment needs, outcomes and range of actions. More specifically, the wide range of realized and possible adaptations found to exist within agricultural systems, goes to show that agricultural adaptive management is fundamental and ongoing, potentially benefitting millions of people globally. The majority of the studies reviewed show agricultural adaptation to be beneficial.

Essay 2 attempted to value an array of possible agricultural adaptations to climate change. Specific adaptation strategies studied were: shifts in crop varieties and planting schedules, altered management practices such as irrigation water use, and a 200-mile northward migration of crop mixes. Adaptation is found to be highly beneficial to agriculture, increasing welfare by up to $16 billion. Interestingly, climate change is beneficial even without planned adaptation. Autonomous adaptation, the outcome of competitive market forces and market adjustments, is capable of generating more than twice the value that physical or planned adaptations (on-farm and mix-migration) generate. In terms of ranking of the two major types of physical adaptations studied, on-farm adaptation contributions outweigh that of a 200-mile crop-mix shift northwards significantly. This finding implies that progressive technical change and significant returns to adaptation research and investment focused on farm management and varietal adaptations may prove to be reasonably beneficial over time. Crop production increases with adaptation. Significantly higher percentage of increase is associated with the on-farm varietal and other adaptations when compared to the mix-migration adaptation. A northward shifting of the corn-acre weighted centroids observed indicates that substantial production potential may shift across regions with the possibility of less production in the South, and more in the North, and thereby, potential redistribution of income. Climate change with or without adaptation is found to support an increase in crop exports, with physical adaptation resulting in greater gains than autonomous adaptation. This possible expansion could lead to a higher comparative advantage and increased income from international trade for the U.S., especially with up to the observed 20% increase.

Spatial price determination and discovery, the focus of essay 3, is pertinent for the ethanol market as it emerges. This study aimed to measure market integration, explore dynamic relationships and establish the extent of the market for ethanol with regards to cities in major producing states as well as major consuming states. Maximum Likelihood Estimation (MLE) following Spiller and Huang's methodology was employed to estimate the probability of arbitrage between pairs of cities in the burgeoning ethanol market, along with time series techniques (ECM, DAG, impulse response analysis and FEVD) carried out to measure market integration and investigate price discovery. Time series techniques show that the markets under study are cointegrated and strongly related, with the observable high levels of interaction between all nine cities. Information is shown to be transmitted rapidly between these markets. Price seems to be discovered (where shocks originate from) in regions of high demand and perhaps shortages, like Los Angeles and Chicago (metropolitan population centers). The MLE approach on the other hand shows that all the nine cities may not belong to the same economic market and that the possibility of arbitrage does not exist between all the markets. The knowledge of which cities have a high probability of being in the same market is important, as this information can be used to form expectations on price movement and the possibility of arbitraging between two markets. Information from this study should prove beneficial in terms of planning, strategizing, decision making, risk mitigation, etc., for relevant players in the ethanol industry, particularly policy makers, and others concerned with the future of ethanol pricing, such as suppliers, retailers and large-scale consumers.

5.2 Limitations and Future Research

The range of possible climate change adaptations as well as the elements of climate change which stimulate adaptation, besides the continued evolution of knowledge, raises a variety of research needs which include the following. On a broad scale, research needs, as gathered from literature, are that studies are needed which:

- Include the cost of adaptation in economic evaluations, as well as work on practical adaptation potential (IPCC WGII 2007);
- Examine the uneven distribution of climate change effects across the world and over time, developing localized and time-specific adaptation strategies;
- Examine adaptation costs (especially aspects of adaptation strategy development, investments in research), burden sharing with respect to adaptation investment that includes the funding of relevant research, and possible diminishing marginal returns;

- Address optimal degrees of adaptation and practical levels of the extent to which climate change vulnerability can be addressed;

- Address means for adapting existing crops and livestock, move varieties of heat-tolerant crops and livestock breeds into regions and alter management (McCarl 2007; Antle 2009);

- Examine new adaptation options through benefit-cost analysis and judge effectiveness using appropriate tools and approaches—not as an add-on, but as a potentially important factor in shaping adaptation decisions.

- Develop understanding of the process in which adaptation is taking place and will occur in the future (IPCC WGII, 2007);

- Examine means of adaptation to altered variability and the effects thereof which could be unpredictable. Parry et al. (2009) argue that this is a big challenge;

- Consider strategies to deal with climate change for unmanaged or passively managed production systems;

- Deal with resource and funds competition for food, energy, adaptation and mitigation;

- Examine levels of investment needed to insure a sufficient food supply given the factor productivity implications of climate change as found by McCarl et al. (2009);

- On a final note, estimations considering only mitigation or effects/adaptation options have a huge possibility of a bias because of the inter-connection between climate change impacts, adaptation and mitigation, motivating therefore the need to investigate the interplay between these policy elements.

Itemized below are limitations associated with essay 2 and avenues for future research:

- No costs of adaptation are included in the study. Costs associated with the social burden of society adapting to a changing climate, scientific or research costs, etc. are important and being excluded presents a bias for this study.
- Although FASOM is solves at 5-year time steps, the model is assumes that producers have full information/perfect foreknowledge about climate change effects on crop yields. This may not be true, and there may perhaps be some inertia preventing taking the adaptation measures timely.
- For crop mix migration, the information costs or to what extent the producers are willing to embrace new cropping patterns is not considered. Nonetheless, FASOM provides the possibility of 200 mile northward migration although it remains up to the producers who make cropping decisions.
- The forest sector not modeled in this study although it is closely related to the agricultural sector.

- FASOM does not provide confidence intervals on the calculations for the welfare effects of the adaptation strategies studied. Specifically, employing the deterministic version of optimization models such as FASOM yield results as only point estimations, and these outcomes may not fully accounting for uncertainties linked with future climate change.
- Finally, the extreme dependence of mathematical programming models like FASOM on model parameters, sometimes taken as given from literature or simply assumed, make results somewhat sensitive to the choice of parameters.

Possibilities for future research abound. FASOM has the property of being flexible and capable of expansion to incorporate more variables and equations. In general, with the availability of more data and regional details, the model can be refined. A natural extension of this work would be to expand the model to include more varietal adaptations or new adaptation strategies, and perhaps observe interactions other sectors. One may also be able to calibrate the model to investigate how adaptation options interact with mitigation alternatives, and whether an optimal mix of both responses is realizable. Future research could use the stochastic version of FASOM to better reflect possible uncertainties.

Issues that have not been addressed in essay 3, such as the inclusion of other cities (East Coast states) and countries (Brazil), could provide additional insights into the dynamics of the ethanol market. States which receive large ethanol imports for instance, are also expected to receive price signals from international markets. Transportation costs which have fluctuated over time are not controlled for in this study. Also, by taking into account individual market characteristics, such as the different policies in different states which could make their markets distinct, these results could be improved. Further work would include carrying out exclusion and weak exogeneity tests to determine which markets are not parts of the cointegrating space and which markets are unlikely to respond to shocks, respectively. Using the same or a modified MLE framework, more city-pairs could also be investigated for the probability of being in the same market or of arbitrage taking place. It would be interesting to investigate whether ethanol and its alternatives (such as the now largely banned MTBE) are in the same market or whether ethanol-blended gasoline and regular/premium gasoline are in the same market.

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